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PAPER

How infants relate looker and object: evidence for a perceptual learning account of gaze following in infancy

Markus Paulus

Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, The Netherlands

Abstract

In two experiments, it was investigated how preverbal infants perceive the relationship between a person and an object she is looking at. More specifically, it was examined whether infants interpret an adult's object-directed gaze as a marker of an intention to act or whether they relate the person and the object via a mechanism of associative learning. Fourteen-month-old infants observed an adult gazing repeatedly at one of two objects. When the adult reached out to grasp this object in the test trials, infants showed no systematic visual anticipations to it (i.e. first visual anticipatory gaze shifts) but only displayed longer looking times for this object than for another before her hand reached the object. However, they showed visual anticipatory gaze shifts to the correct action target when only the grasping action was presented. The second experiment shows that infants also look longer at the object a person has been gazing at when the person is still present, but is not performing any action during the test trials. Looking preferences for the objects were reversed, however, when the person was absent during the test trials. This study provides evidence for the claim that infants around 1 year of age do not employ other people's object-directed gaze to anticipate future actions, but to establish person–object associations. The implications of this finding for theoretical conceptions of infants' social-cognitive development are discussed.

Introduction

Gaze following plays a central role in the social and cognitive development of the child (Astington, 2000; Carpendale & Lewis, 2004, 2006; Doherty, 2008; Moore, 2006; Nelson, 2007). It has, for example, been suggested that gaze following is particularly important in language acquisition (Bates, 1979; Hirotani, Stets, Striano & Friederici, 2009). Furthermore, the ability to follow gaze might be crucial for the development of social understanding of the mental states of others (Barresi & Moore, 1996, 2008).

As gaze following is an important ability, researchers have examined its early development. It has been shown that infants start to follow gaze from about 3 months of age (Scaife & Bruner, 1975), but this early gaze following only occurs when the objects are close to the model and highly salient (D'Entremont, 2000). From 7 months on, the establishment of joint attention facilitates the encoding of information about objects (Cleveland, Schug & Striano, 2007). By 10 to 12 months of age, infants' gaze following is influenced by the perceptual status of the eyes, as infants follow open and closed eyes differently (Brooks & Meltzoff, 2005). Around the same age, infants relate a person and the object of her gaze to each other (Woodward, 2003), indicating that earlier instances of gaze following probably do not lead to the perception of a relation between looker and object. Later in development, human gaze following is affected by the developing knowledge of the world around them. Adults, for example, follow gaze towards objects when the model wears sunglasses but not when the eyes and the objects are separated by a solid barrier (Nuku & Bekkering, 2008).

The findings that around 1 year of age infants relate looker and object to each other (Woodward, 2003) lead to the question of how exactly infants relate both entities to each other. In other words, how is the perceived information about them processed, and, more specifically, how is the intentional relation between looker and object represented by preverbal infants around 1 year of age? Recently, it has been suggested that 12-month-old infants perceive others' object-directed looking as predictive of intentional action (Phillips, Wellman & Spelke, 2002). The infants were presented with an actor on a stage-like display in a habituation-based paradigm. The actor was sitting at a table and facing the child. To the left and right of the actor, there were two toy animals (kittens). The infants observed the actor looking at one of the two kittens while displaying positive emotions. In the consistent test event, the actor subsequently held in her hand the same toy at which she had been gazing, whereas in the inconsistent test event she was presented with the other toy in her hand. It was found that the infants looked longer when they saw the actor with the other object in her hand. This and related findings that

Address for correspondence: Markus Paulus, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands; e-mail: m.paulus@donders.ru.nl

employed the same or similar paradigms (Barna & Legerstee, 2005; Johnson, Ok & Luo, 2007; Luo, 2010; Sodian & Thoermer, 2004; Vaish & Woodward, 2010) have been interpreted as providing evidence for the notion that infants ascribe to the other person a desire for one of the objects and interpret the actor's behavior as an intention for goal-directed action. In particular, it has been argued that these findings may be 'evidence of a primitive concept of desire' (Barna & Legerstee, 2005, p. 63) and that 'infants construct progressively refined understandings that lead to an awareness, before the end of the first year, of people as intentional agents that will act on things they want' (p. 65).

However, although it has been suggested that the findings provide evidence for infants' evolving understanding of others' intentions and desires (Barna & Legerstee, 2005; Phillips *et al*., 2002), it should be noted that the data support this interpretation only indirectly, as in these studies no actions were carried out. The infants only observed an actor's gaze behavior and were subsequently presented with a picture of the actor with one of the objects in her hand. This means that infants never actually saw the actor grasping either of the objects. Moreover, the empirical results of these studies based on habituation measures are open to different interpretations (cf. Bogartz, Shinskey & Speaker, 1997; Hunnius, 2007) and should thus be interpreted with care (e.g. Haith, 1998; Thomas & Gilmore, 2004). More specifically, the results could be explained by associative learning mechanisms. In the current literature, it has repeatedly been suggested that several results obtained with respect to infants' social-cognitive development could best be explained by perceptual learning mechanisms, and in particular, by associative learning (e.g. Csibra, 2003; Gergely, 2001; Kiraly, Jovanovic, Prinz, Aschersleben & Gergely, 2003; Perner & Ruffman, 2005; Sirois & Jackson, 2007). For example, Csibra (2003) as well as Kiraly and colleagues (2003) suggested that several findings on infants' prediction of the goal object of a grasping action (e.g. Woodward, 1998) could likewise be explained by the theory that the infants acquired an association between the visual configurations of the hand and the object it has been grasping. Applying this approach to the study of Phillips and colleagues (2002), infants' longer looking in this study might have been caused by the acquisition of a person–object association between the person and the object she was looking at (cf. Perner & Ruffman, 2005). In other words, it is possible that through the actor's gaze the infants' attention was directed to the object she has been gazing at and that they thus visually associated the visual configuration of the actor with the features of this particular object. When subsequently presented with the same person holding another object in her hand, this grouping of two items was more novel compared to initial pairing, causing the novelty response reported by the authors.

This alternative interpretation is in accordance with theoretical approaches and empirical results, stressing that infants around 1 year of age do not interpret others' gaze behavior in intentional (or representational) terms, but that this ability is a later achievement (e.g. Carpendale & Lewis, 2004; Doherty, Anderson & Howieson, 2009; Moore, 2006; Moore & Corkum, 1994; see also Perner, 1991), and that early gaze following is thus more likely to be subserved by other mechanisms (Butterworth & Cochran, 1980; Moore & Povinelli, 2007; Triesch, Teuscher, Deak & Carlson, 2006; for a current review on the development of gaze understanding see Doherty, 2006). Thus, the results obtained by Phillips and others (2002) could also be interpreted as evidence for the acquisition of an associative relation between looker and object rather than as evidence of an ascription of intentional states. As both theoretical approaches can thus equally well explain the original findings, another experiment is necessary, for which both theories make different predictions.

This study was designed to address this question by making use of the more precise method of measuring infants' eye movements (see Aslin, 2007). Recent studies employing corneal reflection eye-tracking techniques have provided evidence that infants visually anticipate the goals of an ongoing action they observe (Eshuis, Coventry & Vulchanova, 2009; Falck-Ytter, Gredebäck & von Hofsten, 2006; Hunnius & Bekkering, 2010; Paulus, Hunnius, van Wijngaarden, Vrins, van Rooij & Bekkering, in press-b; Paulus, Hunnius & Bekkering, 2011a). This shows that anticipatory eye movements can reveal how an observer perceives and understands the actions of other people. To investigate whether 14-month-old infants perceive an actor's looking behavior as a predictor of intentional action or whether they relate this person and the object via associative learning, infants were presented with movies of a model gazing at one of two objects while showing positive emotions towards this object. In a subsequent test phase, the actor initialized a grasping action. The initial part of the grasping action was not directed toward an object and was thus ambiguous with respect to the action's target. To empirically differentiate anticipations of action targets from associative priming of one of the objects the following measures were taken during the ambiguous part of the grasping movement.

First, as a measure of visual associations, infants' overall looking time to the two objects was analyzed. If infants use the actor's gaze behavior to acquire person–object associations, one would expect that infants in the test phase should look longer at the object the person had been gazing at compared to the other object. In particular, if infants have associated the visual configuration of the actor with the particular object she had been gazing at, the perception of the actor should activate the representation of the corresponding object. This, in turn, should facilitate the processing of the object she has been associated with. Similar effects are well known from studies on language acquisition. For example, when 14-month-old infants hear a word that they have just associated with an object, they subsequently look longer at this compared to other objects (e.g. Houston-Price, Plunkett & Duffy, 2006). Taken together, the presence of the actor should serve as an associative prime and should thus influence infants' looking behavior at the objects (cf. Barr, Vieira & Rovee-Collier, 2002; McNamara, 1992).

Second, strict criteria were used to differentiate anticipations from other gaze shifts or fixation preferences that might reflect mere scanning behavior or associative learning. As a measure of infants' action target anticipations, in line with recent literature infants' first visual anticipatory gaze shift from the ongoing action (i.e. the moving hand) to one of the two possible targets was analyzed (cf. Eshuis *et al.*, 2009; Falck-Ytter *et al.*, 2006; Gredebäck & Melinder, 2010; Kochukhova & Gredebäck, 2010; Paulus *et al.*, 2011a). The reason for relying on infants' first anticipatory gaze shift was to ensure that infants would look at an object as a consequence of their perception of the ongoing grasping action, and to exclude cases in which infants, for example, kept fixating on one object from the beginning of the trial without even having seen the ongoing action (cf. Kenward, 2010) or based on person–object associations. If 14-month-old infants perceive the looking behavior of another person as a predictor of intentional action, one would expect that infants should direct their first visual anticipatory gaze shift to the target the actor had previously been gazing at (see also Astington, 2001). In other words, following this hypothesis, infants should have acquired the knowledge that the actor wants this object, and this knowledge should enable them to anticipate the correct action target when the actor starts the grasping action.

Experiment 1

The first experiment examined whether 14-month-old infants interpret an actor's gaze behavior as a marker of intentional action. To this end, infants in a first condition (*gaze condition*) observed in four gaze trials how a model gazed at one of two objects (gaze-object). In two test trials, the model started a grasping action and it was analyzed whether or not infants anticipated the gaze-object as the target of the actor's grasping action. In addition, infants' looking times to both objects were measured. In a second condition (*action condition*), infants observed in one action trial the actor grasping one of the two objects. Subsequently, two test trials were administered, and infants' anticipations and their overall looking times to both objects were analyzed.

Method

Participants

The final sample consisted of 32 14-month-old infants, 16 in each condition (*range*: 13 months, 15 days to 14 months, 30 days). Six additional 14-month-old infants were tested but were not included in the final sample because of technical failure, refusal to remain seated or becoming inattentive during the experiment. The infants' parents gave informed consent for participation of their child in the study and were given a children's book or monetary compensation for their visit.

Stimuli

The stimuli in the gaze trials consisted of movies which showed a female model sitting at a table (see Figure 1). The model was wearing a khaki-colored sweatshirt over a red T-shirt. The background was light grey. On the table were two toy animals, one blue and white, and the other red and white. The toy animals were also of different shapes, but had the same overall dimensions. Initially, the model's eyes were directed at the camera. After approximately 1 second, she looked at one of the two objects, which were placed to her right and left respectively, and smiled happily while looking at this object (gaze phase; see Figure 1A, for an example). The movie had a duration of approximately 5.5 seconds. Four different versions of this movie were made, whereby the positions of the two objects (right or left side of the table) and direction of the model's gaze (right, left) were counterbalanced.

The stimuli in the action trial consisted of movies in which the actor was looking downwards at her hand to avoid cueing one of the objects and to avoid infants' attention being captured by the face (cf. Falck-Ytter *et al.*, 2006). After 0.5 seconds she slowly raised her right hand up to the height of her chest, waited a while (ambiguous movement phase, lasting approximately 5 seconds) and subsequently grasped one of the two objects (see Figure 1B, for an example). The movie ended showing the model with her hand on the grasped object for approximately 10 seconds. Different versions of the action trials were made, in which the positions of the two objects (right or left side of the table) and direction of the model's grasping action (right, left) were balanced.

Experimental setup and procedure

During the experiment, the infant was seated in an infant seat on his or her parent's lap. The parent was seated on a chair at a viewing distance of approximately 60 cm so that the objects had a size of 7° visual angle. 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″ 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 and a spatial resolution of 0.25° visual angle. Prior to testing, the gaze of each infant participant was calibrated. A 9-point calibration procedure was used, in which a sound-accompanied contracting circle appeared in a screen-wide 3-by-3 grid of calibration points. If seven or fewer

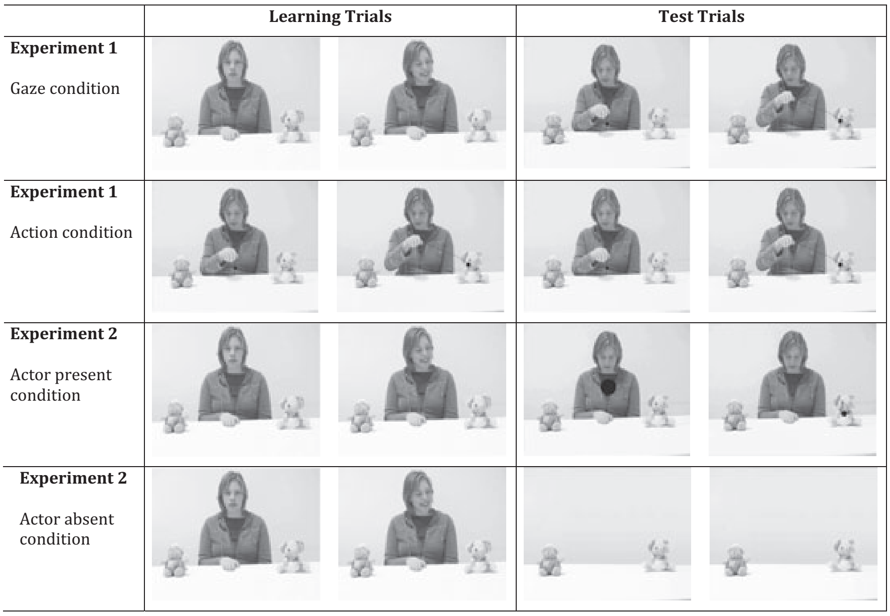

Figure 1 *Key frames from the stimulus movies. Every line represents one condition of the two experiments. The first column gives a description of the condition, the second column shows two key frames from the respective type of learning trial and the third column shows two key frames from the test trial of each condition. Note that the two pictures of the test trials in Experiment 1 show the first, ambiguous part of the grasping action. The dark spot represents an example of a participant's fixation.*

points were calibrated successfully, the calibration was repeated for the missing calibration points; otherwise the experiment was started.

Gaze condition. Infants were first presented with four gaze trials (serving as learning trials). The position of the object (right, left) was counterbalanced within participants between trials, and the object the model was looking at was counterbalanced between participants. After the presentation of the four gaze trials, two action trials were presented to the infants (test trials). In the test trials, the model was grasping the same object she had been looking at in the four gaze trials. The position of the object (right, left) was counterbalanced within subjects between test trials.

Action condition. The procedure was the same as for the *Gaze condition* with the only exception being that there were no gaze trials. Only three grasping trials were presented. The position of the object (right, left) was counterbalanced within participants between trials, and the object the model was grasping was counterbalanced between participants. The first trial served as a learning trial and provided the infants with information about the actor's action target. The latter two action trials were the test trials and were analyzed in the same way as in the *Gaze condition*.

Scoring and data analysis

The infants' looking behavior was recorded using the Clear View software (Tobii Technology, Stockholm, Sweden). Infants' looking behavior was further analyzed by custom-made analysis software for eye-tracking data that analyzes infants' looking behavior on a frame-by-frame basis. Infants' fixations were included when infants' gaze remained within the radius of 30 pixels on the screen for at least 80 ms (cf. Hunnius & Bekkering, 2010; Paulus *et al.*, 2011a). Two rectangular areas of interest (AoI) were defined for both objects. The AoI were calculated to fit around the two objects and were of the same size.

First, infants' overall looking times to both objects during each of the gaze trials of the *Gaze condition* were analyzed. For the statistical analyses, the data were averaged over the four gaze trials and a *t*-test for dependent measures was conducted. Due to directed hypothesis testing only, this *t*-test was conducted one-sided.

For the test trials in both conditions, infants' overall looking time to each of the two objects during the ambiguous stage of the hand movement was analyzed to investigate the person–object associations infants might have acquired. The looking times were analyzed using a three-way ANOVA with the within-subjects factors object (cued object, uncued object) and trial (test trial 1, test trial 2) and the between-subjects factor condition (*Gaze*, *Action*).

Furthermore, as a measure of visual anticipations, infants' first visual anticipatory gaze shift to one of the two objects during the ambiguous movement phase of the grasping action was analyzed. An anticipation was thus defined as a gaze shift from the moving hand to one of the two possible targets (cf. Kochukhova & Gredebäck, 2010). The ambiguous movement phase contained no movement cue as to which object the actor was going to grasp. Differences in infants' anticipation of both objects could thus only be explained with regard to the information infants had obtained in the previous trials. For the statistical analyses of infants' anticipations, we calculated a difference score (DS) as follows (for similar procedures see Corkum & Moore, 1998; Gredebäck, Theuring, Hauf & Kenward, 2008): trials in which infants' first anticipation was directed towards the target the actor had been gazing at were given a value of 1; trials in which infants' first anticipation was directed at the other target were given a value of −1. When infants did not anticipate any object, a value of 0 was assigned. If infants anticipate the cued object, a positive DS in the positive direction should thus be obtained. The DS was analyzed using a two-way analysis of variance (ANOVA) with the within-subjects factor trial (test trial 1, test trial 2) and the between-subjects factor condition (*Gaze*, *Action*).

Results

Gaze trials (*Gaze condition*)

During the gaze phase of the gaze trials the infants looked on average 475 ms (*SE*: 82.0) at the object the model was gazing at and 320 ms (*SE*: 73.9) at the other object. A *t*-test for dependent measures revealed that there was a preference for the gaze cued object, $t(15) = 2.04$, $p < .05$, one-sided.

Test trials

The analysis of infants' looking times revealed only an effect of Object, which approached significance ($F(1, 30) = 3.45$, $p = .07$, $\eta_p^2 = .10$), but no effect of condition or trial (all *p*s > .16). This shows that the infants looked longer at the object the actor had acted upon (mean: 513 ms, *SE*: 67.9) than at the other object (mean: 381 ms, *SE*: 59.2).

Infants performed an anticipatory eye movement toward one of the toys in 61% (*SE* = 7.6) of the presented trials. An ANOVA over the number of anticipations with the between-subjects factor condition and the within-subjects factor trial revealed no effect (all *p*s > .27). The analysis of the DS revealed only a main effect of condition ($F(1, 30) = 5.62$, $p < .05$, $\eta_p^2 = .16$; all other *p*s > .46). To further explore this effect, data were averaged across trials and separately analyzed for each condition (see Figure 2). A *t*-test for independent measures confirmed that the DS in the *Action condition* (first test trial: $M = 0.31$, $SE = 0.20$; second test trial: $M = 0.31$, $SE = 0.20$) was significantly higher than the DS in the *Gaze condition* (first test trial: $M = -0.13$, $SE = 0.18$; second test trial: $M = -0.06$, $SE = 0.19$), $t(30) = 2.37$, $p < .05$. Furthermore, a *t*-test revealed that infants' DS in the *Action condition* was significantly above zero, $t(15) = 2.44$, $p < .05$, whereas this was not the case in the *Gaze condition*, $t(15) = 0.82$, $p = .42$.

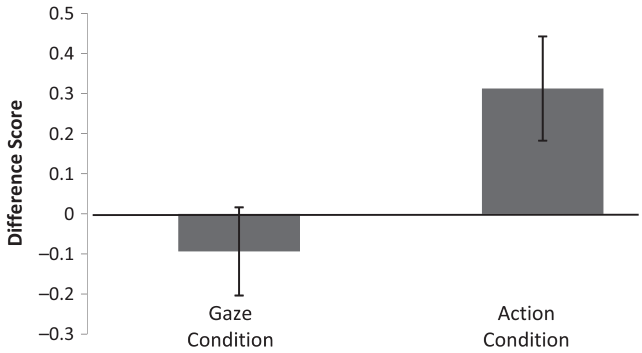

Figure 2 *Average difference scores of the participants' anticipations in Experiment 1. Positive scores indicate anticipations to the cued object, negative scores to the uncued object, respectively. Error bars indicate standard errors of the means. The left bar represents the results of the Gaze condition, the right bar the results of the Action condition.*

Discussion

The results of Experiment 1 demonstrate that 14-month-old infants, after having observed that an actor grasped one of two objects, performed anticipatory eye movements towards this action target in subsequent trials. This demonstrates that the infants perceived the actor's grasping action as goal-directed and were able to anticipate the correct target of the action. Infants did not, however, show systematic anticipatory eye movements towards one of the two objects after they had observed the actor repeatedly gazing at one of the two objects, indicating that they did not interpret the model's gazing behavior as a marker of intentional action.

One might object that infants found it more difficult to recognize the target of the gazing action compared with the grasping action. For example, it has been suggested that already at the age of 6 months infants can relate an actor's grasp to a particular target (Woodward, 1998), whereas only from 9 months on can infants relate an actor's gaze to a target (Woodward, 2003). To account for this difference, infants in this study were presented with four learning trials in the gaze condition compared to only one learning trial in the action condition. Even though the presentation of more learning trials in the gaze condition should have facilitated infants' learning about the relation between looker and object, no systematic anticipations to one of the two possible targets was found in this condition. However, in both conditions infants looked longer at the cued object. This pattern is consistent with the notion that infants established a person–object association, which was independent from any action the model was performing (cf. Perner & Ruffman, 2005).

Experiment 2

To further investigate this claim, Experiment 2 was conducted. In this experiment, infants in two conditions first observed an actor gazing at one or other of two objects. Subsequently, two test trials were presented. In the *Actor present* condition, the test trials showed the model with the two objects on a table. However, this time the model was not performing any action but was sitting quietly and looking downwards at the table. In the *Actor absent* condition, in the two test trials, only the two objects without the model were presented. If infants indeed use a person's looking behavior to acquire person–object associations, the mere presence of the actor should facilitate the processing of the object she has been gazing at, even though she is not performing any action. In other words, the presence of the actor should serve as an associative prime (cf. Barr *et al.*, 2002; McNamara, 1992), which triggers the processing of the object she has been associated with. Thus, infants should look longer at this than at the other object. This, however, should not be the case when the actor is no longer present. Such a finding would also confirm that the looking time preferences for the gaze-object, which were found in Experiment 1, were not the consequence of action target anticipations, but indeed reflect the acquisition of an association between person and object. As the method in this experiment closely followed the method of Experiment 1, only the differences between the experiments will be described.

Method

Participants

The final sample consisted of 32 14-month-old infants, 16 in every condition (*range*: 13 months, 15 days to 14 months, 30 days). Seven additional 14-month-old infants were tested but were not included in the final sample because of technical failure, refusal to remain seated or because they were inattentive during the experiment.

Stimuli

The stimuli of the gaze trials were the same as in Experiment 1. The stimuli of the test trials in the *Actor present* condition consisted of movies which showed the same actor sitting at the same table with the same two objects to her left and right (see Figure 1). During the entire movie, the model looked downwards at the table without performing any action (see Figure 1C). The test trials of the *Actor present* condition showed the same two objects located on the left and right side of the same table. No person was present (see Figure 1D for an example). The movies had a duration of approximately 10 seconds. Two different versions of each movie were made, whereby the position of the two objects (right or left side of the table) was counterbalanced.

Procedure

The procedure was the same as in Experiment 1. The position of the object (right, left) was counterbalanced within participants; the object the model was gazing at was counterbalanced between subjects.

Data analysis

Data analysis of the gaze trials was identical to the analysis steps of Experiment 1. Infants' looking times in the gaze phase of the gaze trials was analyzed using a two-way ANOVA with the within-subjects factor object (cued, uncued) and the between-subjects factor condition (*Actor present*, *Actor absent*). Infants' looking times in the test trials were analyzed using a three-way ANOVA with object (cued object, uncued object) and trial (first trial, second trial) as within-subjects factors, and with condition (*Actor present*, *Actor absent*) as between-subjects factor.

Results

Gaze trials

The ANOVA revealed only a significant main effect of object, $F(1, 30) = 7.07$, $p = .01$, $\eta_p^2 = .19$ (all other ps > .22), indicating that infants looked longer at the gaze-object (543 ms, *SE*: 73.1) than at the other object (350 ms, *SE*: 43.7).

Test trials

An analysis of infants' overall looking times revealed a main effect of condition, $F(1, 30) = 16.20$, $p < .001$, $\eta_p^2 = .35$. This shows that infants looked longer at the two objects in the *Actor absent* condition (mean 1433 ms, *SE*: 201.3) than in the *Actor present* condition (540 ms, *SE*: 93.6), suggesting that in the *Actor present* condition, infants also spend some time looking at the actor herself and thus less time at the objects. More importantly, however, the analysis revealed an interaction effect between the Trial and Condition factors, $F(1, 30) = 4.07$, $p = .05$, $\eta_p^2 = .12$, and between the Object and Condition factors, $F(1, 30) = 4.06$, $p = .05$, $\eta_p^2 = .12$ (see Figure 3). To further examine these effects in greater detail, post-hoc t-tests were conducted for every condition.

Paired-samples t-tests for the *Actor present* condition showed that the infants looked longer at the gaze-object (mean 673 ms, *SE*: 147.0) than at the other object (mean 353 ms, *SE*: 105.4) in the first test trial, $t(15) = 3.55$, $p < .01$, but not in the second test trial (mean 549 ms, *SE*: 160.1 and mean 583 ms, *SE*: 129.0, respectively), $t(15) = 0.19$, $p = .85$. Paired samples t-tests for the *Actor*

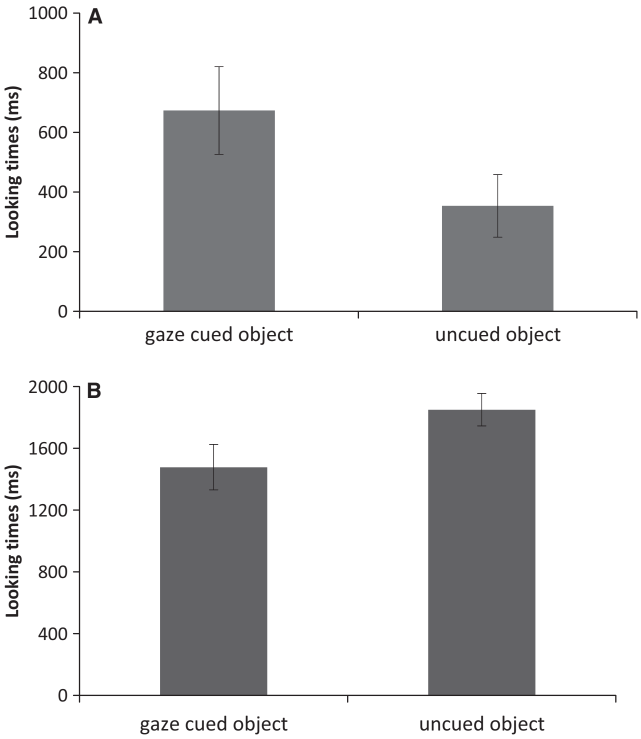

Figure 3 *Overall looking times (in ms) at the gaze cued and uncued object in the first test trial of both conditions of Experiment 2. Figure A represents the results of the Actor present condition and Figure B represents the results of the Actor absent condition. Error bars indicate standard errors of the means.*

absent condition showed that the infants looked longer at the uncued object (mean 1850 ms, *SE*: 313.4) than at the gaze-object (mean 1478 ms, *SE*: 235.1), $t(15) = -1.80$, $p < .05$, in the first test trial (see Figure 3B), but not in the second test trial (1249 ms, *SE*: 258.6, and 1155 ms, *SE*: 198.5, respectively), $t(15) = 0.37$, $p = .36$.

Discussion

In Experiment 2, infants observed a model repeatedly gazing at one of two objects. Subsequently, two trials were presented with both objects. In these two trials, the model was either present, sitting at the table and not performing any action, or absent. When the model was present, infants initially spent more time looking at the object the person had been gazing at. This pattern was reversed when the actor was absent, as infants then spent more time looking at the object the actor had not been gazing at. Interestingly, both effects were only obtained in the first test trial, but not in the second test trial. The results support the notion that infants build a person–object association after having seen a person gazing at one object (e.g. Perner & Ruffman, 2005) because the mere presence of the actor facilitated the processing of the same object, as indicated by infants' looking longer at the gaze-object than at the other object.

An alternative explanation of the results of Experiment 2 could suggest that the pattern of results might be entirely explained by familiarity–novelty effects. On the one hand, one could argue that during the gaze trials the infants' attention was biased towards the gaze-object, leading to enhanced object processing (e.g. Reid, Striano, Kaufman & Johnson, 2004). When the adult stops looking at this object, infants' attention is no longer biased. Subsequently, infants look at the second object, as this object has not been encoded like the gaze-object and is thus more novel (Reid & Striano, 2005). However, the fact that infants in the first test trial of the *Actor present* condition still looked preferentially at the gaze-object (i.e. even when gaze is no longer cued) cannot be solely explained by this alternative framework, and therefore renders this explanation unlikely. In contrast, this result is in line with the predictions derived from the associative learning hypothesis.

On the other hand, one could suggest that infants acquired a general preference for the gaze-object. More precisely, infants became more familiar with this object in the course of the gaze following trials. This familiarity remains, even though the actor is no longer looking at it in the *Actor present* condition. However, results speak against a general familiarity preference for the gaze-object. Infants' longer looking at the other object in the *Actor absent* condition rules out the possibility that the effect in the *Actor present* condition might be due to a familiarity preference or an effect of stimulus enhancement for the gaze-object (cf. Heyes, Ray, Mitchell & Nokes, 2000). In other words, it rules out the possibility that the gaze-object attracted infants' attention independently of the presence of a person, as it was cued in a previous trial. Infants' preference for the uncued object in the *Actor absent* condition might be due to the fact that infants had not yet fully encoded the unattended object and subsequently turned to it when the looker was absent (Reid & Striano, 2005; Theuring, Gredebäck & Hauf, 2007).

Interestingly, the associative learning view can also account for other findings. For example, Itakura (2001) presented infant-mother dyads in two trials with two objects on a screen. In the first experimental condition, the mothers in the first trial socially cued one of the objects. As expected, infants looked longer at this object. In the second trial, when the mother did not cue an object, infants still looked longer at the cued object. In the second experimental condition, one of the two stimuli attracted infants' attention, as it was blinking. As expected, infants looked longer at this object. In the second test trial, when no object was cued, infants did not show a preference for any of the objects. These findings cannot be explained in terms of familiarity–novelty effects, but are rather in line with the associative learning approach put forward in this manuscript. In particular, only when socially cued did infants continue to focus on the previously cued object. This is in line with the associative learning approach, as it suggests that the representation of the mother became associated with the representation of the object. When the mother was subsequently present, the processing of the corresponding object was facilitated.

General discussion

The results of both experiments indicate that 14-month-old infants relate a person and the object she had been gazing at through a mechanism of associative learning instead of interpreting the person's gaze as an indicator of her desire for the gaze cued object. When infants subsequently see the same person, her presence serves as an associative prime and influences infants' looking behavior in relation to the object that had been associated with this person.

Interestingly, the study also shows that the person–object associations infants create are of short-term duration, as they only lasted for one trial. This might indicate that the influence of the person's looking behavior is temporal and influences infants' further object processing only marginally (see also Theuring *et al*., 2007). From a practical point of view, this seems reasonable since in daily life infants' caregivers look continuously at a multitude of objects, often driven by fairly automatic processes like the orienting reflex (e.g. Sokolov, 1963). It would be odd if infants were to expect that this person was going to act on all of these objects or if they were to deeply relate all of those objects to this person. Further research, however, needs to examine whether, and under which conditions, children use a person's object-directed gaze to relate the object to that person in a more enduring way.

What is the developmental significance of this associative relationship between looker and object? The results of this study are in line with the hypothesis that infants relate a gazing person and an object via their ability for associative learning. More specifically, following Perner and Ruffman (2005), it is suggested that they create a two-way person–object association (see also Kiraly *et al*., 2003). Considerable associative and even statistical learning mechanisms have been shown to be present already in the first year of life (Kirkham, Slemmer & Johnson, 2002; Saffran, Aslin & Newport, 1996; see also Canfield & Haith, 1991; Rovee-Collier, 1990) and to play a crucial role in infants' language acquisition (e.g. Lany & Gomez, 2008; Smith & Yu, 2008) and conceptual development (e.g. Hauf & Paulus, 2011; Thelen & Smith, 1994). Extending these findings to the realm of gaze following, the present results suggest that associative and perceptual learning mechanisms are also important factors in infants' social-cognitive development that have been largely neglected in contemporary research.

The present results raise the question of how associative learning mechanisms may contribute or relate to the development of intention understanding. During the past few years, different (but partially complementary) answers have been suggested to account for this relation. Moore and colleagues (Barresi & Moore, 1996; Moore, 2006) have suggested a developmental framework for children's developing social understanding. According to this framework, young infants participate with others in social interactions without having the concept of an intentional agent or an intentional action. Their gaze following, for example, is subserved by learned expectations between gaze direction and interesting sights (Moore, 2008; Moore & Povinelli, 2007). Through repeated interactions with others, toddlers become able to relate their first-person experiences with their third-person experiences of others' actions. By integrating these experiences into a scheme that can be likewise applied to the self and to others, toddlers develop an understanding of others' intentional relations (Barresi & Moore, 1996). Furthermore, motivated by considerations of philosophy of ordinary language (e.g. Anscombe, 1957; Wittgenstein, 1953), proponents of a social constructivist view have shifted the question from intention understanding to intention ascription, i.e. to the question of when do humans ascribe a specific intention to someone. In particular, they stated that all primary interactions with others are based on sensorimotor couplings (e.g. Gallagher & Hutto, 2008; Slors, 2009). In the course of development, by means of participating in narrative interactions with others and supported by their knowledge about social rules (cf. Brandom, 1994; Pettit, 1993), children learn to verbally frame these embodied ways of interaction in terms of mental concepts such as belief or intention (Hutto, 2008). According to this view, the ascription of an intention to another person and the understanding of others' actions in terms of intentions, beliefs or desires is a cultural practice of transforming knowledge about sensorimotor couplings (e.g. associations) into verbal concepts. The present results are in line with both approaches, as they provide evidence for the role of perceptual learning in infants' gaze following. Future studies employing longitudinal designs are necessary to highlight the relation between associative learning mechanisms and intention understanding in more detail.

In sum, whereas research over the past decade has primarily focused on the relative impact of cognitive and motor processes (e.g. Paulus, Hunnius, Vissers & Bekkering, 2011b; Paulus, Hunnius, Vissers & Bekkering, in press-a; Sommerville & Woodward, 2005), the present study shows that more attention needs to be given to perceptual learning mechanisms in infants' social-cognitive development (see also Paulus *et al*., in press-b). An important task for future research is to examine how complex social understanding develops from the interplay between more basic mechanisms (cf. Adolph & Robinson, 2008; Barsalou, Breazeal & Smith, 2007; Carpendale & Lewis, 2004; Mareschal, Johnson, Sirois, Spratling, Thomas & Westermann, 2007; Moore, 2006; Smith, 2005).

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