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Brief article

Do people automatically track others' beliefs? Evidence from a continuous measure

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ABSTRACT

Recent findings suggest that tracking others' beliefs is not always effortful and slow, but may rely on a fast and implicit system. An untested prediction of the automatic belief tracking account is that own and others' beliefs should be activated in parallel. We tested this prediction measuring continuous movement trajectories in a task that required deciding between two possible object locations. We independently manipulated whether participants' belief about the object location was true or false and whether an onlooker's belief about the object location was true or false. Manipulating whether or not the agent's belief was ever task relevant allowed us to compare performance in an explicit and implicit version of the same task. Movement parameters revealed an influence of the onlooker's irrelevant belief in the implicit version of the task. This provides evidence for parallel activation of own and others' beliefs.

1. Introduction

Tracking the mental states of others is a key ingredient for successful social interaction. The ability to represent and understand others' mental states is referred to as Theory of Mind (ToM), and is often measured with the false belief task (Baron-Cohen, Leslie, & Frith, 1985; Wimmer & Perner, 1983). A central issue concerning the nature of ToM is whether people automatically track others' beliefs, or whether such belief tracking relies on a more deliberate system. Recent studies have provided evidence for automatic belief tracking in infants (Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007) and adults (Kovács, Téglás, & Endress, 2010; Schneider, Bayliss, Becker, & Dux, 2012). To reconcile these findings with the fact that reasoning about others' beliefs has a protracted developmental trajectory, is sometimes effortful and error-prone (Saxe, 2005), Apperly and Butterfill (2009) proposed a two systems account. On this account, a limited range of belief attribution is accomplished by a fast and efficient, yet inflexible system (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010) that is complemented by a later developing, deliberate, and slower system.

How the fast and implicit system works and how much it resembles other types of automatic processing (Apperly, 2011) is still unclear. The present study addressed two key questions in this regard. First, an untested prediction following from the assumption of a fast and automatic system for tracking beliefs is that multiple beliefs will be activated in parallel. Most of the studies on belief tracking so far have relied on discrete measures that only reflect the outcome of a decision process. Recent work has incorporated response times and proportional looking times (e.g. Apperly, Riggs, Simpson, Chiavarino, & Samson, 2006; Back & Apperly, 2010; Kovács et al., 2010; Low & Watts, 2013; Schneider et al., 2012), but these measures do not directly

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reveal how conflicts between one's own and others' beliefs are resolved online. Mouse tracking is optimally suited to study online decision processes (e.g., Freeman & Ambady, 2009; Freeman, Ambady, Rule, & Johnson, 2008; Freeman, Dale, & Farmer, 2011; McKinstry, Dale, & Spivey, 2008; Spivey, Grosjean, & Knoblich, 2005; Wojnowicz, Ferguson, Dale, & Spivey, 2009). Here, we studied the mouse cursor's trajectories participants produced to reach the correct object location out of two possible locations while another agent had either the same or a different belief about the object's location. If people hold their own and the agent's belief in mind in parallel, the veridicality of their own belief as well as the belief of the agent should influence the online decision process about the object location, even when the agent's belief is irrelevant and never explicitly mentioned.

A second aim of the present study was to compare the relative influence of own and others' beliefs on the decision making process. Kovács et al. (2010) found that participants were just as fast to detect an object when they had a false belief but an onlooker had a true belief about the object's presence as they were when they had a true belief themselves. Only when both beliefs were false did participants show slower detection times. These results suggest a winner-takes-all model, as the belief representation (be it one's own belief or others' beliefs) that allows the fastest response may fully drive behavior. However, this finding is at odds with findings showing egocentric biases in mental state attribution (e.g., Birch & Bloom, 2003; van Boven & Loewenstein, 2003) and may not generalize to implicit belief tracking in more complex settings.

Finally, different tasks have been used to study implicit and explicit belief tracking, making it difficult to compare the way the two postulated systems operate. In the present study, we directly compared performance on an implicit and an explicit version within a single task setting.

2. Methods

2.1. Participants

81 right-handed students (61 women, 20 men, mean age of 21.7 years, SD = 8.41) participated in the study for course credit. Forty participants were assigned to the implicit belief tracking group and 41 participants to the explicit belief tracking group. We replaced one participant in the explicit group due to failure to complete the task correctly. We ran 51 participants (26 in the implicit group, and 25 in the explicit group) at Radboud University in Nijmegen, the Netherlands. The remaining participants were tested at Rutgers University in Camden, NJ, USA.

2.2. Experimental setup and procedure

Participants watched short movies (see Fig. 1) in which we manipulated the expected location of two objects for the participant and an agent who was present for parts of the movies (similar to Kovács et al.) By including two objects and two object locations, we could measure the influence of the participant's and the agent's belief on the decision process. We instructed participants that they needed to follow the location of one of these objects (a ball), and that the agent could not see what happened when she was absent from the scene.

We manipulated whether the participant and the agent had a true or false belief about the objects' locations at the end of the movie. There were four experimental conditions; true–true (T–T) when both had a true belief, true–false (T–F) when only the participant had a true belief, false–true (F–T) when only the agent had a true belief, and false–false (F–F) when both had a false belief.

At the end of each movie, participants heard a tone (50 ms, 600 Hz) and then were to move to the relevant object as quickly as possible. At the tone, both objects were still behind their occluders. Once the participants moved the mouse cursor upwards by 50 pixels, the occluders dropped and the location of the objects was revealed. Participants had to move the mouse cursor sideways by 252 pixels and upwards by 538 pixels from the start location to get to the target. Because the relevant object was always present, participants always produced a response.

To test whether or not participants tracked the agent's beliefs automatically, we incorporated two groups in our experimental design. Participants in the explicit group were told that they needed to keep track of the agent's beliefs, as they sometimes needed to indicate where the agent thought the relevant object was located. No such mention was made for the implicit group, and the agent's belief was always task-irrelevant.

We recorded responses at 65 Hz with a Logitech G500 mouse (1:1 mapping). Participants started a trial by pressing the left mouse button, while the mouse sat on a marked cross on the table (aligned with and 40 cm forward from the center of the computer monitor). All participants used their right hand to respond. Participants only received feedback when they provided an incorrect response (a 500 Hz tone played for 100 ms), or when they took more than 3000 ms to respond. The latter trials were repeated in a randomized order at the end of the experiment.

Participants completed a set of practice trials before starting the experiment. They then completed 24 trials per condition in a randomized order. In half of these trials for each condition, the objects switched locations in Phase 2 (while the agent was present). We included this variation to control for potential curvature effects due to uncertainty about object locations that may result from differences in location switches across conditions. For the explicit group, we introduced an additional 16 veridicality trials (four trials per condition) in which participants indicated where they thought or where the agent thought the relevant object was located. This was indicated in Phase 4 by the word "YOU" for own belief or "SHE" for the agent's belief in the center of the display that stayed visible until the response was completed. On all other trials, participants indicated the location of the ball, as in the implicit condition. The veridicality trials were randomly interspersed, implying that participants in the explicit group needed to track the agent's belief in every trial in the experiment.

Segments of the movie clips were either 2 (agent (dis)appearing), 3 (objects changing position or returning to their initial position), or 4 (objects entering the scene)

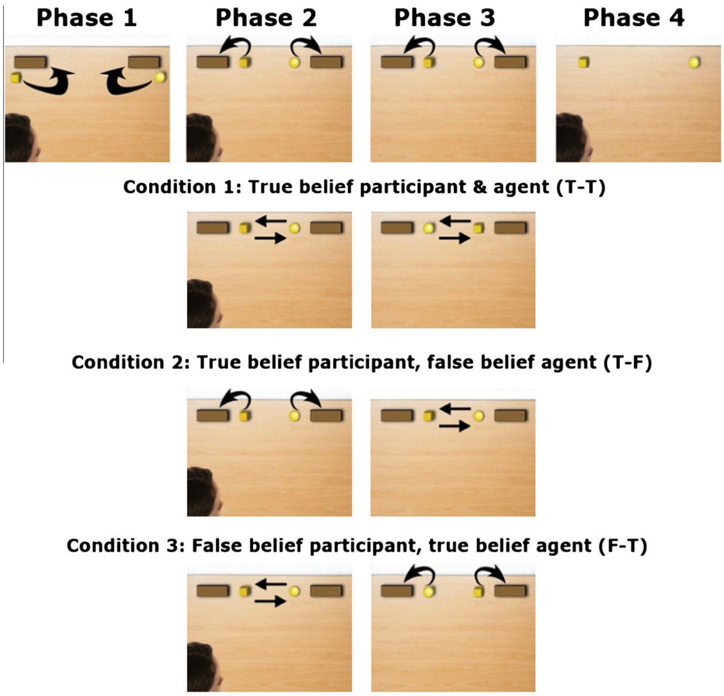

Fig. 1. Overview of the movie sequences. In phase 1, an agent first appeared on the bottom left of the screen. Then, the objects appeared in the scene and disappeared behind one of two occluders (one object behind each). In phases 2 and 3, the objects moved from behind the occluders to either return to their previous location, or switch locations. Depending on the condition, these switches occurred either in the presence or absence of the agent, such that the agent could either have the same or a different belief about the objects' locations. In phase 4, the agent returned and a tone played to indicate that the participant should respond. The occluders disappeared after the participant moved up by 50 pixels. The object locations were then revealed, and could come as a surprise to the participant, to the agent, to neither, or to both.

seconds long. Each full movie for each condition took 16 seconds (1024 pixels by 768 pixels, 23 frames per second, viewing distance approximately 80 cm). We used Matlab's PsychToolbox extensions (Brainard, 1997; Pelli, 1997) for experimental control. We processed the data with Mouse-Tracker (Freeman & Ambady, 2009).

3. Results

We addressed our main questions by examining the movement trajectories and response initiation times. From the time-normalized trajectories, we obtained the Area Under the Curve (AUC). This measure reflects the extent to which the irrelevant response location influenced the movements towards the correct response location. Larger values of AUC reflect a stronger influence of the irrelevant location.

Before analyzing, we subjected the data to an outlier analysis in which we removed trials that showed an AUC greater than 3 standard deviations away from the participant's mean in the given condition. We also removed any trials for which the AUC was more than 3 standard deviation for the mean of all participants in that condition. We visually inspected the data to exclude trials in which a participant almost reached the target, then moved back towards the start location (likely to start the next trial), and then needed to move to the target again to reach it completely. The reported analyses included 3543 correct response trials (92.27%) for the implicit group, and 3355 correct response trials (87.37%) for the explicit group.

For the reported analyses, we entered each participant's mean values into a 2 (Own Belief: True or False) × 2 (Agent Belief: True or False) repeated-measures ANOVA with group (Implicit versus Explicit) entered as a between-subject variable. We conducted separate follow-up ANOVAs for each group. We applied a Huynh-Feldt correction to the degrees of freedom when it was appropriate to do so.

3.1. Movement trajectories

We first analyzed the skew, kurtosis, and bimodality of the AUC distributions in each condition and group. Table 1 provides the results. Importantly, the AUC distributions did not deviate from normality in any of the conditions or groups (Freeman & Ambady, 2010; see Freeman & Dale, 2013, for a recent discussion on this issue).

Fig. 2a and b shows the mean trajectories for each condition and group. Fig. 2c shows the results for the AUC measure. The analysis revealed two main effects. First, participants showed greater curvature towards the irrelevant response location when they had a false belief compared to when they had a true belief, $F(1,78) = 277.06$, $p < .01$, $\eta^2 = .78$. Second, participants also showed greater curvature when the agent had a false belief compared to a true

Table 1
Statistics for the response distributions for each experimental group and condition.

	Implicit group				Explicit group			
	True–true	True–false	False–true	False–false	True–true	True–false	False–true	False–false
Trials	903	902	877	861	870	848	830	807
	Area Under the Curve							
Skew	1.377	1.597	0.336	0.362	0.518	0.720	0.827	0.420
Kurtosis	4.874	3.896	0.460	0.335	3.512	3.583	1.890	0.453
Bimodality	0.367	0.514	0.321	0.423	0.194	0.230	0.344	0.340

belief, $F(1,78) = 4.12$, $p < .05$, $\eta^2 = .05$. The analyses revealed no other main effects or interactions. The effect of Group was not significant.

Because of the theoretical importance, we followed up with an ANOVA on the data for the Implicit group only. This ANOVA revealed two main effects; one for Own Belief, $F(1,39) = 136.17$, $p < .01$, $\eta^2 = .78$, and one for Agent Belief, $F(1,39) = 4.36$, $p < .05$, $\eta^2 = .10$. Thus, although participants did not need to explicitly track the agent's belief, their trajectories suggest that they did so implicitly. The analysis did not reveal an interaction. The same analysis for the Explicit group revealed only a main effect of Own Belief, $F(1,39) = 143.70$, $p < .01$, $\eta^2 = .79$.

To ensure that our results reflect belief tracking effects rather than uncertainty about object locations due to differences in the number of switches across conditions, we

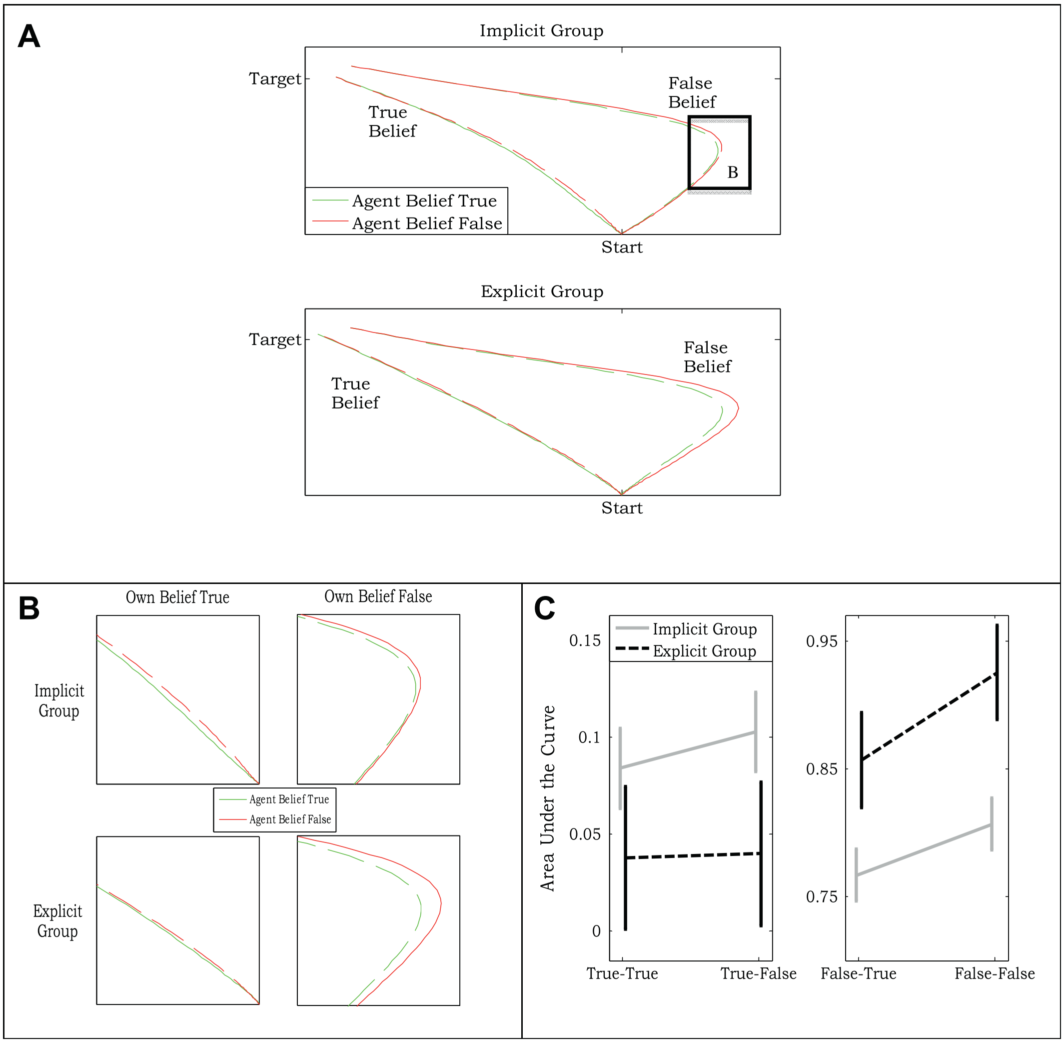

Fig. 2. Movement trajectories. Panel A shows the mean trajectories for each experimental condition. Panel B shows zoom windows with the areas of interest at a finer resolution. Panel C shows the mean Area Under the Curve for each group and condition. Error bars correspond to the 95% confidence interval (Loftus & Masson, 1994).

tested for the effect of a location switch in Phase 2 on AUC for the Implicit group. This analysis did not yield a significant effect, $t(39) = 0.06$, $p = .96$ ($M_{no\,switch} = .453$, $M_{switch} = .452$). Separate paired *t*-tests per condition indicated no significant differences for the Implicit group either, all $p > .50$. See Kovács et al. for additional control conditions for belief tracking effects.

3.2. Initiation times

Fig. 3 shows the response initiation times for each group and condition. The analysis indicated a significant main effect for Group, $F(1,78) = 9.02$, $p < .01$, $\eta^2 = .10$. Participants took longer to start moving in the Explicit group compared to the Implicit group. The results also showed a two-way interaction between Own Belief and Agent Belief, $F(1,78) = 14.72$, $p < .01$, $\eta^2 = .16$, as well as a significant three-way interaction between Group, Own Belief, and Agent Belief, $F(1,78) = 9.84$, $p < .01$, $\eta^2 = .11$. To explore this interaction, we ran separate ANOVAs for each group. For the Implicit group, the ANOVA showed no significant effects, $p > .05$. In contrast, the results for the Explicit group showed an interaction between Own Belief and Agent Belief, $F(1,39) = 24.10$, $p < .01$, $\eta^2 = .38$. Participants in that group took longer to start moving when the Agent had a different belief about the objects' locations than the participant did ($M = 370.59$ ms for congruent beliefs, and $M = 427.73$ ms for incongruent beliefs).

4. Discussion

Apperly and Butterfill (2009) proposed a two-system account of belief tracking. According to this account, people use an automatic and fast system, as well as a controlled, slower system for tracking other people's beliefs. Whereas the automatic system may drive behavior for simple tasks, people may rely more heavily on the controlled system for more complex tasks. Our study was motivated by the fact that evidence for the two systems comes from separate studies, evidence for the automatic system is relatively sparse, and the prediction of parallel activation of competing beliefs has not been tested directly. Also, little is known about the relative weight own and others' beliefs have on decision making.

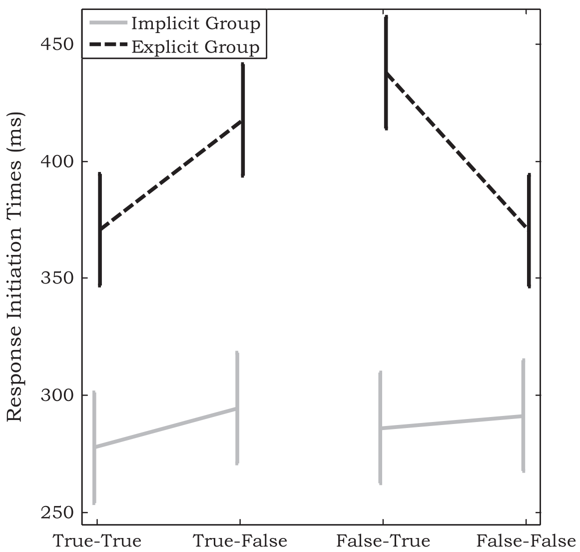

Fig. 3. Mean response initiation times for each group and condition. Error bars correspond to the 95% confidence interval (Loftus & Masson, 1994).

In support of an automatic belief tracking system, our results indicate a reliable influence of the agent's belief on movement trajectories in the implicit group. Thus, even though participants in the implicit group never needed to track the agent's belief for successful performance, the movement trajectories showed an influence of the veridicality of the agent's belief. This finding suggests the parallel activation of participants' own beliefs and those of other agents. In support of a more rule-based and controlled system, we found that response initiation times changed as a function of the congruency of the participant's and the agent's belief in the explicit group only. Thus, when participants had to track both beliefs, they slowed down their responses when there was a belief conflict versus when there was not. The observation that this result only occurred for the explicit group provides evidence for a controlled system. Perhaps due to the engagement of this controlled system, the AUC measure did not show a main effect of the agent's belief in the explicit group. Overall then, our results support a dual-process framework for belief tracking within a single experimental task. Due to the structure of our task, we cannot determine whether participants represented the belief of the agent, or merely kept an experiential record of the events the agent in the scene witnessed (see Apperly & Butterfill, 2009; Perner & Roessler, 2012). In any case, it is unlikely that participants in the implicit group deliberately tracked the agent́s belief or record. First, during debriefing none of the participants in the implicit group was able to articulate the purpose of the experiment. Second, if participants had developed an explicit notion of the purpose of the task, one would expect their results to mirror those of the explicit group. The initiation time results argue strongly against this possibility, as participants in the implicit group did not show a slowing in initiation times for the conflicting belief conditions.

Kovács et al. suggested that people's own and other agents' beliefs may be represented in a similar way. The basis for this claim was that participants only responded more slowly in a simple detection task when neither the participant nor the agent expected a ball to be present behind an occluder. This suggested a winner-takes-all model, with any true belief about object presence driving behavior. Our findings challenge this notion, at least for more complex tasks than the simple detection task Kovács et al. used. Our participants showed much larger movement curvature (and responded both slower and less accurately) when they had a false belief versus a true belief. The size of the participant's belief effect was much larger than the size of the effect we obtained for the influence of the agent's beliefs. Thus, although our results indicate that the agent's belief was tracked automatically, own beliefs weighed more heavily than the agent's belief.

Our results provide a strong demonstration for the usefulness of measuring responses continuously. Whereas based on response initiation times we would have concluded that automatic belief tracking does not appear to take place, the movement trajectories provide clear evidence for such a process. Thus, regardless of a recent debate about possible alternative accounts one may invoke to account for continuous data in some cases (see Spivey, Dale, Knoblich, & Grosjean, 2010; van der Wel, Eder, Mitchell, Walsh, & Rosenbaum, 2009), it is clear that including a continuous response recording as a dependent measure may provide insights that one would not necessarily obtain from more traditional measures alone.

Finally, when we consider our results from a purely probabilistic perspective, it is remarkable that our results revealed any effects of the belief manipulations for our implicit group. As the participants' belief (and the agent's belief) was incorrect in 50% of the trials and participants never needed to indicate their own or the agent's belief about the objects' locations, they could just as well not have tracked the locations of the objects altogether. Thus, our results suggest that people automatically track object locations, as well as the beliefs of others' when there is no particular reason to do so. This may be because tracking the locations of objects and beliefs in everyday life is often extremely useful.

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