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BRIEF REPORT

Eye Movements Reveal Sustained Implicit Processing of Others' Mental States

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The ability to attribute mental states to others is crucial for social competency. To assess mentalizing abilities, in false-belief tasks participants attempt to identify an actor's belief about an object's location as opposed to the object's actual location. Passing this test on explicit measures is typically achieved by 4 years of age, but recent eye movement studies reveal registration of others' beliefs by 7 to 15 months. Consequently, a 2-path mentalizing system has been proposed, consisting of a late developing, cognitively demanding component and an early developing, implicit/automatic component. To date, investigations on the implicit system have been based on single-trial experiments only or have not examined how it operates across time. In addition, no study has examined the extent to which participants are conscious of the belief states of others during these tasks. Thus, the existence of a distinct implicit mentalizing system is yet to be demonstrated definitively. Here we show that adults engaged in a primary unrelated task display eye movement patterns consistent with mental state attributions across a sustained temporal period. Debriefing supported the hypothesis that this mentalizing was implicit. It appears there indeed exists a distinct implicit mental state attribution system.

Keywords: mental state attributions, theory of mind, eye movements, social cognition, implicit cognitive processes

The possession of a theory of mind (ToM), an individual's ability to understand others' mental states (e.g., intentions), is vital for social competency. Underscoring the importance of ToM for social functioning are the severe limitations encountered by individuals with an autism spectrum disorder (Happé, 1999) or non-autism developmental delay (Zelazo, Burack, Benedetto, & Frye, 1996), who are impaired in this process.

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The dominant method for assessing ToM abilities is the false-belief task, for example the Sally–Anne paradigm (Wimmer & Perner, 1983). Here, Sally sees a ball placed in a box and then leaves the room. Anne then hides the ball in a different box. When Sally returns participants are required to identify the box consistent with Sally's belief about the ball's location as opposed to the ball's actual location. Passing this test is thought to reflect a developmental milestone and is typically achieved by four years of age (Perner & Lang, 1999). However, recent eye movement studies suggest that children as early as 7 to 15 months of age preferentially look toward the location of Sally's belief, indicating mental state attribution (Kovács, Téglás, & Endress, 2010; Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007).

To accommodate these conflicting findings, a two-path ToM system has been proposed (Apperly & Butterfill, 2009), consisting of a later developing path, more dependent on general cognitive functions that allow the explicit inference of others' mental states, and an earlier developing path, which operates in an implicit manner, allowing efficient monitoring of other's mental states in a social environment. Evidence for the distinctiveness of these paths was provided in a study of false-belief processing in participants with Asperger's syndrome (Senju, Southgate, White, & Frith, 2009). Despite similar performance between an Asperger group and controls on a false-belief task requiring an explicit response (see also Bowler, 1991), the participants with Asperger's syndrome displayed no anticipatory looking behavior in an implicit false-belief task, whereas the control participants did. This finding dissociated the two paths and suggested that they may develop independently.

Although there is some support for the existence of an implicit ToM system, it remains unclear whether the proposal of a distinct, unconsciously operating mechanism is indeed justified. To date, anticipatory looking behavior toward locations of belief attribution has been demonstrated only in single-trial designs (Onishi & Baillargeon, 2005; Senju et al., 2009) and multiple-trial reaction time designs that did not investigate the temporal profile of the system's activity (Back & Apperly, 2010; German, Niehaus, Roarty, Giesbrecht, & Miller, 2004; Kovács et al., 2010). It has long been known that many automatic cognitive processes (e.g., orienting behavior) habituate rapidly over time (Groves & Thompson, 1970; Thompson & Spencer, 1966; see also Sokolov, Spinks, Näätänen, & Lyytinen, 2002). For example, a surprising, task-irrelevant stimulus that captures attention impairs the detectability of a subsequent target only in the first few trials of a design (Asplund, Todd, Snyder, & Marois, 2010). If implicit mentalizing behavior is active across only a small number of trials we cannot be confident that it taps into a mental state attribution system, which has been hypothesized to be important for our "social sense" (Kovács et al., 2010) and spontaneous monitoring during social interactions (Apperly & Butterfill, 2009). If this is the case, then these operations should be temporally sustained given the dynamic nature and duration of typical social interactions. Consequently, it is crucial to establish whether previously observed implicit ToM findings can be replicated over the course of a prolonged multiple-trial design.

In the current experiments we investigated the temporal profile of the implicit mentalizing system. By employing a combined eye movement and manual response paradigm our study ensured a distinct measurement of the implicit ToM system, which we confirmed through extensive debriefing. Specifically, we monitored participants' eye movements while they viewed Sally–Anne-like movies in a multiple-trial design. Concurrently, participants engaged in a primary detection (Experiment 1) or discrimination task (Experiment 2), both unrelated to belief processing. Implicit ToM processing was assessed in a postexperimental screening in Experiment 1 and in a comprehensive funneled debriefing procedure in Experiment 2 (Bargh & Chartrand, 2000).

Experiment 1

Method

Thirty-seven neurotypical volunteers (mean age: 21.08 years; 14 men) participated in a protocol approved by the local ethics committee. All completed an Autism-Spectrum Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), and none scored above the clinical cutoff of 32/50 (mean AQ = 17.97). Movies were controlled with Presentation software on a 17" LCD display. Viewing distance (58 cm) was constrained with a chin rest, and eye movements were measured with an Eyelink 1000 (500 Hz). Forty filler and 20 experimental movies were presented in a random order over approximately 50 min. In filler trials participants saw a red ball on top of one of two boxes (movie duration: 3 s) or a puppet hiding a red ball in one of the boxes (movie duration: 29 s). Each of these concluded with a bell sounding and the actor reaching toward the ball (see Figure 1).

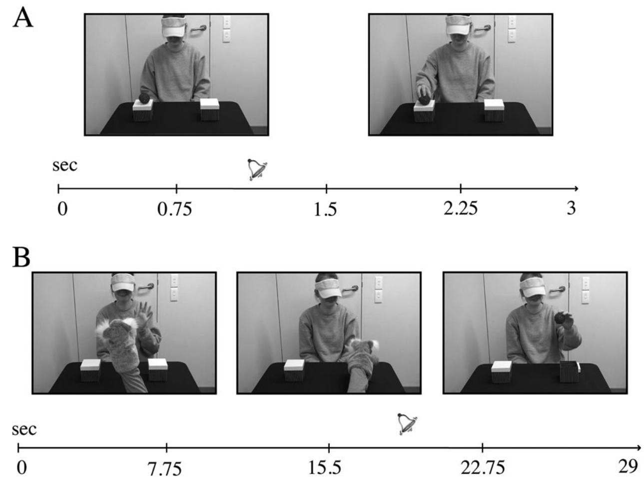

Figure 1. Filler trial movies: The actor reaches for the ball or reveals a hidden ball. A: Participants see a red ball visible on top of one of two boxes (right side of the actor in this case). Subsequently a bell sounds and the actor reaches for the ball. B: Participants observe the actor waving to the puppet; then the puppet hides a red ball in one of the two boxes (left side of the actor in this case). Subsequently, a bell sounds and the human actor reveals the ball from the box. For the entire Experiment 1 the participants' only task instruction was to press the space bar as quickly and accurately as possible when the human actor waved (first panel). Wave trials made up 15 of the total trials. Thus, there was no motivation for the participants to follow the human actor's beliefs.

Importantly, one filler condition (see Figure 1B) included the actor waving toward the puppet (15 of total trials: http://youtu.be/7BkFwInVNcg). Participants made a speeded button press to this wave with feedback given (>90% accuracy performance on this task). This task ensured that participants were motivated to watch the movies and were not explicitly concerned with the belief state of the actor. The only other instruction given to participants was to watch the movies. Participants never reported belief tracking when questioned in an open format after the experiment ("What do you think this experiment was about?"). Furthermore, this verbal debriefing about the experiment's purpose never triggered participants to indicate that they followed the actor's belief state. Note that our actor wore a visor to avoid gaze-cueing effects (e.g., Frischen, Bayliss, & Tipper, 2007).

For the experimental trials, in false-belief scenarios (10 in total), the puppet hid a ball in one of two boxes and then moved it into the other box while the actor watched. Then the actor left the room and the puppet exchanged the ball from that box back to the initial box. The actor then returned with her belief mismatching the ball's actual location (see Figure 2A; http://youtu.be/HMaLIBRwN-Q). The true-belief scenarios (10 in total) were identical to the false-belief trials except that the actor left the room after the first ball movement (the actor was absent when the ball was moved to the other box and back to the initial box). Thus, when the actor returned, her belief and the location of the ball matched (see Figure 2A; http://youtu.be/yf2vVSaaF9Q). Total movie duration for experimental trials lasted between 66 and 73 s. On all experimental trials, once the actor was seated after her return, a bell sounded and the final movie frame froze for 5 s. These final frames were divided for the eye movement analysis into three areas of interest

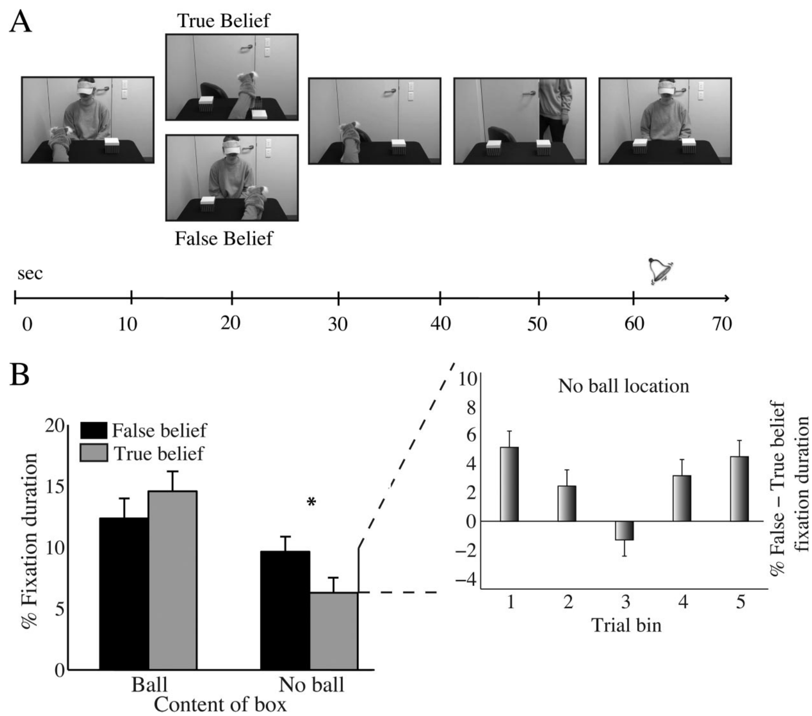

Figure 2. Belief processing scenarios and Experiment 1 results. A: False- and true-belief scenarios. Lower stream: False-belief scenario (with ball finishing in the box to the right of the actor): A hand puppet transfers a ball from one box to another, then the actor leaves the room and the hand puppet transfers the ball back to the initial box. The returning actor has the false belief that the ball is in the box on her left side. Upper stream: True-belief scenario (with ball finishing in the box to the right side of the actor): An actor leaves the room, then a hand puppet transfers a ball from one box to another and then back to the initial box. The returning actor has the true belief that the ball is in the box on her right side. After the human actor is seated, approximately at the 60 s mark of each movie, a bell sounds and the movie is frozen for 5 s. B: Percentage of fixation duration, after the bell sounds, devoted to the two boxes as a function of the belief state of the human actor. In the ball and no ball false-belief conditions the belief and actual location of the ball mismatch, whereas in the ball and no ball true-belief conditions the belief of the actor and actual location of the ball match. The remaining percentage of fixation duration was allocated to the face, thus ceiling effects for the boxes are unlikely. Error bars represent effect-based (false vs. true-belief) within-subject standard error of the mean. The outset of the plot represents the difference in the percentage of fixation duration at the no ball location between false-belief and true-belief trials (false-belief − true-belief) across the entire testing session. Each bin represents the difference between the averages of two consecutive trials from each belief condition. * $p < .05$.

(face, left box, and right box). Eye movement tracking allowed us to determine whether participants looked for longer at locations where the ball was not (the empty box), under conditions where the actor believed it was at that location (false-belief) compared with when she believed it was not at that location (true-belief). The same comparison was then possible for the ball location. Note that two versions of the experimental trials were used (true-belief right, false-belief right, true-belief left, false-belief left) in order to counterbalance the initial and final locations of the target object as well as the final location of the actor's gaze.

Results

A repeated-measures analysis of variance (ANOVA) revealed a significant interaction between belief (true vs. false) and location (face vs. ball vs. no ball), $F(2, 72) = 3.29$, $p = .04$, on eye movement behavior. Importantly, follow-up paired t tests demonstrated that the no ball location was looked at for significantly longer in false- (9.65%) than in true-belief (6.30%) trials, $t(36) = 2.72$, $p = .01$; however, this was not the case at the ball location, $t(36) = -1.36$, $p = .18$ (see Figure 2B, total percentage of fixation duration as a function of box content). Given that in our task participants were never instructed to follow the belief of the actor, were engaged in an unrelated detection task, never reported having followed the belief of the actor, and many observations were acquired, this is strong evidence for the existence of an implicit ToM system.

Of primary interest was whether this false- versus true-belief viewing difference was observed throughout the experiment. To assess the temporal profile of this effect, the average of every two consecutive trials from each belief condition was calculated and then their difference was computed, resulting in five bins. The overall preference to view the no ball location in false-belief trials compared with true-belief trials did not vary across the bins, $F(4, 144) = 1.48$, $p = .21$ (see Figure 2B).

Discussion

Experiment 1 demonstrated that implicit mentalizing lasts over a prolonged time period when measured with anticipatory eye movements. This behavior was observed under conditions where participants were not instructed to follow beliefs, were engaged in a primary task, and never reported belief processing in postexperimental screening. Therefore, it provides evidence for the proposed implicit ToM system (Apperly & Butterfill, 2009).

A potential issue, however, is that the primary task (detecting the actor's wave) was relatively easy and did not occur during the key phase of belief formation. In addition, the detection of the actor's hand wave may have acted as an ostensive cue facilitating belief tracking of the actor (Csibra & Gergely, 2009). Further, one could argue that the employed debriefing procedure did not adequately examine the extent of conscious ToM processing. To address these concerns, in Experiment 2 a more difficult primary task was employed continuously throughout the critical phases of belief establishment. In addition, an extended debriefing procedure was used (Bargh & Chartrand, 2000).

Experiment 2

Method

The method used for Experiment 2 was identical to that of the first experiment except where specified. Thirty-five new volunteers participated (mean age: 22.17 years; 12 men; mean AQ = 18.14). Twenty filler and 20 experimental trials were presented randomly. The same movies were employed; however, a reduced number of filler trials were presented (as the concurrent task was now not implemented in these trials). Participants' primary task involved making a speeded discrimination between high and low tones, which were played at different time points throughout the experimental trials and two of the four filler trial types (see Figure 1B; filler trial duration: 29 s). For the experimental conditions, five pseudorandomly determined tone-sequence versions were implemented, with one of the two tones sounding every 5 to 10 s (eight across each trial) until the puppet left the scene for the final time (tone duration 100 ms; http://youtu.be/ob4Vg0lF72Q). Each version repeated four times over 20 false- and true-belief trials. For the dual-task filler trials another five versions were implemented, with four pseudorandomly assigned tones being presented in each movie. These versions repeated four times over the 10 filler trials. The remaining 10 filler trials (see Figure 1A; filler trial duration: 3 s) were displayed without tones and served as rest trials. Again, on all experimental trials the final movie frame froze for 5 s, allowing anticipatory eye movements to be measured. At the end of each eye-tracking session participants completed a funneled debriefing protocol for implicit higher mental processes (Bargh & Chartrand, 2000) adjusted to the current paradigm. This probed, in an increasingly specific manner, whether participants were aware of the belief state of the actor (see Appendix).

Results

There was high accuracy (M = 96.34) on tone discrimination, confirming that the participants engaged in this primary task. The funneled debriefing procedure also indicated that five participants potentially had explicit knowledge of the experiment's aims. These participants were excluded from further analysis.

Again, a repeated-measures ANOVA revealed a significant interaction between belief (true vs. false) and location (face vs. ball vs. no ball), $F(2, 58) = 4.78$, $p = .01$, on eye movements. Follow up paired t tests revealed a pattern identical to that of Experiment 1, with the no ball location looked at for significantly longer under false-belief (8.62%) than under true-belief (5.36%) conditions, $t(29) = 2.72$, $p = .01$, and no difference at the ball location, $t(29) = .64$, $p = .53$ (see Figure 3; total percentage of fixation duration as a function of box content). In addition, the overall preference for viewing the no ball location on false-belief trials

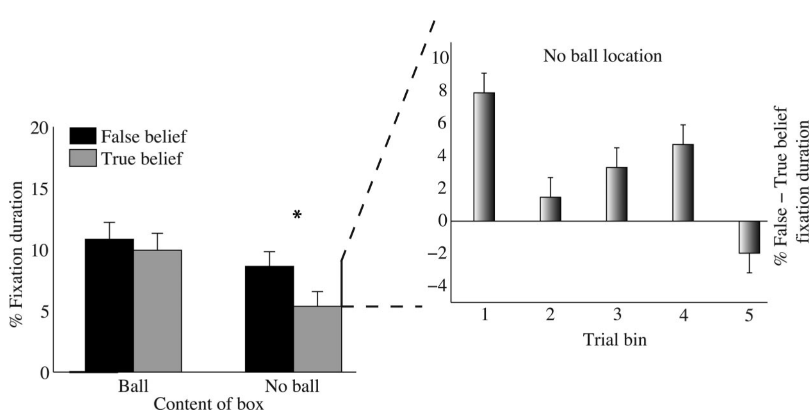

Figure 3. Experiment 2 results: Percentage of fixation duration, after the bell sounds, devoted to the two boxes as a function of the belief state of the actor. In the ball and no ball false-belief condition the belief and actual location of the ball mismatch, whereas in the ball and no ball true-belief condition the belief of the actor and actual location of the ball match. Note that the remaining percentage of fixation duration was allocated to the face. Error bars represent effect-based (false- vs. true-belief) within-subject standard error of the mean. The outset of the plot represents the difference in the percentage of fixation duration at the no ball location between false-belief and true-belief trials (false-belief − true-belief) across the entire testing session. Each bin represents the difference between the averages of two consecutive trials from each belief condition. $^{*}p < .05$.

compared with true-belief trials did not vary across trial bins, $F(4, 116) = 1.58$, $p = .18$ (see Figure 3).

Discussion

The present experiment replicated Experiment 1's findings of implicit mentalizing over multiple trials. Importantly, here we employed a more difficult primary task that occurred during belief formation processes and a more thorough debriefing protocol, which was sensitive enough to detect five participants who potentially engaged in explicit mentalizing. Thus, we can be more confident that we are indeed examining an implicit ToM process.

General Discussion

To the best of our knowledge no other study has investigated and demonstrated implicit mental state attributions over a prolonged temporal period with anticipatory eye movements. This is an important finding as other automatic cognitive processes habituate rapidly over time (e.g., orienting; Asplund et al., 2010; Sokolov et al., 2002). Thus, not only does the sustained nature of the implicit ToM system differentiate it from such processes, but it also supports the idea that there exists a continuously acting implicit mental-state attribution system. This system may be vital for our social sense (Kovács et al., 2010) and for the spontaneous monitoring of social interactions, as, for example, encountered in rapid competitive or strategic communications (Apperly & Butterfill, 2009).

Importantly, the present results highlight that this effect is indeed implicit (Apperly & Butterfill, 2009) as the eye movement behavior was observed under conditions where participants were not instructed to follow beliefs and were engaged in primary tasks unrelated to belief processing. In addition, the pattern of results held when an extensive debriefing protocol was employed and participants were excluded who potentially engaged in explicit mentalizing.

Our findings complement those of Kovács et al. (2010), who also recently examined the implicit ToM system using a multiple-trial reaction time design. In contrast to the present report, these researchers did not conduct an analysis regarding the temporal profile of this effect. In addition, eye movements were not employed in that study, with participants instead required to make a manual response in relation to an object an agent had interacted with (had released a ball to go behind an occluder). As the agent in these scenarios interacted with the object that participants were required to respond to (the occluder vanished and participants made a speeded ball present/absent judgment), it is possible they explicitly processed the agent's mental state, as they thought it was predictive of the ball's presence or absence (even though it was not). Last, Kovács et al. (2010) did not include a secondary task unrelated to belief processing, nor did they formally debrief the participants with regard to explicit mental state processing. Our findings, therefore, add to those of Kovács et al. (2010) by demonstrating implicit belief attribution over a prolonged period with anticipatory eye movements.

Might a gaze-cueing account explain our data? In our movies, the actor naturally followed the actions with head turns, while her eyes were not visible. On false-belief trials, this meant she looked at the no ball position last but not on true-belief trials. Did this cue carry over to the measurement period 40 s later? Further analyses of our data suggest that this is not the case. If cueing explains our results, then participants should fixate for longer at the ball location during true-belief trials relative to false-belief trials. This is the case as this is the last gaze-cue given to the participants in the former condition. In Experiment 1, at the ball location there was no significant fixation duration difference ($p = .18$) between the false- and true-belief trials. The same held true for Experiment 2's ball location ($p = .53$). Thus, these results are inconsistent with a gaze-cueing account. Moreover, the literature suggests that gaze-cueing is unlikely to give rise to our preferential looking results for false-belief trials at the no ball location. Although long-term gaze-cueing effects have been noted by one study (Frischen & Tipper, 2006), they were observed only with manual reaction times and famous faces. Hence, the gaze-cueing literature, as well as our data, provides very little support for a cueing account of our findings.

Taken together our results show that neurotypical adults engaged in a primary task with no belief-processing requirements display eye movement patterns consistent with implicit mentalizing. This behavior was observed consistently across multiple trials. These findings support the hypothesis that there exists an implicit mental state attribution system, which appears vital for our social sense (Kovács et al., 2010), that allows the spontaneous and continuous monitoring of social interactions (Apperly & Butterfill, 2009). As such, the implicit ToM system may be predominantly active in rapidly changing social environments. This may set it apart from its explicit ToM counterpart that gives rise to well-reasoned reflections of others' thoughts, feelings, and actions (Frith & Frith, 2005).

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Appendix

Funneled Debriefing Procedure (adapted from Bargh & Chartrand, 2000. Copyright © Cambridge University Press 2000. Reprinted with the permission of Cambridge University Press.)

1. What do you think the purpose of the experiment was?
2. What do you think this experiment was trying to study?
3. Did you think that any of the tasks you did were related in any way? (If "yes") In what way were they related?
4. Did anything you did on one task affect what you did on any other task? (If "yes") How exactly did it affect you?
5. When you were completing the tone detection task, did you notice anything unusual about the movies?
6. Did you notice any particular pattern or theme to the movies that were included in the tone detection task?
7. What were you trying to do while watching the movies and detecting the tones? Did you have any particular goal or strategy?

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