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Cognitive Load Disrupts Implicit Theory-of-Mind Processing

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Abstract

Eye movements in Sally-Anne false-belief tasks appear to reflect the ability to implicitly monitor the mental states of other individuals (theory of mind, or ToM). It has recently been proposed that an early-developing, efficient, and automatically operating ToM system subserves this ability. Surprisingly absent from the literature, however, is an empirical test of the influence of domain-general executive processing resources on this implicit ToM system. In the study reported here, a dual-task method was employed to investigate the impact of executive load on eye movements in an implicit Sally-Anne false-belief task. Under no-load conditions, adult participants displayed eye movement behavior consistent with implicit belief processing, whereas evidence for belief processing was absent for participants under cognitive load. These findings indicate that the cognitive system responsible for implicitly tracking beliefs draws at least minimally on executive processing resources. Thus, even the most low-level processing of beliefs appears to reflect a capacity-limited operation.

Keywords

theory of mind, social cognition, dual-task performance, eye movements, implicit cognitive processes, cognitive load

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One feature that separates humans from other primates is the propensity to make inferences regarding other individuals' mental states, and particularly inferences relating to beliefs (Call & Tomasello, 2008; Premack & Woodruff, 1978). For example, imagine that you see a man you do not know walk by and glance at you—twice. You would likely question his intentions for doing so and consider that maybe he mistakenly thought he knew you. This ability that allows a person to reason about another's beliefs, feelings, desires, intentions, or goals is termed *theory of mind* (ToM; Premack & Woodruff, 1978).

Given the important role that such social processing plays in people's everyday lives, and the benefits it affords individuals in interacting with others and with the environment, it is not surprising that ToM has been a major topic of investigation in cognitive science. Moreover, the severe limitations encountered by individuals who are impaired in ToM operations (e.g., those with an autism spectrum disorder, or ASD; Baron-Cohen, 1995; Baron-Cohen, Leslie, & Frith, 1985; Frith, 2003) make the understanding of how belief inference operates all the more crucial. A key paradigm for assessing ToM abilities is the *Sally-Anne false-belief task* (Wimmer & Perner, 1983): In still images, movies, or "live" performance (with puppets, actors, or both), "Sally" sees an object (e.g., a ball) being placed in a container. Sally then leaves the room. Next, "Anne" hides the object in a different container. When Sally returns to the room, participants are required to identify the location where they think Sally will first look for the object. To succeed at the task, participants must select (e.g., point to) the location that is consistent with Sally's *belief*, as opposed to the actual, known location of the object.

Passing this *explicit* Sally-Anne task is thought to reflect a developmental milestone, which is typically achieved by the age of 4 years (Perner & Lang, 1999). Such findings suggest that children understand other people's beliefs by this age. However, recent research using a variety of *implicit* ToM tasks suggests that children as young as 7 months may be able to register other individuals' beliefs (Clements & Perner, 1994; Kovács, Téglás, & Endress, 2010; Onishi & Baillargeon, 2005). For example, monitoring of eye movement behavior in free-viewing false-belief scenarios has demonstrated that 2-year-olds preferentially look toward the location at which the actor believes the

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ball to be (Southgate, Senju, & Csibra, 2007; see also Senju, Southgate, Snape, Leonard, & Csibra, 2011).

Do humans fail to understand other individuals' internal mental states until the age of 4, or is this fundamental ability already present during the 1st year of life? To accommodate these seemingly incongruent findings, Apperly and Butterfill (2009) proposed that throughout the life span, ToM is subserved by two distinct systems. According to this framework, an earlier-developing system, which operates implicitly (see Schneider, Bayliss, Becker, & Dux, 2011) and is independent of the development of language and executive function (e.g., working memory), is responsible for efficient monitoring of belief-like states. A later-developing system, which is dependent on domain-general cognitive functions (e.g., executive function), allows conscious (explicit) ToM inferences. Evidence supporting this framework includes a dissociation found in adults with Asperger's syndrome, who can pass explicit false-belief tasks but do not display eye movement patterns consistent with implicit ToM in a Sally-Anne free-viewing paradigm (Senju, Southgate, White, & Frith, 2009).

Apperly and Butterfill's (2009) account explains a wide range of data. However, until now, a key test of this theory had yet to be undertaken. That is, no studies had tested whether the implicit ToM system is independent of domain-general, capacity-limited, cognitive resources (e.g., working memory). There is considerable evidence, from both behavioral and neuropsychological studies, that domain-general executive resources contribute strongly to social reasoning in tasks that involve explicit ToM judgments (e.g., McKinnon & Moscovitch, 2007; Rowe, Bullock, Polkey, & Morris, 2001). In the study reported here, we tested the role of such resources in implicit ToM processing by manipulating cognitive load while measuring neurotypical adults' eye movements in a free-viewing false-belief paradigm modeled after the Sally-Anne task. To ensure that our task tapped implicit ToM, we thoroughly assessed the extent to which participants engaged in explicit belief processing using an extensive debriefing procedure (see also Schneider et al., 2011).

Method

Sixty-five neurotypical volunteers (mean age = 20.83 years; 37 females, 28 males) participated in a protocol approved by the University of Queensland's ethics committee. All completed the Autism-Spectrum Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), and none scored above the clinical cutoff of 32 (out of 50; mean AQ = 17.14).

Movies portraying scenarios modeled after the Sally-Anne paradigm (see Schneider et al., 2011) were displayed on a 17-in. LCD monitor using Presentation software (Neurobehavioral Systems, Albany, CA). Participants sat 58 cm from the screen with their head position constrained via a chin rest. Eye movements were measured with an EyeLink 1000 eye tracker (sampling rate: 500 Hz; SR Research, Mississauga, Ontario, Canada). Filler and experimental movies were presented in a random order over approximately 50 min.

In filler trials, participants saw an actor sitting in a chair behind a desk with two opaque boxes on it. In one type of filler movie, a hand puppet placed a red ball on top of one of the boxes (movie duration = 3 s); in the other type, the puppet placed the red ball in one of the boxes (movie duration = 29 s). The filler movies concluded with a bell sounding and the actor then reaching toward the ball.

There were two types of experimental trials (duration between 66 and 73 s; see Fig. 1a). In false-belief scenarios, which began with the same general scene as the filler movies, the puppet hid the ball in one of the boxes and then moved it into the other box, all while the actor was present and watching. Then the actor left the room, and the puppet moved the ball back to the initial box. This resulted in the actor's belief mismatching the ball's actual location when she returned (an example of a false-belief movie is available at http://youtu.be/HMaLIBRwN-Q). The true-belief scenarios were identical to the false-belief trials except that the actor left the room after the puppet first hid the ball (i.e., the actor did not see the ball being moved to the other box and back to the initial box). Thus, upon the actor's return, her belief was consistent with the ball's actual location (an example of a true-belief movie is available at http://youtu.be/yf2vVSaaF9Q). The initial (and final) location of the ball was counterbalanced, such that there were two versions of each type of experimental trial (false-belief scenarios with the ball ending up in the box on the right and with the ball ending up in the box on the left; true-belief scenarios with the ball ending up in the box on the right and with the ball ending up in the box on the left).

In each experimental trial, once the actor reentered the room and sat behind the desk, a bell sounded, and the final movie frame froze for approximately 6 s. This frame was divided into three areas of interest (face, left box, and right box) for the eye-tracking analysis. This allowed us to examine our key question: whether participants would view the empty box (no-ball location) longer when the actor falsely believed the ball was at that location (false-belief condition) than when she correctly believed it was not at that location (true-belief condition). Note that our actor wore a visor to avoid gaze-cuing effects (Frischen, Bayliss, & Tipper, 2007; Schneider et al., 2011). To ensure that the eye movement data reflected implicit ToM processing, we employed a funneled debriefing protocol at the end of each session (as used by Schneider et al., 2011). This protocol, which was adapted from a procedure used to assess implicit higher mental processes in previous work (Bargh & Chartrand, 2000), probed, with increasing specificity, whether participants engaged in conscious processing of the actor's belief states.

All participants were required to make a simple speeded button press when they saw the actor waving at the puppet (this occurred in one of the types of filler trials, an example of which is available at http://youtu.be/7BkFwInVNcg). These waves occurred in 7 or 15 of the filler trials, depending on condition. This task ensured that participants were motivated

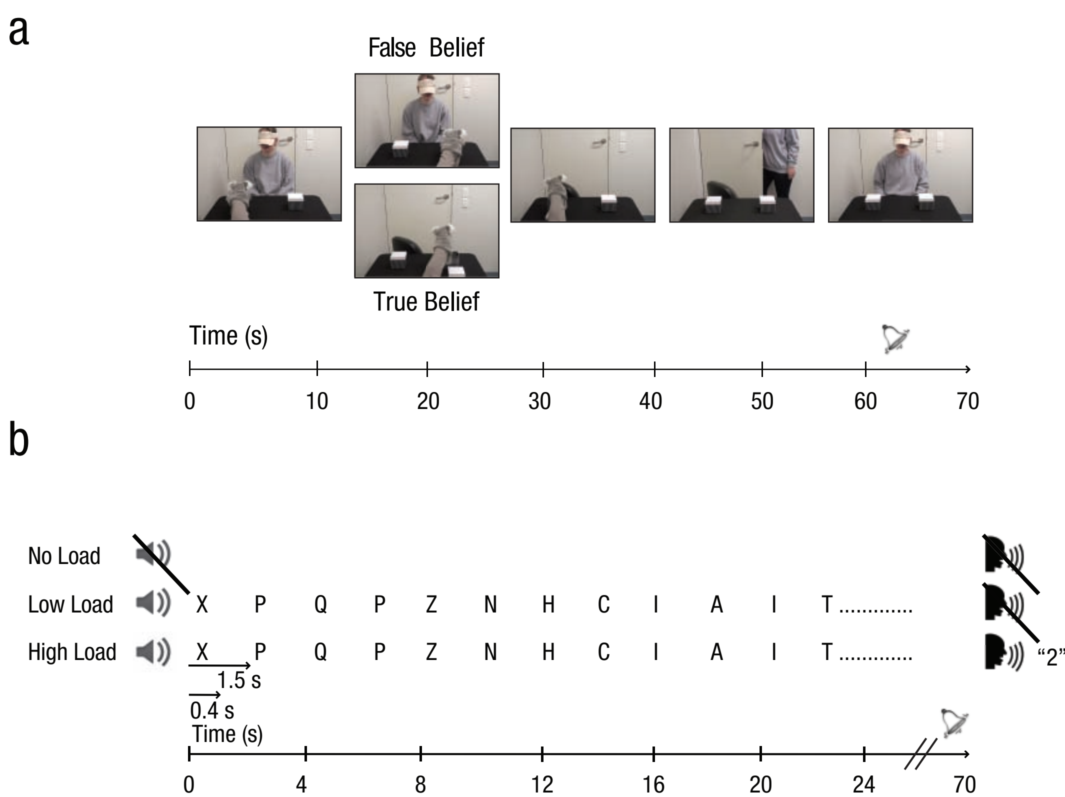

Fig. 1. Illustration of the belief-processing scenarios and cognitive-load manipulation. In experimental trials (a), an actor watched a hand puppet hide a ball in one of two opaque boxes (here, the box on her right side). In the false-belief scenario, the puppet then transferred the ball to the other box, the actor left the room, and the puppet transferred the ball back to the initial box. The returning actor therefore had a false belief about which box contained the ball. In the true-belief scenario, the actor also watched the puppet hide the ball in one of two opaque boxes, but then left the room. Next, the puppet transferred the ball to the other box and then back to the initial box. The returning actor therefore had a true belief about which box contained the ball. In both false-belief and true-belief trials, after the actor reentered the room and was seated (at approximately the 60-s mark), a bell sounded, and the movie was frozen for about 6 s. As part of the movie-viewing task, all participants were required to make a simple speeded button press whenever they saw the actor waving at the puppet (implemented in one type of filler trial). Cognitive load was manipulated by having some participants perform a concurrent primary task (implemented in the experimental trials; b). In the no-load condition, the only task was the movie-viewing task. In both the high- and the low-load conditions, participants also listened to a continuous auditory stream of randomly selected letters; participants in the low-load condition simply listened to the letters, but those in the high-load condition were asked to report the number of 2-back letter repetitions at the end of each trial (here there are two such repetitions, of "P" and "I").

to watch the movies but not explicitly concerned with the belief state of the actor. Further, it was not meant to severely tax executive processes.

To manipulate cognitive load, we assigned some participants another task to perform concurrently with the movie-viewing task (Fig. 1b). Neither of these tasks was related to belief processing. Participants in the no-load group performed the movie-viewing (wave-detection) task only. Thus, the procedure for this group replicated the method of the first experiment in Schneider et al. (2011). Participants in the low- and high-load conditions also listened to a continuous auditory stream of letters randomly selected from the full alphabet and voiced by an English-speaking female (~400 ms per item, presentation rate = 0.67 Hz); these streams were presented only during the experimental movies (i.e., at times crucial for belief establishment) via headphones adjusted to a comfortable volume. The onset of each auditory stream was synchronized to the start of the movie, and the stream ended just before the bell sounded. Each stream contained two, four, six, eight, or ten 2-back letter repetitions (repetitions separated by one item: e.g., ". . . R, L, R. . ."). Participants in the low-load condition were instructed to simply listen to the letters, but not respond to them, as they watched the movies. This condition was designed to tax the executive system to some extent (more than in the no-load condition), as participants needed to avoid being distracted by the continuous auditory stimuli presented during the key phases of belief processing. In the high-load condition, participants were required to count the number of 2-back repetitions and report this total at the end of each experimental trial. This task was designed to draw heavily on executive processes, as participants needed to direct working memory resources toward this task to succeed. The only other instruction given to participants was to watch the movies; thus, the movie component was a free-viewing paradigm with no task related to the belief scenarios.

All participants were presented with 10 false-belief and 10 true-belief trials. In addition, to equate run time for all the groups, we included 40 filler trials (15 of which were wave-detection trials) in the no-load condition and 22 filler trials (7 of which were wave-detection trials) in the low- and high-load conditions. Schneider et al. (2011) have demonstrated that eye movement behavior consistent with implicit ToM processing is identical when these two numbers of filler trials are used.

Results and Discussion

Eleven participants were removed from analyses, as debriefing revealed that they may have explicitly processed beliefs. The final sample included 18 participants in each group. Participants in the high-load group performed the 2-back-repetition task with a mean accuracy of 45%, which was significantly above the chance level of 20%, $t(17) = 6.91$, $p < .001$, but still quite low. Given this low level of performance, it is clear that this task was demanding, and as participants were required to both maintain and update information, it likely drew heavily on executive resources (Smith & Jonides, 1999).

To assess eye movement behavior, we calculated the percentage of fixation duration toward each of the three areas of interest (ball, no-ball, and face locations) relative to the total time fixating these three areas in the last 6 s (the final frame) of the experimental movies. These data were submitted to a 3 (group: no load vs. low load vs. high load) × 2 (belief condition: true vs. false belief) × 2 (location: ball vs. no ball) mixed factorial analysis of variance (ANOVA). Crucially, the three-way interaction was significant, $F(2, 51) = 3.61$, $p = .034$, $\eta_p^2 = .124$; the pattern of eye movements to the ball and no-ball locations in the true- and false-belief scenarios differed as a function of cognitive load (Fig. 2). To further investigate this interaction, we submitted the data from each group to a separate 2 (belief condition: true vs. false belief) × 2 (location: ball vs. no ball) repeated measures ANOVA.

For the no-load group, there was a significant two-way interaction, $F(1, 17) = 6.95$, $p = .017$, $\eta_p^2 = .290$. Planned follow-up t tests revealed that for the no-ball location, the percentage of fixation duration was higher on false-belief than on true-belief trials, $t(17) = 2.32$, $p = .033$; however, no such difference was seen at the ball location ($p = .505$). There was also an effect of location, with the ball location looked at more overall than the no-ball location, $F(1, 17) = 4.91$, $p = .041$, $\eta_p^2 = .224$. These results replicate those of Schneider et al. (2011) and demonstrate eye movement behavior consistent with belief processing: Participants spent more time looking at the no-ball location when the actor believed the ball was at that location (false-belief condition) as opposed to when the actor believed the ball was at the other location (true-belief condition). Recall that participants were not instructed to track the beliefs of the agent and that our debriefing procedure was sensitive enough to detect participants who engaged in explicit ToM analysis. Thus, this belief-tracking behavior appears to have operated implicitly.

Implicit belief processing was not observed in the low-load group, as the two-way interaction between belief condition and location was not significant ($p = .174$); however, there was a main effect of location, with participants fixating the ball location to a greater extent than the no-ball location overall, $F(1, 17) = 5.005$, $p = .039$, $\eta_p^2 = .227$. There was no influence of belief condition or location on eye movement behavior in the high-load group, nor did these variables interact ($ps > .63$). Thus, it appears that increased cognitive load impairs implicit belief processing; the no-load group tracked both the belief

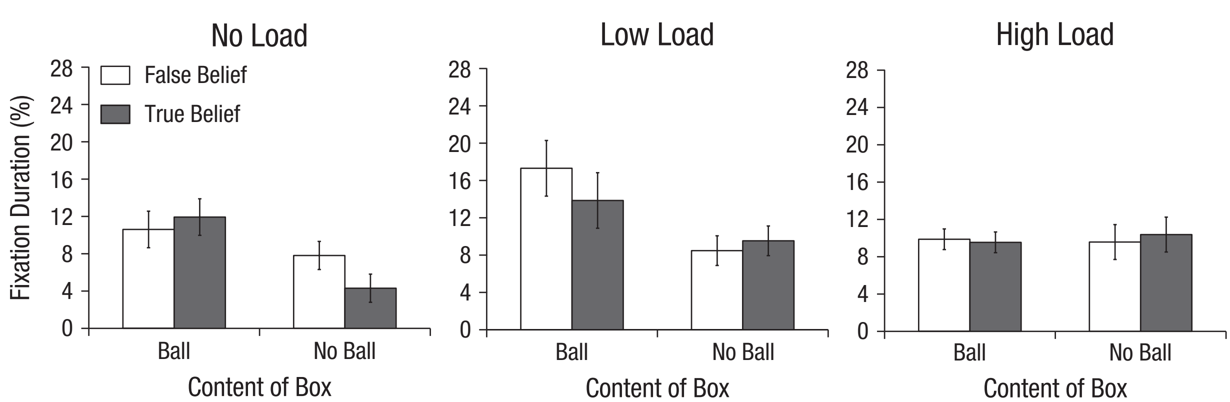

Fig. 2. Percentage of fixation duration toward the box containing the ball and toward the box not containing the ball in the false-belief and true-belief conditions, separately for the no-load, low-load, and high-load groups. Error bars represent standard errors of the difference between the true- and false-belief conditions for each location in each group.

state of the actor and the ball's location, the low-load group tracked only the actual position of the ball, and the high-load group tracked neither. These results suggest that although there may be a ToM system that operates implicitly, it is not independent of executive function as hypothesized by Apperly and Butterfill (2009).

Did we fail to see eye movement behavior consistent with implicit belief processing in the low- and high-load groups simply because cognitive load impaired visual scene processing generally? Our eye movement data suggest this is not the case. First, there was no overall effect of group ($F < 1$) in the three-way mixed factorial ANOVA; across the three groups, the boxes were fixated for the same percentage of time. Second, a similar 2 (location: face vs. nonface) × 3 (group) mixed factorial ANOVA comparing the percentage of fixation duration for the face location and the average percentage of fixation duration across the two nonface locations demonstrated only a main effect of location, $F(1, 51) = 302.49$, $p < .001$, $\eta_p^2 = .856$, with individuals in all groups devoting a greater percentage of fixation duration to the face of the actor (M = 76.56%) than to either of the two boxes (M = 10.27%). The interaction did not approach significance ($F < 1$). Thus, it appears that cognitive load influenced only the implicit analysis of the actor's belief and the location of the ball. Finally, when we examined eye movement behavior only in the no- and low-load groups, in which we could be sure that participants tracked the ball (given the effect of location), we found a significant Group (no load vs. low load) × Belief Condition (true vs. false belief) × Location (ball vs. no ball) interaction, $F(1, 34) = 6.487$, $p = .016$, $\eta_p^2 = .160$. Crucially, a follow-up test showed that the only difference between these groups was the relative percentage of fixation duration at the no-ball location in the false- and true-belief conditions, $t(34) = 2.084$, $p = .045$. There was no such effect at the ball location ($p = .189$). This is further evidence that our main findings do not simply reflect cognitive load disrupting eye movements in general.

Collectively, the present work suggests that, although there may be distinct ToM systems that operate at implicit and explicit levels of processing, both of these appear to draw, at least to some extent, on executive resources. These results stand in contrast to those found for implicit "Level-1" visual perspective calculation (tracking what an agent can or cannot see), a related process, which is not influenced by dual-task manipulations (Qureshi, Apperly, & Samson, 2010). Seemingly, even the most low-level belief analysis reflects a capacity-limited operation. Future work should further examine the relative demands placed on executive resources by explicit and implicit ToM processes.

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Dana Schneider and Rebecca Lam contributed equally to this work.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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