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Where will the triangle look for it? Attributing false beliefs to a geometric shape at 17 months

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Prior research on implicit mind-reading skills has focussed on how infants anticipate other persons' actions. This study investigated whether 11- and 17-month-olds spontaneously attribute false beliefs (FB) even to a simple animated geometric shape. Infants were shown a triangle chasing a disk through a tunnel. Using an eye-tracker, we found that 17-month-olds in a change-of-location true belief (TB) task anticipated that the triangle would search for the disk in the correct place while in a FB test they anticipated that it would search for it in the wrong, belief congruent place. These results suggest that 17-month-olds' psychological-reasoning system is applied to the actions of unfamiliar agents and it is employed to anticipate agents' actions even in the absence of any morphological features that are typical of natural agents. These findings provide support for theoretical accounts that emphasize continuity in the development of theory of mind core concepts and belief reasoning skills.

More than 60 years ago, Heider and Simmel (1944) demonstrated that, when people look at animated events involving interacting geometric shapes, they readily go beyond the encoding of low-level visual aspects of the stimuli and spontaneously attribute underlying psychological motives and other mental states to such shapes. In short, they apply their explicit mind-reading skills to make sense of the events. Most cognitive scientist agree that such skills require a metarepresentational competence, although they diverge on how such competence is acquired (e.g., Leslie, 1987; Meltzoff, 1999; Perner, 1991; Surian & Leslie, 1999) and how we employ it to attribute mental states to ourselves and other people (e.g., Carruthers, 2009; Gallese & Goldman, 1998).

Developmental investigations have been first focussed on preschoolers' explicit mind-reading skills as revealed in tasks that require the child to attend the false beliefs (FB) of story characters. Typically, successful performance on verbal test questions was not found before the age of 4 (Wellman, Cross, & Watson, 2001). Spontaneous gaze responses elicited in verbal tasks (Clemens & Perner, 1994; Garnham & Ruffman, 2001; Low, 2010), or responses to pragmatically unambiguous test questions (Siegal & Beattie, 1991; Yazdi,

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German, Defeyter, & Siegal, 2006) suggested the presence of beliefs understanding in 3-year-olds, but not before.

Recently, however, researchers have turned to violation-of-expectation tasks that are more suitable to tap implicit belief-desire reasoning in preverbal infants (see Baillargeon, Scott, & He, 2010; Luo & Baillargeon, 2010 for reviews). In the first study of such sort, Onishi and Baillargeon (2005) suggested that 15-month-olds' looking time responses reveal that they can attribute FB. Infants saw a person holding a true or a false belief about an object location searching either in a place that was congruent with her belief or in a belief incongruent location. Infants looked longer at belief incongruent searches both in the informed and in the misinformed agent conditions.

Furthermore, infant studies have successfully replicated and extended Onishi and Baillargeon's findings using scenarios involving agents that were misinformed about the location of an object (Kovacs, Teglas, & Endress, 2010; Song, Onishi, Baillargeon, & Fisher, 2008; Surian, Caldi, & Sperber, 2007; Trauble, Marinovic, & Pauen, 2010), and about objects' identity (Scott & Baillargeon, 2009), or agents that were deceived by objects' misleading appearances (Song & Baillargeon, 2008). Song *et al*. (2008) have also found that by 18 months infants are able to take into account the messages received by a person to predict whether she would correct her FB.

Converging evidence on early psychological understanding comes also from a study on how infants choose to help a misinformed agent (Buttelmann, Carpenter, & Tomasello, 2009), and how they interpret referential messages produced by a speaker that holds a FB (Southgate, Chevallier, & Csibra, 2010). In one previous eye-tracking study (Southgate, Senju, & Csibra, 2007), 25-month-olds' anticipatory looks were recorded in two FB scenarios involving a puppet hiding a toy in one of two boxes placed behind two windows. Following the illumination of the windows, the experimenter searched for the toy by opening one of the windows. On test trials, immediately after the windows lighted up, most infants looked first at the window that was coherent with the experimenter's FB about a toy's location, suggesting that they reasoned about her FB. In the present study, we employed a procedure that does not require participants to learn arbitrary pairing of illumination-search action. This procedural simplification was aimed at assessing infants that were much younger than those tested by Southgate *et al.* (2007).

An early FB competence is clearly more coherent with nativist models (e.g., Leslie, 1987, 1994; Premack & Premack, 1997; Scott & Baillargeon, 2009) than with the conceptual change theories (e.g., Perner, 1991; Wellman, 1990). Scott and Baillargeon (2009) pointed out that most current nativist accounts of the human psychological-reasoning system make four assumptions. These accounts assume that the psychological-reasoning system:

(1) is made up, to a large extent, of unconscious processes (Low, 2010),
(2) it is triggered by the actions of *any* entity that infants construe as an agent (Premack & Premack, 1997),
(3) it includes an assumption about the rationality of agents' actions (Csibra, 2008; Gergely & Csibra, 2003), and
(4) it can be fractionated into two main subsystems, one dedicated, in most proposals, to reasoning about goals and perception (actional or teleological understanding) and the other to belief-desire reasoning (Leslie, 1994).

The aim of the present study was to investigate the second assumption of these system-based accounts by using an implicit FB task involving very unfamiliar agents.

It is well established that typically developing adults need no relevant morphological cues to engage spontaneously in mind-reading processes (Castelli, Frith, Happé, & Frith, 2002; Heider & Simmel, 1944; Kanizsa & Vicario, 1968; see also Tremoulet & Feldman, 2000). By contrast, it is far from clear that this is also true of young infants. Several previous works showed that infants perceive causally contingent reactions displayed by two geometric shapes (Schlottmann & Surian, 1999; Schlottmann, Surian, & Ray, 2009) and can reason teleologically about the actions performed by a box (Csibra, 2008; Luo & Baillargeon, 2005), a flat disk (Gergely, Nádasdy, Csibra, & Bíró, 1995), or an amorphous furry object (Shimizu & Johnson, 2004). Teleological reasoning is based on the ability to attribute goals and interpret agents' motion accordingly. These results suggest that associative processes and previous experiences with natural agents play a modest role in triggering infants' teleological construals.

All previous studies on infants' attribution of FB, by contrast, have presented infants with events involving natural agents, typically real people (e.g., Onishi & Baillargeon, 2005; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Song *et al.*, 2008; Southgate *et al.*, 2007; Trauble *et al.*, 2010). One study presented animated events involving an animal (Surian *et al.*, 2007), but no previous study examined whether infants can reason about reality incongruent informational states held by entities that are morphologically very different from familiar or natural agents.

Investigating the scope of infants' attribution of beliefs is important because it allows us to reveal differences and similarities between infants and older individuals that help to clarify the role of experience on the development of the psychological-reasoning system. Suppose that domain general learning processes, fed by experiences with familiar agents, play a crucial role in children's acquisition of mind-reading skills. If this is the case, one should expect that infants first restrict mental state attribution to agents that are similar to familiar agents on several salient aspects, such as their shape or their semi-rigid, biological motion (Simion, Regolin, & Bulf, 2008). By contrast, let us assume that infants' mind-reading system is triggered, or acquired, by means of domain-specific developmental mechanisms specialised to process agents' actions, regardless of any information concerning agents' morphological features. If this were the case, then one should predict that infants' mind-reading system should be triggered even by very unfamiliar agents, as long as they display some dynamic cues that are diagnostic of agency, such as autonomous (Carey & Spelke, 1994; Luo & Baillargeon, 2005; Mandler, 2004; Shimizu & Johnson, 2004; Surian & Caldi, 2010), contingent (Gergely & Watson, 1999; Schlottmann & Surian, 1999; Schlottmann *et al.*, 2009) or equifinal motions (Csibra, 2008; Gergely & Csibra, 2003).

EXPERIMENT 1

Method

Subjects

Twenty-four infants participated in the experiment (10 females; mean age = 17 months 4 days, *SD* = 46 days, range = 14 months 6 days through 18 months 27 days). To be included in the study, infants had to show an anticipatory look in at least one of the two familiarisation trials. Another two infants were tested, but were excluded because they failed to meet this criterion.

Apparatus

The experiment was conducted in the quiet rooms of 4-day nurseries located in an urban area of Northern Italy. A Tobii 1750 eyetracker was used to collect data on gaze direction and looking times. The eyetracker was integrated into a 17-in. monitor and the stimuli were presented on this monitor via a laptop computer running the Tobii's Clearview AVI presentation program. Each infant sat on an educator's lap, 50 cm from the monitor while the experimenter was behind a white curtain and controlled the stimuli presentation using the laptop computer. Two cameras were also used to record the testing sessions. One camera was placed behind the monitor to record infants' faces and the other was placed behind the infant to record the stimuli.

Stimuli and procedure

The testing session started with a five-point calibration procedure in which a picture of a rattle or a puppet appeared repeatedly on five different locations of the screen accompanied by attractive sounds. Infants automatically looked at the toys and their looks were used to calibrate the eyetracker. The presentation was repeated until the calibration was considered successful, that is when measures from three or more calibration points were obtained (for further technical details on the calibration procedure see von Hofsten, Dahlström, & Fredriksson, 2005). To reduce errors due to differences in pupil size, the light level during the calibration phase and the test phase was kept constant.

Familiarisation trials

Each infant was presented with two familiarisation trials. The events shown in the familiarisation trials involved a red triangle following a blue disk at a short distance on a complex curvilinear path (see Figure 1). Undergraduate students spontaneously describe such event as an instance of a chase or an escape, presumably relying on the directional cues and the initial 'avoidance' reaction displayed by the disk (see Schlottmann & Surian, 1999; Schlottmann *et al.*, 2009, for more details on infants' and adults' perception of intentional reactions). At the beginning of the events, the disk (1.7 cm wide) was stationary in the central lower part of the monitor and the triangle was not visible. The attention of the infant was attracted on the screen with a sound. The triangle (1.7 cm × 2.6 cm) entered the scene from the left side of the monitor and approached the disk. Before being reached by the triangle, the disk moved away in the same direction and at the same speed. The disk changed direction several times, followed by the triangle, along the path illustrated in Figure 1. Then the disk entered in a Y-shaped tunnel (each branch of the tunnel was about 12 cm long) from the lower entrance, it came out from one of the two upper exits and went inside a nearby 5 cm × 5 cm box. The red triangle followed the disk until the disk went into the tunnel, and then it stopped in front of the tunnel's lower entrance. The triangle turned smoothly towards the disk as soon as the disk started to come out from one of the tunnel's upper branches and continued to orient towards it when the disk went to hide into the nearby box. Finally, the triangle entered the tunnel and, after a 3.5 s delay, it came out of the tunnel from the upper exit near the box chosen by the disk and went inside it. Familiarisation trials ended when the infants looked away for more than two consecutive seconds or until 60 s elapsed. The familiarisation trials were identical except for the chosen hiding place. The rationale of the triangle to stop in front of the tunnel when the disk disappeared was that infants could look at it when it followed the disk's final hiding place, and therefore they could reason about what the triangle believed about the disk's final location. Gaze plots were replayed by one experimenter to check whether infants had attended at the chasing motions in the lower parts of the screen, at the disk hiding locations, at the exit of the triangle, and at its return. All infants watched these aspects of the stimuli in both familiarisation trials.

Test trials

On test events, the disk and the triangle moved in the lower part of the screen like as they did in the familiarisation trials. Then the disk went inside the tunnel while the triangle waited in front of the lower entrance. When the disk came out to hide in one of the two boxes, the triangle oriented towards it, as in the familiarisation trials. At this point, the test events diverged from the familiarisation events in which the disk came out from the first hiding place and finally moved into the other box (see Figure 1). The disk's final hiding place (right or left) was counterbalanced across participants.

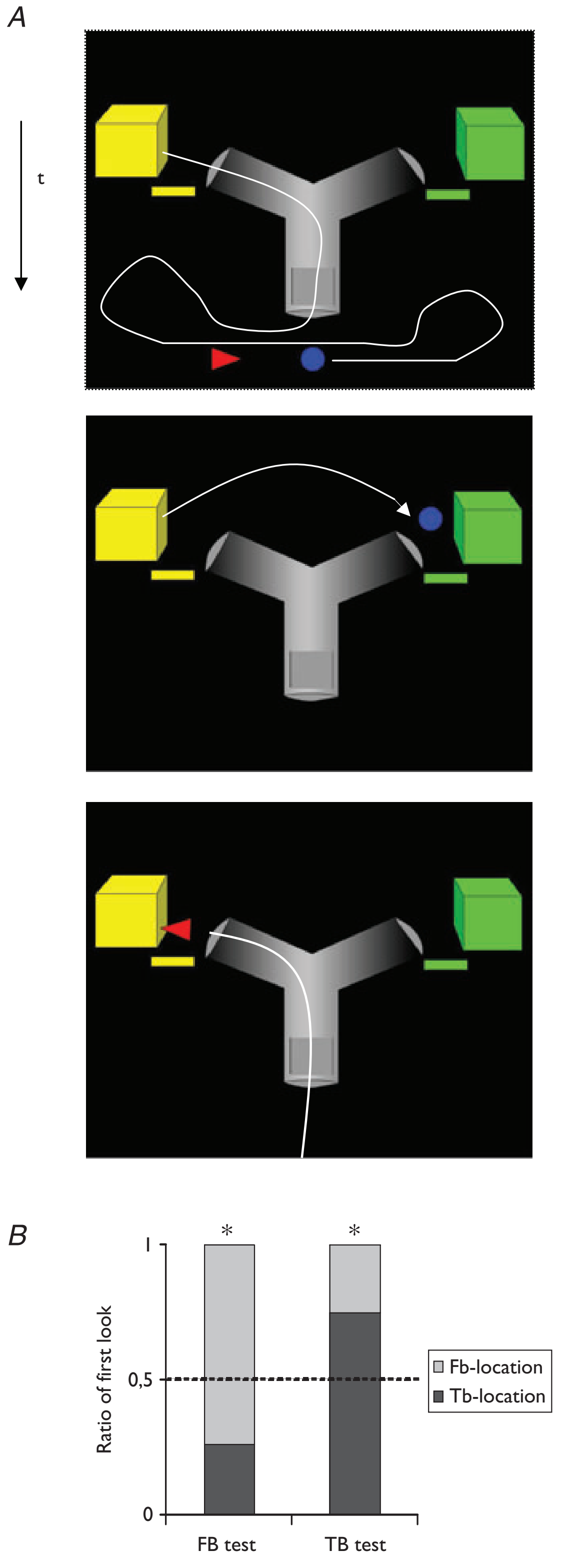
On the FB task, the triangle was present when the disk went into the first box, then the triangle made a 180° rotation and moved briefly (1.4 s) out of the screen, disappearing below the lower border of the monitor, *before* the disk made its final motion to the second box. Therefore the triangle was absent when the disk changed its hiding place. By contrast, in the true belief (TB) task the triangle was present when the disk changed its hiding place and oriented smoothly towards the disk during all its motions. The triangle left the screen immediately *after* the disk went into the second and final hiding place. This motion was included to maximise the similarity of the TB and the FB trials: in both trials, the triangle left the screen, but given the different timing of this motion, only in the TB trial the triangle was informed about the disk's final location. All infants were tested on one FB and one TB test trial.

After returning to the scene, on both tasks, the triangle went inside the tunnel from the lower entrance and, after a 3.5 s delay, it came out from the upper exit next to the belief congruent box. That is, it went to the final hiding place in the TB task and to the first hiding place in the FB task. Half of the infants received the TB task first and the other half received the FB task first.

Results

To assess infants' expectations about the triangle's search actions, we first coded the first saccade they made during the 3.5 s period after the triangle entered in the tunnel and before it came out of it, towards one of the two 12 cm × 9 cm areas, the Areas of Interest (AOI) in the Clearview program terms, that included the two boxes.

The effect of the trial order on the number of successful anticipatory looks was not significant neither in the TB trials, nor in the FB trials (Fisher exact probability test, $p > .06$ and $p > .64$, respectively). No significant effect was found for final disk location (Fisher exact probability test, TB: $p = 1$, and FB: $p > .66$). Twenty-three infants showed anticipatory looks on both test trials and one infant showed an anticipatory look on the TB trial only. Of the 24 infants that showed anticipatory looks on TB trials, 18 gazed correctly towards the TB congruent location ($p = .022$, $p_{\text{rep}} = .923$, two-choice binomial test, two-tailed). Of the 23 infants that showed anticipatory looks on FB trials, 17 gazed correctly towards the FB congruent location ($p = .034$, $p_{\text{rep}} = .902$, two-choice binomial test, two-tailed, see Figure 1B). Six infants looked at the last hiding box (*tb-location*) and


A
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1
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Ratio of first look
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Fb-location
Tb-location
FB test
TB test

Figure 1. (A) Selected frames from a false belief test trial in Experiments 1 and 2. The red triangle chased the blue disk in the lower part of the screen (first frame; white line, trajectory), the disk passed across the Y-shaped tunnel to hide inside one of the boxes while the triangle oriented towards it; then, while the triangle was out, the disk came out from left box and went to hide in the other box (second frame); finally the triangle returned and looked in the first box visited by the disk (third frame). (B) Experiment 1: proportions of first gazes towards the false belief (*fb-location*) and the true belief (*tb-location*) congruent locations in the false belief (FB) and true belief (TB) test trials; * $p < .05$, two-choice binomial test; dotted line, chance level.

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6 infants looked at the first hiding box (*fb-location*) on both trials, 11 gazed correctly on both trials, namely they looked at the *tb-location* in the TB trial and at the *fb-location* in the FB trial, and none showed the reversed pattern (McNemar χ^2 $(1, n = 23) = 9.09, p < .01, p_{\text{rep}} = .979$, two-tailed). The 11 infants that gazed correctly on both trials were evenly distributed in the two trial orders (4 vs. 7) and the two last disk location counterbalancing conditions (6 vs. 5). Their mean age did not differ significantly from the mean age of the rest of the sample (16.5 and 17.6 months, respectively, $t(22) = 1.8$, $p > .08$).

The gaze plots of all infants were replayed and analysed by two coders independently to assess whether infants had looked at: (1) the disk's initial and final hiding location and (2) the exit and return of the triangle. Both coders found that all infants had attended to all these crucial aspects of the event stimuli both in the TB and in the FB trails.

We also analysed the amount of time infants spent looking at each AOI from the moment the triangle went into the tunnel to the moment it came out of it. When the looking times of all infants were included in the Analysis of Variance (ANOVA, $F(1, 23) = 2.55$, $p = .13$, $\eta_p^2 = .10$) the predicted test X location interaction, due to longer looks at the *tb-location* in the TB trial and at the *fb-location* in the FB trial, was not significant. However, the predicted interaction was significant when the looking times of the infants that showed correct anticipatory looks on both test trials ($N = 11$) were analysed separately. On TB test trials, these infants spent more time looking at the *tb-location* than at the *fb-location* ($M = 677$ ms, $SD = 557$ ms and $M = 497$ ms, $SD = 649$, respectively), whereas, on FB trials, they showed the reversed pattern ($M = 191$ ms, $SD = 236$ ms and $M = 425$ ms, $SD = 581$, respectively), $F(1, 10) = 5.41$, $p = .042$, $p_{\text{rep}} = .889$, ${\eta_p}^2 = .351$. This pattern is consistent with the hypothesis that they expected to see the triangle to go in the belief congruent location.

The gaze plots of all infants were replayed and analysed by two coders independently to assess whether infants had looked at the disk hiding locations, at the exit of the triangle and at its return. Both coders judged that all infants had attended to all these events both in the TB and in the FB trials.

EXPERIMENT 2

The aim of Experiment 2 was to test whether FB reasoning skills could also be revealed in infants as young as 11 months by using their spontaneous anticipatory looks. In a recent study by Kovacs *et al.* (2010), infants' looking times revealed evidence of FB attribution in 7-month-olds. However, in that study, infants did not have to anticipate the agent's action in order to react differently in the true and FB conditions.

Subjects

Sixteen infants participated in the second experiment (six females; mean age = 11 months 15 days, range = 10 months 0 days through 12 months 2 days). The criterion for subject inclusions was the criterion used in Experiment 1. Another three infants were tested but excluded, one because he failed to meet the inclusion criterion, and two due to fussiness.

Apparatus, stimuli, and procedure

The experiment was conducted in the same rooms used for Experiment 1. The apparatus, stimuli, and procedure were the same as in Experiment 1.

Results

Infants' expectations about the triangle's search actions were assessed by coding the first saccade they made after the triangle entered in the tunnel and before its exit from it. Fifteen infants showed anticipatory looks on both test trials and one infant showed the anticipatory look on the TB trial, but failed to complete the FB trial.

On TB trials, only 7 of 16 infants gazed correctly towards the belief congruent location ($p > .80$, two-choice binomial test, two-tailed). On FB trials, only 7 of 15 infants gazed correctly towards the belief congruent location ($p = 1$, two-choice binomial test, two-tailed). Two infants looked at the last hiding box (*tb-location*) and three infants looked at the first hiding box (*fb-location*) on both trials, four gazed correctly on both trials, namely they looked correctly at the *tb-location* in the TB trial and at the *fb-location* in the FB trial, and six failed both trials (McNemar χ^2 $(1, n = 14) = .100$, $p = .752$, $p_{\text{rep}} =$ .315, two-tailed).

The gaze plots of all infants were replayed and analysed by two coders independently to assess whether infants had looked at the disk hiding locations, at the exit of the triangle and at its return. One coder judged that all infants had attended to all these events both in the TB and in the FB trials, the second coder agreed on all but one evaluations (99% inter-judge agreement). In Experiment 2, infants attended all the crucial phases of the event stimuli, but they did not show any sign of anticipating the agent's actions on the basis of the agent's belief.

GENERAL DISCUSSION

The results of Experiments 1 and 2 are consistent with the conclusion that 17-month-old infants can attribute a FB to a simple animated shape and anticipate its actions by relying on such attributions, whereas no evidence of correct anticipations was found in the 11-month-olds. These findings corroborate the conclusions of previous studies on infants' FB reasoning and suggest that, in the first half of their second year of age, infants begin to apply their mind-reading system to interpret and anticipate agents' actions. Moreover, these findings provide support for one of the assumptions made by the system-based theoretical models by showing that infants' mind-reading activities are not restricted to objects that are morphologically similar to familiar agents or agents that display non-rigid motion (Scott & Baillargeon, 2009). This aspect of our findings suggests that morphological information concerning familiar agents does not play a crucial role in the acquisition or triggering of infants' mind-reading competence. The present evidence does not rule out that previous experiences with agents play a role in triggering infants' mental state reasoning, but it weakens the theoretical accounts that posit a crucial role for domain general associative mechanisms, namely mechanisms that are not specialised to attend the agents' actions.

These results suggest that once an entity is identified as an agent, presumably by relying on the equifinality of its actions or the presence of other agent-like dynamic cues (Mandler, 2004; Surian & Caldi, 2010), infants at 17 months can reason about its goals and beliefs. Infants' ability to attribute beliefs to a self-moving, interacting object lacking agent-like morphological features suggests that infants rely on dynamic cues to activate their psychological-reasoning system. These cues may include the ability to move autonomously (Luo & Baillargeon, 2005) and contingently at a distance (Gergely & Watson, 1999; Schlottmann & Surian, 1999; Schlottmann *et al.*, 2009; Shimizu & Johnson, 2004; Surian & Caldi, 2010). These findings also indicate that adults' tendency to mindread even the actions of geometric shapes (Heider & Simmel, 1944; Castelli *et al.*, 2002) is not the product of a process based on analogical reasoning. Instead it is more likely to be the output of a mind-reading system that, from the start, is set up to interpret psychologically the behaviour of any entity that was identified as an agent because such behaviour is the domain proper of that system (Carey, 2009; Carruthers, 2009; Leslie, 1994; Surian *et al.*, 2007).

Kovacs *et al.* (2010) have recently reported looking time data from 7-month-olds that suggest an ability to represent true and FB and, in light of their results, one may wonder why 11-month-olds in the present study failed. There are many procedural differences between that study and the present one that could provide a viable explanation. Most important, we think, it is the fact that in Kovacs *et al.*'s study the responses concerned latencies in object detection in the presence of an agent holding a TB or FB, whereas our study required an anticipation of the agent's action. Thus the inferential processes required in these studies may differ in computational complexity, but both may include a mentalist concept. In future studies, it would be interesting to test whether the effects reported by Kovacs *et al.* (2010) are found in 7-month-olds also when geometrical shapes are used as main characters in the animation stimuli, thus providing further evidence relevant to the issue of domain specificity of developmental mechanisms involved in the acquisition of metarepresentational skills.

It has been argued that the violation-of-expectation tasks do not require any predictive inferences and therefore looking times results reported in studies that used such tasks may be the outcome of reasoning about the incongruence of the test outcomes *after* they have occurred and have been observed by the infants, not the outcom of predictive inferences (Keen, 2003; Southgate *et al.*, 2007). In this view, infants react differently at the final test events in the violation-of-expectation method because they notice their incongruence with the previous parts of the test events, not because they anticipate a different final outcome. We doubt that this is the case, but from this perspective the evidence on anticipatory gazes serves to strengthen the claim that infants by the age of 17 months are indeed able of predictive mentalistic reasoning. The only previous study on infants' anticipatory looks in a FB scenario has reported positive results in 25-month-olds (Southgate *et al.*, 2007). The positive results on 17-month-olds reported in the present study suggest a remarkable continuity in infants' and preschoolers' belief reasoning, as revealed also by the other studies on anticipatory looks (Clemens & Perner, 1994; Garnham & Ruffman, 2001; Low, 2010; Southgate *et al.*, 2007) and looking times (e.g., He, Bolz, & Baillargeon, 2011).

Why do infants succeed in these non-verbal tasks while preschoolers, before 4 years of age, typically fail verbal FB tasks? This question raises a hotly debated issue and it has been asked in several areas of developmental research (e.g., Keen, 2003). One plausible explanation is that verbal tasks may require an explicit understanding that is not necessary to succeed on the implicit tasks used in infant studies (Onishi & Baillargeon, 2005; Perner, 2010) and that is acquired with a crucial contribution of language development (Low, 2010). Another possibility is that only the standard FB tasks commonly used to assess preschoolers' skills require a process of response selection. Participants in verbal tasks are explicitly required to provide an answer to a question, whereas in implicit tasks dependent variables are based on infants' spontaneous reactions (Scott & Baillargeon, 2009). A third class of explanations emphasize the role of inhibitory processes (Leslie, Friedman, & German, 2004; Sabbagh, Xu, Carlson, Moses, & Lee, 2006), particularly the processes involved in the inhibition of your own knowledge of reality while one is required to reason about other individuals' mental states of ignorance or FB (Birch & Bloom, 2003; Wang & Leslie, 2011). But why should inhibition of your own knowledge be more difficult in explicit compared to implicit tasks? One possibility is that inhibitory processes compete for cognitive resources and they turn out to be more demanding, in relative terms (Surian, 1995), when they are performed in verbal tasks because of the extra processing costs required by the response selection component typically present in such tasks.

There are three main accounts of infants' success in FB tasks that do not grant them an understanding of FB. These accounts are based on (1) familiarity effects, (2) behavioural rules, and (3) ignorance attribution. We now examine these alternative explanations in light of the available evidence. According to the familiarity effects account, in violation-of-expectation studies infants simply look longer at the test outcomes that are more familiar given the agent-object-location associations previously established during the familiarisation trials (Perner & Ruffman, 2005).

As in Southgate *et al.* (2007), the dependent measure in the present study was not looking the time at test events, but anticipatory looks. Therefore, the relative familiarity of final outcome events could not have had any effect on our dependent measures. As it was originally proposed, the familiarity effects account cannot explain our results, but one may imagine a new version of such account in which previously established object-agent-place associations are involved in generating predictive looks. Given that the difference in our conditions was only in the timing in the triangle's absence, we believe this explanation is unlikely to be true, but that it deserves to be investigated in future studies.

According to the behavioural rules account, infants' inferences about agents' actions are based on behavioural generalisations, processing inferences that do not require any mentalistic concept (Perner, 2010). Such rules link search actions to situations related to previous perceptual experiences directly, without the mediation of mental states. For example, in the particular case of change-of-location tests (e.g., Onishi & Baillargeon, 2005; Southgate *et al.*, 2007; Surian *et al.*, 2007), infants may have relied on the rule 'agents search for a goal object where they last looked at it'. By exploiting such rule, infants (and older children too) could respond successfully in change-of-location tests without the need to form a metarepresentation. Empirical evidence currently available cannot yield a conclusive rejection of the behavioural rules accounts. In fact, it has been proposed that generating the evidence necessary to this final rejection may be beyond the reach of methods we currently have to study cognitive processes in nonverbal organisms (Povinelli & Vonk, 2004; but see Perner, 2010 for a less pessimistic perspective on possible empirical tests).

However, leaning towards a cognitively 'rich' account rather than the 'economical' behavioural alternatives may be a rationally motivated choice after considering the results of all the previous studies. With little effort, one could concoct specific behavioural rules that would generate the looking times (e.g., Onishi & Baillargeon, 2005; Song *et al.*, 2008; Surian *et al.*, 2007), anticipatory looks (Southgate *et al.*, 2007; the present study), pointing behaviours (e.g., Liszkowski, Carpenter, Striano, & Tomasello, 2006; Liszkowski, Carpenter, & Tomasello, 2008), helping actions (Buttelman *et al.*, 2009), elicited showing, (Tomasello & Haberl, 2003) and referential communication (Southgate *et al.*, 2010) reported in prior research. But the rules would be explanations proposed *post hoc* for each of these cases. More importantly, their viability would depend on the plausibility of a number of additional assumptions required to specify the relevant environmental input, learning mechanisms, and experiences that allow young infants to acquire all these rules.

Many researchers believe that the relative parsimony of each account can help us to choose between competing models of infants' performance (Haith, 1993). Since behavioural rules accounts posit no knowledge of mental states concepts, they are seen as more parsimonious and, therefore, preferable (Heyes, 1998; Povinelli & Vonk, 2004). But the relative parsimony of behavioural rules models, compared to mentalistic models, may be not so easy to evaluate. Consider the variety of contexts and tasks in which positive results have been reported so far (for a review Baillargeon *et al.*, 2010). While behavioural rules models need to posit specific rules for each of these situations, mentalistic models may need only to posit the general principle that link perceptual access to belief formation and belief to action (but see Perner 2010, for a different view on this).

Also, we believe that arguments based on relative parsimony of theoretical models are not a safe ground to decide among competing models concerning natural information processing systems. The core aspects of such systems are not the outcome of a rational design, but the result of a messy evolutionary process. Therefore, there is no reason to expect that more parsimonious models are more likely to be true than less parsimonious ones.

The third account is the proposal that assumes an incomplete metarepresentational competence. Numerous studies showed that by 12 months infants can reason about what others can see (Brooks & Meltzoff, 2002; Luo & Baillargeon, 2007; Luo & Johnson, 2009) and differentiate between informed and uninformed people when producing their communicative gestures (Liszkowski *et al.*, 2006; Liszkowski *et al.*, 2008). Could successful anticipatory gazes, in implicit FB tasks, be due to the ability to attribute ignorance, rather than the FB? This would be an incomplete mentalistic competence, because it allows infants to think about the mental states of agents that lack information they themselves have, but it does not allow infants to consider others' reality incongruent mental representations. Southgate *et al.* (2007) proposed such a view for the results reported by Onishi and Baillargeon (2005) and Surian *et al.* (2007) and claimed that, in the FB conditions of those studies, infants' longer looking times for the correct search actions as compared to looking times for incorrect actions were due to an 'ignorance-leads-to-error rule': infants assumed that 'ignorant agents will not search in the correct place'.

The ignorance account makes predictions that are compatible with the results reported in the present study. However, a change-of-location study carried out by Scott and Baillargeon (2009) has recently shown that infants behaves differently in conditions with misinformed agents holding FB and conditions with ignorant agents lacking relevant knowledge. In the FB conditions infants were surprised to observe that agents looked in the correct location, but in a condition involving an ignorant agent infants were *not* surprised when she searched in the correct location. This finding suggests that the ignorance-leads-to-error heuristic is not what causes the patterns of anticipatory gazes reported in the present study.

In sum, the available evidence from a variety of infant studies suggests that, in the first half of their second year of life, infants display an implicit psychological-reasoning system that allows them to compute agents' reality congruent and reality incongruent mental representations. It is a challenge for future research to reveal processing limitations that constrain the expression of this system during childhood, to investigate the role language experience (Astington & Baird, 2005; Low, 2010; Meristo *et al*., 2007) and to explore its links with other core aspects of social cognition (Geraci & Surian, in press; Pellizzoni, Girotto, & Surian, 2010; Pellizzoni, Siegal, & Surian, 2009).

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