Cognitive Development 33 (2015) 1–13

Contents lists available at ScienceDirect

Cognitive Development

Six-month-olds actively predict others' goal-directed actions

Eun Young Kim, Hyun-joo Song *

Department of Psychology, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, South Korea

ARTICLE INFO

Keywords:
Action understanding
Action prediction
Goal attribution
Social cognition
Infancy

ABSTRACT

The current experiment investigated whether 6-month-olds can predict the goal of others' actions. Infants were familiarized to an actor repeatedly reaching for and grasping object-A as opposed to object-B. Object-B was either (1) visible to the actor; (2) hidden by an opaque screen from the actor (but not the infants); or (3) placed behind the screen by the actor herself, so that even though she could no longer see object-B, she was aware of its presence. The positions of the two objects were then reversed. During the test trial, we measured the infants' eye fixations while the actor paused for 6 s. The infants generated predictive eye movements toward object-A only when the actor could see object-B (1) or was aware of its presence in the situation (3). Thus, 6-month-olds can predict, rather than only retrospectively respond to, the goal objects of others' actions.

As adults, we can predict others' actions before they initiate those actions. Various social interactions including driving safely, negotiating job offers, delivering a lecture, and soothing a fussy baby, among others, require our prospective reasoning about others' future actions. Very often, an essential aspect of such reasoning is predicting others' goals. For instance, if you have been observing a toddler repeatedly playing with his ball in a playground and you then see him accidentally throw his ball into the middle of a busy street, you will be alarmed because you will expect him to attempt to get the ball and you will prevent him from running into the street even before he starts to move. The present

* Corresponding author. Tel.: +82 2 2123 2449.
E-mail address: hsong@yonsei.ac.kr (H. Song).

http://dx.doi.org/10.1016/j.cogdev.2014.09.003

research explores whether 6-month-olds possess the social competence to reason prospectively about others' future actions.

Young infants can detect the goals of others. After watching an actor repeatedly reach for one of two objects, infants looked longer when she reached for a new object rather than the old one (e.g., Luo, 2011; Luo & Baillargeon, 2007; Sommerville, Woodward, & Needham, 2005; Song, Baillargeon, & Fisher, 2014; Woodward, 1998; Woodward & Sommerville, 2000). Infants can even infer the goals of incomplete actions. After observing an uncompleted reaching action, 6-month-olds looked longer when the actor grasped the object she had not previously reached toward (Daum, Prinz, & Aschersleben, 2008). In addition, when an action sequence ended with an unexpected outcome (e.g., the actor holding a spoon in front of his open mouth and then touching his forehead with the spoon), 9-month-olds showed an increased N400 component of an event-related potential (Reid et al., 2009); this is a negative deflection that typically peaks around 400 ms after the onset of an event that does not fit with the previous context (Kutas & Federmeier, 2011).

Infants thus respond to seeing others' goals achieved or nearly achieved, demonstrating that, at a minimum, they make retrospective judgments about the consistency between initial actions and final outcomes. However, we know less about whether infants have the ability to generate on-line predictions about others' goals, a critical aspect of human social competence, which permits us to plan our own actions in a timely and appropriate manner in response to others' actions (e.g., Knudsen & Liszkowski, 2012).

With respect to action sequences, infants do have some ability to make on-line predictions. For example, while watching a human hand repeatedly grasping and moving sets of three toys into a bucket one at a time, 12-month-olds, but not 6-month-olds, moved their eyes to the goal location (the bucket) before the hand actually arrived there (Falck-Ytter, Gredebäck, & von Hofsten, 2006). And even younger infants can make predictions about actions that are familiar to and executable by infants. Kanakogi and Itakura (2011) showed 6-, 8-, and 10-month-old infants a human hand reaching for and grasping one of two objects and found that the infants showed anticipatory eye movements to the goal object before the hand arrived there.

It is possible, however, that the infants in these studies predicted the motion trajectory rather than the actor's goal. In Falck-Ytter et al. (2006), the goal location (the bucket, the only container in the situation) was always placed in the same spot, and thus the path of the hand movement was identical in every trial; infants' proactive eye movements might have reflected the extrapolation of this repeated movement path. In Kanakogi and Itakura (2011), the goal object and the direction of the actor's movement were not the same from trial to trial. However, because their primary measure was the infants' eye movements after the actor started the action, when information about the movement direction was already available, the infants might have anticipated the action based on the initial movement direction rather than the goal.

Some recent findings challenge this possibility. Cannon and Woodward (2012) showed that 11-month-old infants can make goal-based action predictions even when the visible portion of the action is ambiguous. The infants were familiarized with events in which a human hand reached for and grasped one of two toys. Then, the locations of the two toys were reversed. During test, the hand moved forward and stopped between the two toys, an action that did not indicate which of the two toys would be grasped. Infants predictively looked at the goal object for which the hand had repeatedly reached during familiarization.

In addition, previous studies exploiting infants' brain responses suggest that younger infants can predict an action even when information about the actor's movement trajectory is incomplete (Southgate, Johnson, Karoui, & Csibra, 2010; Southgate, Johnson, Osborne, & Csibra, 2009). For instance, when 9-month-olds watched a hand that looked as though it was about to grasp an object (although the object was not visible; the hand disappeared behind an occluder), they showed brain activation related to goal-directed actions, suggesting their prediction of a likely outcome—the grasping of a hidden goal object (Southgate et al., 2010). In contrast, the 9-month-olds did not show such brain responses when there was clearly no object present (the same action was directed toward an empty space without occlusion). Similarly, 9-month-old infants showed motor cortex activity when merely observing a paused scene consisting of an agent and an object for which the agent had repeatedly reached (Southgate & Begus, 2013). Even infants as young as 6 months showed predictive brain responses to a static scene which had cues suggesting an upcoming action. The infants showed motor cortex responses when observing an actor seated in front of a closed box when the actor had a false belief that a ball was in the box but not when the actor had a false belief that the ball was not in the box (Southgate & Vernetti, 2014). These results confirm that by the age of 6 to 9 months, infants make predictions about whether an actor will produce a goal-directed action even in the absence of visual information about the pathway of the action.

Building on these studies, the current work examines whether 6-month-olds can make predictions about which object an actor is likely to act on in a two-object situation. The infants were shown 6 familiarization trials in which an actor paused for 6 s then grasped object-A as opposed to object-B. Following familiarization, the locations of the two objects were switched. During the test trial, the actor paused for 6 s and the trial ended (*experimental* condition). Would infants predict the actor's grasp based on her goal, and look toward the goal object in anticipation of the action? Since the physical context changed from familiarization to test, an action along the same path would not lead to the attainment of the same goal object in the test situation as in the familiarization situation (see Cannon & Woodward, 2012 for a similar paradigm). Predicting a path of movement would lead to looks toward the non-goal object. However, predicting a goal object-directed reach should lead to looks toward the goal object in its new location.

To rule out the possibility that predictive looking toward the goal object was due to a mere association between the actor and the object, half of the infants saw the actor perform actions identical to the experimental condition except that during familiarization, an opaque screen was present between the actor and object-B (*control* condition; for similar controls, see Luo & Baillargeon, 2007; Luo & Johnson, 2009). Thus, the actor could not see object-B, while the infants could. There is, as yet, no direct evidence that 6-month-olds can distinguish what they see from what the actor sees in situations exactly like our experimental set-up. However, Luo and Johnson (2009) showed 6-month-olds an agent directing actions towards a target object but not toward a non-target object that was behind a screen. Infants behaved differently when the non-target was visible (it was taller than the screen) and when it was not (it was shorter than the screen). Thus the 6-month-olds seemed to understand whether the non-target would be visible to the agent or not and used the agent's visual experience to make inferences about her preference for the target. Given this finding, we expected that the 6-month-olds in our study would also understand that the actor had no visual access to object-B.

There are two possible ways in which infants might respond in the control condition. First, if infants simply form an actor-object association during familiarization, then infants in both the experimental and control conditions should form similar associations (since they see the exact same actions), and both groups of infants should look toward the goal object in the test. Second, if infants predict the actor's actions in terms of an underlying goal and understand that object-B (behind the occluder) is not visible to the actor, then the infants in the control condition have no basis for attributing to the agent a preference for the target object during familiarization (e.g., she might reach for it simply because she does not have any other choice). Previous studies have consistently found that infants do not attribute to an actor a preference for a particular object, even when she grasps it repeatedly, if that is the only object she can see (Kim & Song, 2008; Luo & Baillargeon, 2005, 2007; Luo & Johnson, 2009). Thus, during the test trial in which the actor has the choice between two objects, infants might be unable to predict which object the actor would prefer. Thus, unlike the infants in the experimental condition, the infants in the control condition might look equally to the two objects.

To measure infants' predictive looking, we measured the infants' eye fixations during a scene in which the actor paused, looking as if she was about to reach for an object, without indicating which one. In contrast, most previous studies examined infants' eye fixations or brain responses as ongoing actions unfolded (Cannon & Woodward, 2012; Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011; Southgate et al., 2010). Some recent research has revealed that, prior to the observation of an action, 6- to 9-month-olds can use previously attributed goal or belief information and generate a simple anticipation regarding whether the actor will act at all (Southgate & Begus, 2013; Southgate & Vernetti, 2014). Together with these recent studies, the current work can be taken as a stronger test of prediction than other previous studies that evaluated infants' anticipatory looks during the observation of ongoing actions, given that infants must generate a prediction regarding the goal of an impending action in the absence of visual information about movement.

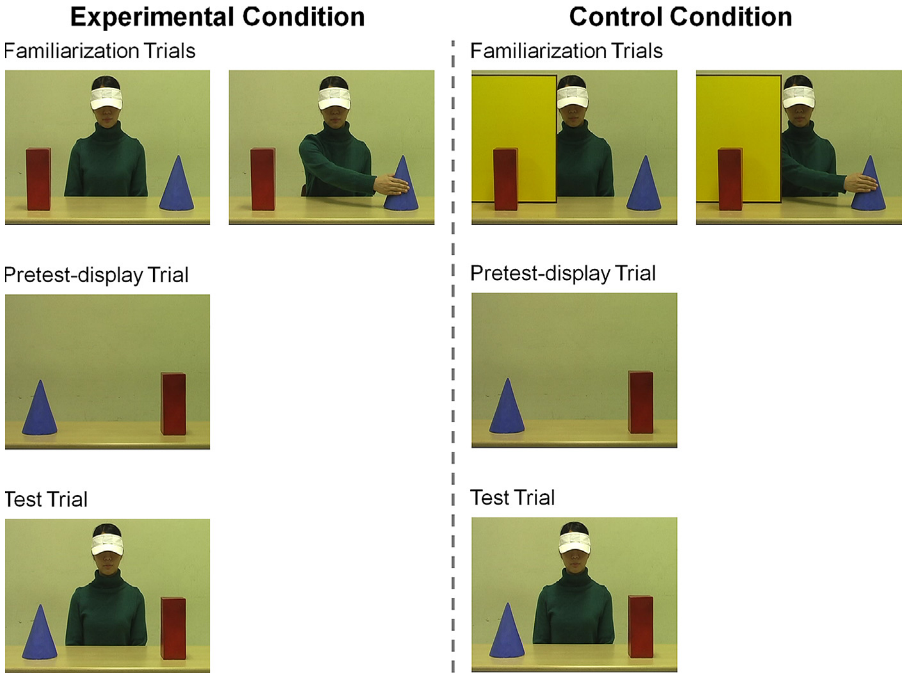

Fig. 1. Selected frames from the videos of the experimental and control conditions.

1. Experiment 1

1.1. *Material and methods*

1.1.1. *Participants*

Participants were 28 healthy term infants, 14 males and 14 females (*M* = 6 months, 13 days, range = 5 months, 21 days to 6 months, 28 days). The infants were randomly assigned, half to the experimental condition and half to the control condition. Data from another 13 infants were eliminated from the final analysis because of fussiness (2), distraction (1), inattentiveness during the test trial (8), parental interference (1), or during the test trial, looking at the non-goal object over 3 SD from the mean of their condition (1).

1.1.2. *Procedure*

Each infant sat on a parent's lap, centered in front of a 40-in. TV monitor at about infant eye-level, at a distance of about 100 cm. A hidden camera centered below the monitor recorded the infant's face. Parents were instructed to close their eyes and remain silent and neutral throughout the experiment.

Before the video started, a purple star appeared on the screen for 5 s in 3 successive locations accompanied by a beep sound: at the location of the actor (center), the left object (left), and the right object (right). Coders, when ascertaining the directions of infants' looks from the video recording, were able to use looks during this calibration phase as a reference.

Following the calibration phase, infants were shown the familiarization video (6 times), followed by the pretest-display video (1 ×) and a test video (1 ×). Fig. 1 shows selected shots from the videos. During the *Familiarization* trials, a female actor was seated at a table wearing a green sweater with a white visor covering her eyes. At the beginning of each event, the actor's hands were hidden underneath the table. A red block and a blue cone were placed on the left and right. In the videotaped scenes, the red block was 20.5 cm tall and 13.0 cm wide, and the blue cone was 18.0 cm tall and 18.0 cm wide. The centers of the two objects were 70.5 cm apart. The objects were 6.5 cm from the lower edge of the

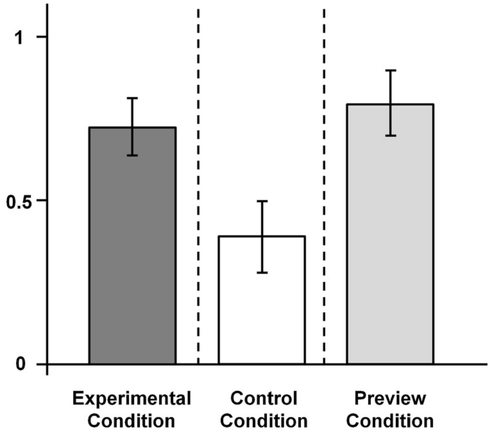

Fig. 2. The mean proportion of time looking toward the goal object (out of the time looking toward goal and non-goal objects) across the test trial for each subject.

monitor. In the control condition, an opaque yellow screen was placed behind an object; the screen was 37.5 cm tall and 42.5 cm wide. It was positioned 9 cm from the center of the monitor. In each familiarization trial, the actor paused (6 s), grasped one of the two objects (2 s), then paused again until the end of the trial (8 s). For half of the infants in each condition, the actor grasped the block (for the others, the cone) and for half, the opaque screen was behind the right (for the others, the left) object. Then, the infants received a *Pretest-display* trial in which the positions of the two objects were reversed. During this static 10-s trial, the actor was absent from the scene. During the *Test* trial, the actor sat at the table and paused for 6 s.

1.1.3. Coding

We coded the infants' fixations as in a preferential-looking paradigm (e.g., Fernald, Zangl, Portillo, & Marchman, 2008). The primary coder coded, from the video recordings of the infant's face, where the infant looked (left, right, center, or away), frame (1/30 s) by frame. In all trials, we regarded looks to the left or right of the monitor as fixations toward an object. In all trials except for the pretest-display trial, in which the actor was absent, we regarded looks to the center as fixations at the actor. A second coder independently coded the looking behavior of 7 (25%) randomly selected infants. The coders agreed on where the infant was looking on 89% of the video frames.

1.2. Results

1.2.1. Comparison across conditions for predictive looking during the test trial

For the test trial for each infant, the proportion of looking time toward the goal object (the object the actor repeatedly grasped during the familiarization trials) was calculated as the total looking time toward the goal object divided by the total looking time toward both the goal and non-goal objects. Preliminary analyses showed no significant main effect of sex or goal object (block or cone) or interactions involving these factors, Fs < 1.06, ps > .31; subsequent analyses therefore collapsed across sex and goal object.

On average, infants looked longer toward the goal object in the experimental condition (M = .73, SD = .33) than in the control condition (M = .39, SD = .40), a difference supported by a one-way analysis of variance (ANOVA) with condition (experimental or control) as a between-subjects factor, $F(1, 26) = 5.88$, $p < .05$, $\eta^2 = .18$ (see Fig. 2). Infants in the experimental condition looked reliably longer toward the goal object than expected by chance, $t(13) = 2.60$, $p < .05$, $d = 1.44$, but those in the control condition did not, $t(13) = 1.01$, $p = .33$. Eleven of the 14 infants in the experimental condition looked longer at the goal object than at the non-goal object, whereas only 6 of 14 infants in the control condition did so, with the difference between conditions confirmed by a Wilcoxon rank-sum test, $W_s = 155.5$,

$p < .05$. Thus, infants in the experimental condition showed predictive looking toward the goal object during the test trial, but those in the control condition did not.

1.2.2. Comparison across conditions for attention to the actor and objects throughout the experiment

Follow-up analyses were conducted to determine whether the infants in the two conditions were equally attentive across the conditions[1]. Table 1 shows the mean (across subjects) looking time at the actor, the goal, and the non-goal object for each type of trial (familiarization, pretest-display, test). We first evaluated whether the infants' level of overall attention to *the actor* was similar in the two conditions. The infants in the experimental and control conditions looked about equally at the actor during both familiarization and test trials, $Fs < 3.45$, $ps > .07$. Next, we examined whether infants' total attention to both *the objects* was similar between the two conditions during each type of trial (familiarization, pretest-display, and test). The infants in the two conditions looked about equally at the objects during each type of trial, $Fs < 1$. These results suggest that differences in infants' overall attention during the familiarization, pretest-display, and test trials between the experimental and control conditions did not drive the different anticipatory looking patterns during the test trial.

We next examined whether the distribution of infants' attention toward the goal and non-goal objects during the familiarization trials was similar between the two conditions. Looking times during the 6-s pause before the action, the 2-s action, and the 8-s pause after the completion of the action were analyzed separately by means of a 2×2 repeated measures ANOVA with condition (experimental or control) as a between-subjects factor and with object (goal or non-goal) as the within-subject factor. During the 6-s pause before the onset of the action, no effect was significant, all $Fs < 1$, suggesting that the infants looked about equally at the goal and non-goal objects in the two conditions[2]. During the 2-s action and during the 8-s pause after the action was completed, the main effect of object was significant, $Fs(1, 25) > 7.33$, $ps < .05$, $\eta^2 > .23$, though the main effect of condition and the interaction between condition and object were not, $Fs(1, 25) < 2.51$, $ps > .12$, suggesting that infants attended more to the goal object, the endpoint of the action, than to the non-goal object to the same extent in the two conditions. These results suggest that, during the familiarization phase, the two conditions led infants to direct their attention similarly to the goal and non-goal objects.

1.3. Discussion

After 6-month-olds watched an actor repeatedly grasping one of two objects during familiarization, they then looked longer during the test toward the goal object in its new location than toward the other object, even before the actor started to reach for the goal object again. Our findings confirm that infants' anticipatory looks are not merely tracking the trajectory of an actor's hand movement. Based on prior work, infants seem to (1) interpret an actor's repeated actions during familiarization as goal-directed and (2) expect the actor to pursue the same goal object even when the location of the objects is switched (Woodward, 1998). We expected that infants in our experiment would do the same, and given that they have the expectation that the actor will continue to pursue her goal, they looked toward that goal object in anticipation of the actor's reach toward it.

The control condition suggests that the results obtained in the experimental condition were not due to a simple actor-object association. Infants in the control condition (1) seemed to know the actor could see only one (object-A) of the two objects (object-A and object-B) and (2) did not interpret the actor's repeated grasping of object-A as revealing her preference for it. When both objects were visible to the actor in the test trial, the infants had no basis on which to predict which object the actor would

---

[1] The data from one infant in the experimental condition was not included in this and subsequent analyses of Experiment 1, because the video recording of the infant during the familiarization and pretest-display trials was damaged.

[2] If infants had shown anticipatory looks during the 6-s pause in the familiarization trials, such looks could have been driven by predicting the endpoint of previously repeated movements, not by a prediction of the actor's goal; thus, they may not have been directly relevant to our question, as the location of the objects remained the same across the familiarization trials. We speculate that the infants might have been more motivated to generate a *prediction* when the context changed (during the test trial) than when the context remained the same (during familiarization trials).

Table 1
Mean (SE) looking times (s) for each condition in each trial.

		Experimental condition			Control condition			Preview condition		
		Goal object	Non-goal object	Actor	Goal object	Non-goal object	Actor	Goal object	Non-goal object	Actor
Familiarization trials	Before action onset	0.43 (0.18)	0.64 (0.23)	3.21 (0.36)	0.68 (0.28)	0.56 (0.15)	2.67 (0.30)	0.37 (0.08)	0.38 (0.08)	2.99 (0.24)
	After action onset	1.86 (0.34)	0.68 (0.16)	3.21 (0.40)	1.58 (0.34)	0.83 (0.15)	2.30 (0.34)	1.15 (0.20)	0.05 (0.10)	2.50 (0.41)
Pretest-display trial		3.19 (0.53)	2.37 (0.51)	–	2.73 (0.55)	2.74 (0.46)	–	2.01 (0.45)	1.48 (0.31)	–
Test trial		1.08 (0.20)	0.53 (0.17)	2.96 (0.27)	1.00 (0.38)	0.77 (0.18)	2.02 (0.43)	0.74 (0.20)	0.19 (0.09)	2.45 (0.37)

reach for, and thus they looked equally toward the two objects. Our results add to the evidence that 6-month-olds can consider an actor's perceptions when predicting her goal.

However, an alternative low-level interpretation for the results of the control condition is that infants might look equally at the two objects due to confusion. For example, the opaque screen increased the visual complexity of the scene and might have led to difficulty in processing the control-condition scenes. This interpretation is unlikely given that the looking times during the familiarization trials (when the screen was present in the control but not the experimental condition) do not differ across the conditions, but to rule out this possibility more directly, we conducted an additional experiment. The procedure of Experiment 2 was identical to that of the control condition of Experiment 1 except that an additional preview trial was added prior to familiarization trials (for a similar trial, see Luo & Baillargeon, 2007). At the start of the preview trial, only object-B (non-goal object) was placed at the center of the table, and the opaque screen was in its usual location to the right (or left); object-A (goal object) was absent. The actor then pushed object-B so that it stood in front of the screen (its position for the familiarization trials), then returned her hands to the starting position and paused. Following the preview trial, infants watched exactly the same familiarization, pretest-display, and test trials as those in the control condition of Experiment 1.

If infants in the preview condition (1) realized that the actor knew of the presence of object-B during familiarization, (2) interpreted the actor's repeated grasping of object-A as a preference for object-A over object-B (although object-B was not immediately visible to her), and (3) expected the actor to continue to prefer object-A to object-B, then (4) they should predict that in the test, the actor will grasp object-A. Thus, infants should look toward object-A (as they did in the experimental condition).

The results of Experiment 2 rely critically on the ability of infants to remember that the actor was aware of the presence of object-B. To our knowledge, there is little evidence that 6-month-olds have this ability. However, some evidence suggests that infants can track others' knowledge states during their first year of life (Kovács, Téglás, & Endress, 2010; Luo, 2011; Southgate & Vernetti, 2014). For example, in Kovács et al. (2010), 7-month-olds watched the following scenes: (1) an agent placed a ball on a table, (2) the ball rolled behind an occluder, (3) the ball rolled out from behind the occluder before (true-belief condition) or after (false-belief condition) the agent left the scene, (4) the agent returned, and (5) the occluder was lowered, revealing the ball's absence. The infants in the false-belief condition looked longer at the final event than the infants in the true-belief condition did, suggesting that the infants were tracking the agent's knowledge (since the infant always knew the ball was gone), which depended on tracking the sequence of events. Similarly, Southgate and Vernetti (2014) reported that 6-month-old infants can use an actor's false belief to predict whether she will act or not. The infants' motor cortex activated when the actor falsely believed a ball was present in a box but not when she falsely believed a ball was absent from the box. Positive findings in Experiment 2 would provide converging evidence that 6-month-olds have the ability to track the content of others' minds and would render unlikely the low-level (confusion) interpretation of the control condition of Experiment 1. In addition, they would provide corroborative evidence that 6-month-old infants can predict the goal of others even before the onset of action.

2. Experiment 2

2.1. Material and methods

2.1.1. Participants

Participants were 14 healthy term infants, 8 males and 6 females (M = 6 months, 16 days, range = 5 months, 22 days to 7 months, 4 days). Data from another 8 infants were eliminated due to inattentiveness (5), distraction (1), or parental interference (2).

2.1.2. Procedure and coding

The stimuli and procedure of Experiment 2 were identical to those of the control condition of Experiment 1, with one exception: The infants received a preview trial prior to the familiarization trials (Fig. 3). The preview trial consisted of a 10-s video clip. At the start of the preview trial, object-B (block or cone) stood at the center of the table, whereas the other object was absent. The actor sat at

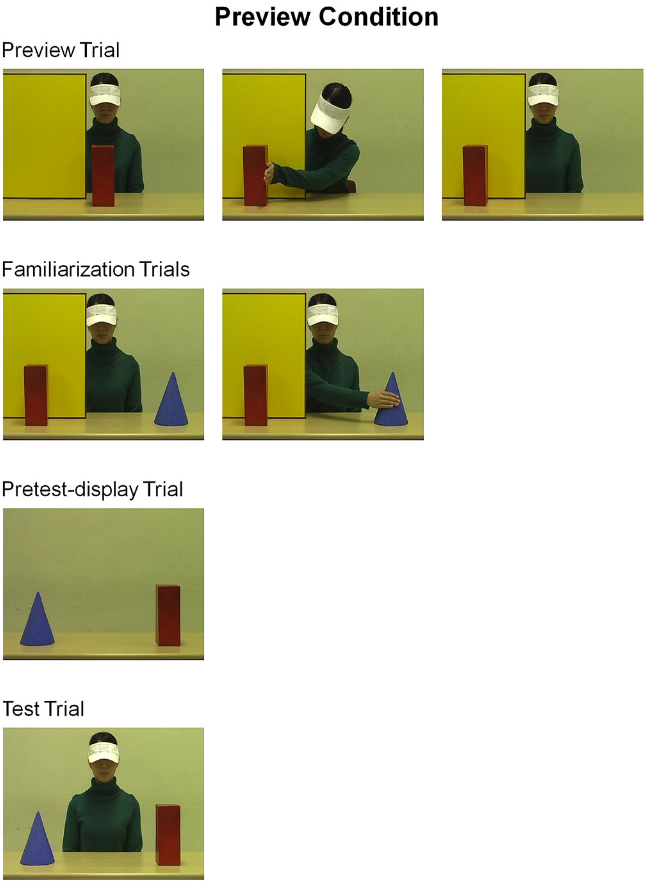

Fig. 3. Selected frames from the videos of the preview condition.

the table with her hands under the table. The actor paused (1 s), placed her palm against one side of the block or the cone (1 s), and pushed the object in a straight line until it stood in its standard position in front of the screen (3 s). Finally, the actor returned her hand to its starting position under the table (2 s) and paused (3 s). In the preview trial, infants were attentive during the 10-s video clip (looking times: $M = 7.29$ s, $SD = 1.69$). Following the preview trial, the infants received the familiarization, pretest-display, and test trials which were identical to the control condition of Experiment 1. The preview trial was consistent with the familiarization trials for each infant; the pushed object was the one that would be hidden by the screen, and the screen was on the appropriate side.

The second coder independently coded the video of 4 (29%) randomly selected infants; coders agreed on where the infant was looking on 87% of the frames.

2.2. Results

2.2.1. Comparison across conditions for predictive looking during the test trial

For the test trial for each infant, the proportion of looking time toward the goal object was calculated as the total looking time toward the goal object divided by the total looking time toward both the goal and non-goal objects. Preliminary analyses showed no significant main effect of sex or goal object (block or cone) or interactions involving these factors, $Fs < 2.44$, $ps > .13$; subsequent analyses collapsed across sex and goal object.

Infants looked longer toward the goal object in the preview condition ($M = .80$, $SD = .37$) than in the control condition ($M = .39$, $SD = .40$), a difference supported by a one-way ANOVA with condition (preview, control) as a between-subjects factor, $F(1, 26) = 7.83$, $p < .05$, $\eta^2 = .23$ (see Fig. 2). Infants in the preview condition looked reliably longer toward the goal object than expected by chance, $t(13) = 3.05$, $p < .01$, $d = 1.69$. Eleven of the 14 infants in the preview condition looked longer toward the goal object than toward the non-goal object. A difference between the preview and control conditions was confirmed by a Wilcoxon rank-sum test, $W_s = 147$, $p < .01$.

2.2.2. Comparison across conditions for attention to the actor and objects throughout the experiment

The infants in the preview and control conditions were equally attentive to the actor during familiarization and test trials, Fs < 1. The infants were also equally attentive to the objects during familiarization, pretest-display, and test trials, Fs < 3.95, ps > .057 (see Table 1).

We next examined whether infants in the two conditions attended to the goal and non-goal objects to the same extent during the familiarization trials. During the initial 6-s pause, no effect was significant, Fs(1, 26) < 2.80, ps > .10, suggesting that infants in the two conditions looked about equally at the goal and non-goal objects. During the 2-s action, the main effect of object was significant, $F(1, 26) = 37.90$, $p < .001$, $\eta^2 = .59$, whereas the main effect of condition and the interaction between condition and object were not, Fs < 1, suggesting that infants attended more to the goal object than to the non-goal object to the same extent in the two conditions. During the 8-s pause after completion of the action, the main effect of condition approached statistical significance, $F(1, 26) = 4.16$, $p = .052$, $\eta^2 = .14$, indicating that infants in the control condition tended to look longer at the objects than those in the preview condition. The main effect of an object was marginally significant, $F(1, 26) = 4.11$, $p = .053$, $\eta^2 = .14$, with infants tending to look more at the goal than the non-goal object. However, the interaction between condition and object was not significant, $F < 1$. These results suggest that, even though the longer procedure of the preview condition tended to make the infants less attentive during the final 8-s pause, the infants in the two conditions allocated their attention similarly to the goal and non-goal objects throughout the familiarization phase.

2.3. Discussion

Experiment 2 again demonstrated that 6-month-olds showed predictive looks toward the goal object during the test trial. The results suggest that the infants (1) realized that, based on the preview trial, the actor knew that object-B was present behind the opaque screen; (2) interpreted the actor's grasping of object-A as signaling her preference for the visible object-A over the hidden object-B in the familiarization trials; (3) expected the actor to pursue the same goal object-A even when object-B was again visible during the test; and therefore (4) looked more toward object-A, in anticipation of the actor's action toward it.

The positive results of Experiment 2 rule out the possibility that the infants in the control condition of Experiment 1 were confused by components not shared with the experimental condition. If the control condition was too confusing, then the infants in the preview condition, who received exactly the same familiarization, pretest-display, and test trials, should also have been confused and hence should also have demonstrated no anticipatory looking.

3. General discussion

The present research suggests that infants can sometimes predict others' actions even before actions are initiated. In the experimental condition of Experiment 1, the infants (1) interpreted the actor's repeated grasping of object-A as opposed to object-B in the familiarization trials as signaling her preference for object-A over object-B, and (2) predicted that the actor would again reach for object-A during the test trial. The results obtained in the control condition suggest that the infants' anticipatory looking was not due to a simple association between the actor and the goal object. Experiment 2 replicated the findings of the experimental condition of Experiment 1 and confirmed that the control condition results were not due to perceptual aspects of the scenes not shared by the experimental condition.

Our results with 6-month-olds are consistent with previous results obtained with 11-month-olds (Cannon & Woodward, 2012). In both studies, the positions of the two objects were switched from the familiarization to the test phase, making it possible to distinguish infants' predictions based on their detecting the actor's goal object from their simply predicting the endpoint of the actor's hand movement trajectory. Together these findings suggest that infants (1) attend to others' goals over paths or end locations, when watching the grasping actions of others, (2) expect others to continue to pursue the same goal, and (3) thus, look in anticipation toward where the goal object is located when its location is changed. Therefore, our results show that 6-month-olds, like older infants, can anticipate others' actions in terms of goals. As in Cannon and Woodward (2012), we examined infants' looking before an action was apparent, unlike previous researchers, who measured infants' anticipatory looking while the infants observed ongoing actions (Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011). Thus, the present findings suggest that infants' eye movements are not merely a response to an ongoing visual input, but that they can reflect a process induced by the knowledge of previous and upcoming actions. Our findings are consistent with neurophysiological evidence that adults' and infants' anticipatory motor activation precedes the onset of an observed action (Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004; Southgate & Begus, 2013; Southgate et al., 2009; Southgate & Vernetti, 2014).

As the principal measure, we measured the proportion of infants' total looking times to the goal object out of the total looking time toward the goal and non-goal objects, following previous preferential-looking paradigms (e.g., Fernald et al., 2008; Song & Fisher, 2005) and several eye-tracking experiments (e.g., Kidd, White, & Aslin, 2011; Vlach & Johnson, 2013). In contrast, other eye-tracking studies have used as their main measure the first gaze shift after the onset of an event (or after the pausing of an incomplete action; e.g., Cannon & Woodward, 2012; Senju, Southgate, Snape, Leonard, & Csibra, 2011; Southgate, Senju, & Csibra, 2007).

We also examined infants' first gaze shift to either of the objects for the infants who were looking away or looking at the center at the onset of the test trial ($N = 29$). More infants made a first shift towards the goal in the experimental (7 out of 10) and preview conditions (7 out of 9) than in the control condition (3 out of 10), $p < .05$, one-tailed Fisher's exact test. Our "poor man's eye-tracker" gaze shift results (see also Snedeker & Thothathiri, 2008 for similar methods for measuring children's eye movements) are consistent with results from our analyses of infants' looking-time proportions. Future research should examine whether these findings hold with an eye-tracking paradigm having the advantage of higher spatial and temporal resolution.

An important question raised by our findings regards the mechanism underlying infants' action prediction. The *direct-matching hypothesis* of the mirror neuron system proposes that action prediction is possible through mapping the visual representation of others' actions to the motor representation of the same action (Rizzolatti, Fogassi, & Gallese, 2001). In the current study, visual information about an action (bottom-up identification of an action) was not necessary to generate eye movements. Thus, our findings do not fit with the direct-matching hypothesis. Instead, our findings support the proposal that motor activation can also be induced by action interpretation in a top-down manner (Csibra, 2007).

Another question that remains concerns the relationship between infants' action production and action prediction. Both the present research and Kanakogi and Itakura (2011) have shown that 6-month-olds can predict the goal or movement patterns of others' grasping actions, whereas Falck-Ytter et al. (2006) reported that 6-month-olds did not predict the outcome of transporting actions, specifically the moving of toys across a table and putting them into a bucket. This discrepancy raises an interesting question about the developmental roots of the ability of infants to predict others' goals. One account of how infants acquire this ability is the *experience-based account*, which suggests that first-person experience is necessary, and thus that infants' goal prediction should be restricted to actions that infants themselves can execute (Sommerville et al., 2005; Woodward & Guajardo, 2002). According to this account, 6-month-olds can grasp and move objects but cannot transport an object and place it in a container across the table; thus they can predict actions based on grasping goals but not those based on transporting goals. In contrast, the *cue-based account* argues that infants can detect goals as long as certain behavioral cues are present, and that infants are naturally sensitive to these cues (Csibra, 2008). Relevant behavioral cues include self-initiated motion, equifinal variation of the actions, action contingency, and rationality of an action (Biro & Leslie, 2007; Luo & Baillargeon, 2005; Premack, 1990). According to the latter account, infants may be able to predict others' actions regardless of their own motor abilities, as long as these behavioral cues are provided and goals can be detected. Future research should examine whether the presence of specific behavioral cues can help 6-month-olds make predictions about actions they rarely produce (e.g., pointing actions).

Finally, the current findings have implications for other aspects of cognitive development in infancy. First, the present findings add to the evidence on 6-month-olds' ability to represent the visual experience of others when it differs from the infants' own perspective. Differentiating the visual perspectives of others from their own allows 6-month-olds not only to detect but also to predict others' goals in a wider range of situations. Second, the current findings add to the existing evidence on infants' ability to exploit others' past visual experience when making current predictions. Previous work showed that 7-month-olds were influenced by others' past visual experience (Kovács et al., 2010), but we, along with Southgate and Vernetti (2014), demonstrate that 6-month-olds can make active predictions about someone's actions based on what she knows/does not know about.

In conclusion, 6-month-olds not only have the ability to encode the goal of others' grasping actions but can also predict others' future actions based on that goal. Infants' prediction of others' actions is not necessarily induced by the visual input of ongoing actions but can be induced by infants' understanding of the goals of others' previous and future actions.

Acknowledgements

This work was supported by National Research Foundation Grant of Korea (NRF-2012-S1A3-A2033375) and the Yonsei University Research Fund of 2014. We would like to thank Kris Onishi for helpful comments on this manuscript. In addition, we are grateful to the parents and infants who participated in this study and the members of the Yonsei Child Development Laboratory.

References

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: Development through cue-based bootstrapping. *Developmental Science*, *10*, 379–398. http://dx.doi.org/10.1111/j.1467-7687.2006.00544.x

Cannon, E., & Woodward, A. L. (2012). Infants generate goal-based action predictions. *Developmental Science*, *15*, 292–298. http://dx.doi.org/10.1111/j.1467-7687.2011.01127.x

Csibra, G. (2007). Action mirroring and action interpretation: An alternative account. In P. Haggard, Y. Rosetti, & M. Kawato (Eds.), *Sensorimotor foundations of higher cognition. Attention and performance XXII* (pp. 435–459). Oxford: Oxford University Press.

Csibra, G. (2008). Goal attribution to inanimate agents by 6.5-month-old infants. *Cognition*, *107*, 705–717. http://dx.doi.org/10.1016/j.cognition.2007.08.001

Daum, M. M., Prinz, W., & Aschersleben, G. (2008). Encoding the goal of an object-directed but uncompleted reaching action in 6- and 9-month-old infants. *Developmental Science*, *11*, 607–619. http://dx.doi.org/10.1111/j.1467-7687.2008.00705.x

Falck-Ytter, T., Gredebäck, G., & von Hofsten, C. (2006). Infants predict other people's action goals. *Nature Neuroscience*, *9*, 878–879. http://dx.doi.org/10.1038/nn1729

Fernald, A., Zangl, R., Portillo, A. L., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language comprehension by infants and young children. In I. Sekerina, E. M. Fernández, & H. Clahsen (Eds.), *Developmental psycholinguistics: On-line methods in children's language processing* (pp. 97–135). Amsterdam: John Benjamins.

Kanakogi, Y., & Itakura, S. (2011). Developmental correspondence between action prediction and motor ability in early infancy. *Nature Communications*, *2*, 341. http://dx.doi.org/10.1038/ncomms1342

Kidd, C., White, K. S., & Aslin, R. N. (2011). Toddlers use speech disfluencies to predict speakers' referential intentions. *Developmental Science*, *14*, 925–934. http://dx.doi.org/10.1111/j.1467-7687.2011.01049.x

Kilner, J. M., Vargas, C., Duval, S., Blakemore, S. J., & Sirigu, A. (2004). Motor activation prior to observation of a predicted movement. *Nature Neuroscience*, *7*, 1299–1301. http://dx.doi.org/10.1038/nn1355

Kim, M., & Song, H. (2008). Korean 9- and 7-month-old infants' ability to encode the goals of others' pointing actions. *The Korean Journal of Developmental Psychology*, *21 (3)*, 41–61.

Kovács, Á. M., Téglás, E., & Endress, A. D. (2010). The social sense: Susceptibility to others' beliefs in human infants and adults. *Science*, *330*, 1830–1834. http://dx.doi.org/10.1126/science.1190792

Knudsen, B., & Liszkowski, U. (2012). Eighteen- and 24-month-old infants correct others in anticipation of action mistakes. *Developmental Science*, *15*, 113–122. http://dx.doi.org/10.1111/j.1467-7687.2011.01098.x

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, *62*, 621–647. http://dx.doi.org/10.1146/annurev.psych.093008.131123

Luo, Y. (2011). Do 10-month-old infants understand others' false beliefs? *Cognition*, *121*, 289–298. http://dx.doi.org/10.1016/j.cognition.2011.07.011

Luo, Y., & Baillargeon, R. (2005). Can a self-propelled box have a goal? Psychological reasoning in 5-month-old infants. *Psychological Science*, *16*, 601–608. http://dx.doi.org/10.1111/j.1467-9280.2005.01582.x

Luo, Y., & Baillargeon, R. (2007). Do 12.5-month-old infants consider what objects others can see when interpreting their actions? *Cognition*, *105*, 489–512. http://dx.doi.org/10.1016/j.cognition.2006.10.007

Luo, Y., & Johnson, S. C. (2009). Recognizing the role of perception in action at 6 months. *Developmental Science*, *12*, 142–149. http://dx.doi.org/10.1111/j.1467-7687.2008.00741.x

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition*, *36*, 1–16. http://dx.doi.org/10.1016/0010-0277(90)90051-k

Reid, V. M., Hoehl, S., Grigutsch, M., Groendahl, A., Parise, E., & Striano, T. (2009). The neural correlates of infant and adult goal prediction: Evidence for semantic processing systems. *Developmental Psychology*, *45*, 620–629. http://dx.doi.org/10.1037/a0015209

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Review Neuroscience*, *2*, 661–670. http://dx.doi.org/10.1038/35090060

Senju, A., Southgate, V., Snape, C., Leonard, M., & Csibra, G. (2011). Do 18-month-olds really attribute mental states to others? A critical test. *Psychological Science*, *22*, 878–880. http://dx.doi.org/10.1177/0956797611411584

Snedeker, J., & Thothathiri, M. (2008). What lurks beneath: Syntactic priming during language comprehension in preschoolers (and adults). In I. Sekerina, E. Fernández, & H. Clahsen (Eds.), *Developmental psycholinguistics: On-line methods in children's language processing* (pp. 251–315). Amsterdam: John Benjamins.

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, *96*, B1–B11. http://dx.doi.org/10.1016/j.cognition.2004.07.004

Song, H., Baillargeon, R., & Fisher, C. (2014). The development of infants' use of novel verbal information when reasoning about others' actions. *PLoS ONE*, *9*, e92387. http://dx.doi.org/10.1371/journal.pone.0092387

Song, H., & Fisher, C. (2005). Who's "she"? Discourse prominence influences preschoolers' comprehension of pronouns. *Journal of Memory and Language*, *52*, 29–57. http://dx.doi.org/10.1016/j.jml.2004.06.012

Southgate, V., & Begus, K. (2013). Motor activation during the prediction of nonexecutable actions in infants. *Psychological Science*, *24*, 828–835. http://dx.doi.org/10.1177/0956797612459766

Southgate, V., Johnson, M. H., Karoui, I. E., & Csibra, G. (2010). Motor system activation reveals infants' on-line prediction of others' goals. *Psychological Science*, *21*, 355–359. http://dx.doi.org/10.1177/0956797610362058

Southgate, V., Johnson, M. H., Osborne, T., & Csibra, G. (2009). Predictive motor activation during action observation in human infants. *Biology Letters*, *5*, 769–772. http://dx.doi.org/10.1098/rsbl.2009.0474

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science*, *18*, 587–592. http://dx.doi.org/10.1111/j.1467-9280.2007.01944.x

Southgate, V., & Vernetti, A. (2014). Belief-based action prediction in preverbal infants. *Cognition*, *130*, 1–10. http://dx.doi.org/10.1016/j.cognition.2013.08.008

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*, 375–382. http://dx.doi.org/10.1016/j.cognition.2013.02.015

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34. http://dx.doi.org/10.1016/s0010-0277(98)00058-4

Woodward, A. L., & Guajardo, J. J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development*, *17*, 1061–1084. http://dx.doi.org/10.1016/s0885-2014(02)00074-6

Woodward, A. L., & Sommerville, J. A. (2000). Twelve-month-old infants interpret action in context. *Psychological Science*, *11*, 73–77. http://dx.doi.org/10.1111/1467-9280.00218