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Efficient belief tracking in adults: The role of task instruction, low-level associative processes and dispositional social functioning

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Abstract

A growing body of evidence suggests that adults can monitor other people's beliefs in an efficient way. However, the nature and the limits of efficient belief tracking are still being debated. The present study addressed these issues by testing (a) whether adults spontaneously process other people's beliefs when overt task instructions assign priority to participants' own belief, (b) whether this processing relies on low-level associative processes and (c) whether the propensity to track other people's beliefs is linked to empathic disposition. Adult participants were asked to alternately judge an agent's belief and their own belief. These beliefs were either consistent or inconsistent with each other. Furthermore, visual association between the agent and the object at which he was looking was either possible or impeded. Results showed interference from the agent's belief when participants judged their own belief, even when low-level associations were impeded. This indicates that adults still process other people's beliefs when priority is given to their own belief at the time of computation, and that this processing does not depend on low-level associative processes. Finally, performance on the belief task was associated with the Empathy Quotient and the Perspective Taking scale of the Interpersonal Reactivity Index, indicating that efficient belief processing is linked to a dispositional dimension of social functioning.

Keywords

Social cognition

Mentalising

Belief

Self vs. other

Low-level associative processes

Empathy

1. Introduction

In order to guide their behaviours in social interactions, humans process what other people see, feel, desire or believe and differentiate these mental states from their own mental states, an ability referred to as mentalising or reflecting the possession and use of a ‘‘Theory of Mind” (Premack & Woodruff, 1978). Amongst the different mentalising activities, belief reasoning has for a long time been seen as one of the most complex and effortful form of mental state processing. It was mainly investigated by testing performance in classic false-belief tasks. In one version of these tasks, participants are presented with scenarios in which the protagonist sees an object at a given location, the object is then moved during the protagonist's absence and eventually the protagonist comes back. Participants are then asked to judge the protagonist's belief (‘‘Where does he think the object is?”) or to predict his behaviour (‘‘Where does he first search for the object?”). Typically, before the age of 4, children fail to ascribe false beliefs because they suffer from an egocentric/reality bias: they respond according to their own knowledge of reality (e.g., Wimmer & Perner, 1983). Later in development, once participants are able to respond according to other people's beliefs, performance still shows a signature of egocentric interference. Indeed, adults have been found to be slower and more error-prone to judge someone else's belief when the person's belief is false compared to true (Back & Apperly, 2010; German & Hehman, 2006).

However, in the past decade, there has been accumulating evidence showing that humans at different stages of their development are able to efficiently track other people's beliefs. These studies tested belief reasoning more implicitly in experimental designs with reduced or no demands in terms of language, conceptual understanding and executive control. In such contexts, it has been shown that infants are sensitive to other people's beliefs (Kovács, Téglás, & Endress, 2010; Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007), that three-year-old children have the ability to process someone else's beliefs at an implicit level before they can do it efficiently in an explicit condition (Clements & Perner, 1994; Garnham & Ruffman, 2001), and that adults spontaneously process other people's beliefs (e.g., Kovács et al., 2010; Van der Wel, Sebanz, & Knoblich, 2014), sometimes without awareness (Schneider, Bayliss, Becker, & Dux, 2012) and even under explicit instructions to track an object's location (Schneider, Nott, & Dux, 2014). Recently, Schuwerk et al. showed that the extent to which other people's belief interfered with judgments about the self-belief (altercentric interference) was similar to the interference from self-belief on judgments about others' belief (egocentric interference) (Schuwerk, Döhnel et al., 2014; Schuwerk, Schecklmann et al., 2014).

These pieces of evidence in favour of an early-developing and efficient belief processing mechanism are at odds with the traditional view that belief reasoning is late-developing and resource-consuming. This apparent paradox has opened debates about the validity of the evidence for efficient belief tracking and the nature of this processing. Regarding the validity of these evidence, some authors argued that the findings could be explained without referring to mentalising, either by domain-general processes that are recruited by the tasks (e.g., Heyes, 2014; Phillips et al., 2015) or by the use of behavioural rules (Perner & Ruffman, 2005). Researchers are currently developing different experimental designs to address the validity issue and have started to show association between efficient belief tracking in experimental tasks and self-reported measures of empathy in everyday life (Ferguson, Cane, Douchkov, & Wright, 2015). Regarding the nature of belief processing, some authors have suggested that efficient belief tracking is a form of mentalising that differs from explicit belief reasoning (Apperly & Butterfill, 2009; De Bruin & Newen, 2012, 2014). While explicit belief reasoning would activate full-fledged representations of beliefs, implicit belief tracking would represent ‘‘belief-like states”, which is a relation between an individual and an object, for example, that is or has been in the individual’s field of view. Such representations would support action predictions in fast-moving interactions, but would not allow complex beliefs to be represented (such as beliefs that involve quantifiers, complex combinations of properties or how the agent sees the object). So far empirical evidence in favour of such limits is still scarce: it has been shown that at an implicit level adults can track others’ beliefs about the location and the presence of an object but not about its identity (e.g., Kovács et al., 2010; Low & Watts, 2013).

In order to further understand the nature of efficient belief tracking and situational and dispositional factors that influence this processing, the current study addressed three key issues. 1. Do adults compute other people’s belief when there are objective reasons to give priority to their own beliefs, and if so, is the altercentric interference as strong as the egocentric interference? 2. To what extent is such processing influenced by the availability of external cues that can boost low-level associations? 3. Is such processing related to dispositional factors such as empathic skills, and if so, to which component of empathic skills? The ways in which we address each of these issues are explained below.

First, we tested whether adults compute other people’s beliefs when they are instructed to give priority to their own belief before belief-related events unfold.

Finding an altercentric interference effect in such a context would be of particular interest because it would indicate that implicit belief tracking is not disrupted by the explicit instruction to track self-belief. This would extend the finding that implicit belief tracking is not disrupted by the explicit instruction to track reality (Schneider et al., 2014). Furthermore, we hypothesised that the dynamics between the self- and the other-belief processing, and hence the balance between egocentric and altercentric interference effects, depends on situational factors such as the time point at which priority could be given to the self and the other-beliefs. We hypothesised that when priority can be assigned at the time of computation, it would be easier to give priority to self-related information and to ignore other-related information than the reverse due to a natural tendency to prioritise self-related information (e.g., Sui & Humphreys, 2015). This would lead to a smaller altercentric interference effect compared to the egocentric interference effect. This asymmetry in the magnitude of the egocentric and the altercentric interference effects would contrast with the symmetry shown by Schuwerk, Döhnel et al. (2014) and Schuwerk, Schecklmann et al. (2014)when the to-be-judged belief was indicated at the end of the belief scenarios, once the belief-related events had been unfolded.

In order to test efficient belief tracking in a context in which priority can be given to the self before belief computation, we asked adult participants to watch belief scenarios and to judge whether a given picture matched their own belief or the protagonist's belief. The to-be-judged belief was indicated prior to the unfolding of the events. Such an experimental context provides a measure of an implicit form of other-belief processing (the degree to which an agent's belief affects participants' judgement about their own belief, or the altercentric interference effect) that can be compared to the classic egocentric interference effect (the degree to which the participant's own belief affects the judgement about the agent's belief) in order to assess the balance between the self-and the other-belief processing. Implicit belief processing should be understood here as processing of another person's belief in the absence of explicit instruction to track that person's belief. We do not assume automaticity by using this term in the present paper as both the self- and other-beliefs were relevant in the general context of the task.

Second, we tested the hypothesis that implicit belief tracking could be explained by the registration of associations between the social agent and the object in the line of sight of the agent (e.g., Apperly & Butterfill, 2009; De Bruin & Newen, 2012, 2014). We reasoned that such association would be based on the visual perception of both the agent and the object. We hypothesised that if such processes underlie any altercentric interference effect in our experimental design, then any altercentric interference effect should only be observed when both the agent and the object are visible from the participant's view. In order to test this hypothesis, participants performed two different versions of the belief task. In one version, the agent and the object in his line of sight were visible to participants at the critical point in time when associations should be stored (when the object reached the last location before the agent's exit of the scene). In another version, the object was not visible but its position could be inferred from an indirect cue (sound). The first version allowed a direct visual association between the agent and the potential content of the agent's belief to be formed while the second version did not.

Third, we aimed to extend the understanding of the association between self-reported empathic skills and belief processing by testing associations between performance in the new belief task used in the current study and different self-reported measures of empathy (global measure vs. measure of the distinct components of this construct). Participants filled in the Empathy Quotient (EQ; Baron-Cohen & Wheelwright, 2004), a global measure of empathy, and the Interpersonal Reactivity Index (IRI; Davis, 1983) that consists of four scales assessing distinct components of empathy: the perspective taking scale ‘‘assesses the tendency to spontaneously adopt the psychological point of view of others”, the fantasy scale ‘‘taps respondent’s tendency to transpose themselves imaginatively into the feelings and actions of fictitious characters in books, movies, and plays”, the empathic concern scale ‘‘assesses other-oriented feelings of sympathy and concern for unfortunate others” and the personal distress scale ‘‘measures self-oriented feelings of personal anxiety and unease in tense interpersonal settings” (Davis, 1983). Ferguson et al. (2015) showed an association between the EQ and the spontaneous computation of another person’s belief in a passive reading task. In the current study, we expected that participants who reported high levels of empathy on the EQ should be more oriented toward others and less oriented toward the self. Accordingly, they should be more prone to altercentric interference, less prone to egocentric interference, and should show a reduced or no advantage for judging the self-compared to the other-belief. Furthermore, we expected that performance should be associated with the score on the perspective taking scale of the IRI as our task required the representation of other’s beliefs (i.e., other’s cognitive perspectives).

2. Methods

2.1. Participants

Forty-two healthy young adults (27 females; 39 right-handed; mean age = 22, SD = 2.5, range: 19–30) took part in the experiment. They were recruited by an advert posted on the Facebook page of a pool of volunteers at the Université catholique de Louvain (Belgium). They received a monetary compensation for their participation. All participants had normal or corrected-to-normal vision and hearing. They gave their written informed consent prior to the experiment. The present study was approved by the local ethical committee under the reference Projet2012-27.

2.2. Design

We designed a task in which participants were presented with belief scenarios and were asked to alternately judge their own belief (self-trials) and someone else's belief (other-trials). The belief scenarios were presented as animated videos involving the transfer of a ball in the presence or absence of a human avatar. Two variables were manipulated within the videos: the consistency between the participant's belief and the avatar's belief (consistent vs. inconsistent) and the visibility of the object from the participant's point of view (visible vs. occluded) (see Fig. 1 for still shots of the videos, see Supplementary Materials 1 to 4 for the videos). In the consistent-belief condition, the avatar witnessed the location transfer so that his belief about the ball's location was consistent with the participants' belief (equivalent to a true-belief condition). In the inconsistent-belief condition, the avatar left the room before the location transfer so that he did not witness the transfer and his belief was inconsistent with the participants' belief (equivalent to a false-belief condition). In the occluded condition, a large opaque screen appeared in front of the two possible locations and the space in which the ball could move so that the participants could not see the location transfer, the location of the ball last seen by the agent nor the final location of the ball. The participants could however infer these events based on the initial ball location and the rolling sound produced by the ball during its transfer. In the visible condition, the large screen was transparent, which allowed the participants to see both the agent and the object at the critical time point (i.e., when the association between the agent, the object and its location could be stored).

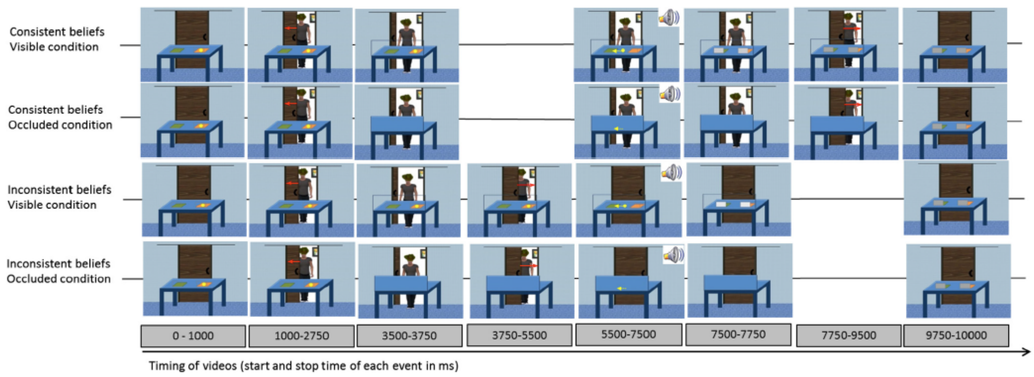

Fig. 1. Screenshots showing the sequence and the timing of the events as a function of the consistency between the participants' own belief and the agent's belief (consistent vs. inconsistent) and the visibility of the critical events (visible vs. occluded). The lines show sections of videos during which there was any change in scene, so that the timing was matched between the consistent and the inconsistent conditions. The arrows indicate when the door was opening/closing in videos and when the ball moved in videos, the sound icon indicates the time at which participants heard the ball rolling.

2.3. Stimuli

Eight experimental videos (2 belief consistency conditions / 2 visibility conditions / 2 initial ball locations) were created. They depicted a room with a door on the back wall and a table that stood in the centre. Two coloured squares on the table marked two locations for the ball (green on the left and orange on the right). Videos began with the ball in one location and a human avatar who entered through the door. The large screen, either transparent or opaque, appeared and then the location transfer occurred. The transfer was always associated with a rolling sound. After the transfer, two small opaque screens occluded the two marked locations on the table and then the large screen disappeared. Small screens were used to ensure that the final point at which participants learnt about object location was matched across the visible and occluded conditions. In order to make videos less regular and hence force the participants to watch them in their entirety, twelve filler videos were created. They displayed the ball without transfer (n = 4), two transfers in the agent's presence (n = 4), or one transfer in the agent's presence and one transfer in his absence (n = 4). All videos were created with the animation options of PowerPoint (Microsoft Office, suite 2013). The social agent was a male human avatar created by using the software Poser 9 (version 1.0.1, Smith Micro). His eyes were masked by a hat in order to avoid any possible misleading cueing about the object's location. Participants viewed the videos on a screen positioned at a distance of 60 cm. The width and the height of videos were respectively 25.8 L and 19.1L.

The cues that indicated to the participants which belief had to be tracked were the words VOUS (YOU in English) and LUI (HE in English). They were presented on the centre of the computer screen. The picture that participants had to judge depicted the ball at one of the two locations with a reminder of the cue and a question mark inviting the participant to respond.

2.4. Procedure

Before performing the computerised task in the lab, participants were asked to fill out the IRI (Davis, 1983; adapted in French by Guttman & Laporte, 2000) and the EQ (Baron-Cohen & Wheelwright, 2004, adapted in French by Berthoz, Wessa, Kedia, Wicker, & Grèzes, 2008) via online forms at the time they registered for the experiment. The EQ is made up of 60 items (40 experimental and 20 filler items) that participants rated on a 4-level Likert scale. The IRI consists of four scales of 7 items that participants had to rate on a 5-level Likert scale.

The belief task was performed in the lab and included a total of 176 trials. Thirty-two experimental trials were created by pairing each experimental video (n = 8) with each cue (HE vs. YOU) and each picture probe (matching vs. mismatching the content of the target belief). Each of these experimental trials was presented four times, leading to a total of 128 experimental trials. In addition, 48 filler trials were created by combining filler videos with cues and picture probes so that all variables were balanced in the whole experiment. Filler trials were presented once and hence represented 27% of all trials. Due to the duration of the task (about 80 min), participants performed the two visibility conditions in two separate sessions. The condition order was counterbalanced across participants. For each visibility condition, trials were presented in four blocks, each made up of 16 experimental trials (2 initial locations 2 consistency conditions 2 target beliefs 2 picture probes) and 6 filler trials. Within sessions, blocks were presented according to a Latin-Square. Within blocks, trials were presented in a random order.

Each trial started with a fixation cross (1000 ms), a cue (1000 ms), a blank screen (500 ms), a video (10000 ms), a second blank screen (500 ms) and a picture probe that remained on the screen until the participant's response or when 2000 ms elapsed. Participants were asked to judge as quickly and as accurately as possible whether the picture matched the target belief content. Half of the participants responded by pressing the up arrow on a computer keyboard for yes and the down arrow for no, and the other half responded yes/no using the reversed arrow keys. Psychopy 1.78.00 (Peirce, 2007) was used for stimuli presentation and performance recording.

In each session, participants were familiarized with the videos. They were told that the ball would move once, twice or not move at all and that any transfer would be audible. A demonstration video displaying two transfers was shown. For the visible condition, participants were informed that a large transparent screen would appear in front of the table and that it would not prevent them from seeing the events; for the occluded condition, they were informed that a large opaque screen would prevent them from seeing the transfer but that the sound would allow them to know when a transfer is occurring. A demonstration video was shown for each condition. Finally, participants were told that a man, introduced as Luc, would enter and leave the room and that he would see and hear the transfer when he is in the room. A demonstration video with one transfer in Luc's presence was shown for each visibility condition. To ensure that participants understood that Luc could see the transfer even when the large opaque screen was used, a second demonstration video was shown in each visibility condition with a camera showing Luc's view (Luc was seen from his back). Next, they were given instructions about the task, performed a practice block of seven trials with feedback on the accuracy for each response and then performed the four experimental blocks with a feedback about the overall accuracy at the end of each block. At the end of each session, participants performed the visual perspective task developed by Samson, Apperly, Braithwaite, Andrews, and Bodley Scott (2010) in order to address issues that are beyond the scope of this paper.

2.5. Statistical analyses

We excluded RTs associated with an error and RTs outside the range delimited by ±3 SD around the individual means. The maximum percentage of outlier RTs across participants was 4.7% (M = 1.4, SD = 1.2). We next computed the inverse efficiency score (IES) for the experimental trials requiring a YES response (i.e., with a picture probe matching the content of the target belief) by dividing the mean RT (expressed in ms) by the proportion of correct responses (expressed by a decimal number between 0 and 1) per participant and per condition.

In order to test any altercentric interference effect, its asymmetry with the egocentric interference effect and its modulation by low-level associative processes, a 2 2 2 2 mixed ANOVA was conducted on IES with the target belief (self vs. other), the belief consistency (consistent vs. inconsistent) and the visibility condition (visible vs. occluded) as repeated factors and the condition order (visible first vs. occluded first) as a between-participant factor. According to the hypotheses that adults process other people's belief even when priority can be given to the self, that such processing relies on low-level associative process and that it is nevertheless easier to give priority to the self than to the other in competing situation, we expected a significant three-way interaction between the target belief, the belief consistency and the visibility condition. The condition order was introduced in the analysis in order to test any carry-over effect from one visibility condition to the other.

In order to test inter-correlations between performance in the belief task and the self-reported measures of empathy, we computed three individual scores from the performance in the belief task (without distinguishing the visibility condition): (1) egocentric interference score = $IES_{\text{other-inconsistent}}$ - $IES_{\text{other-consistent}}$, (2) altercentric interference score = $IES_{\text{self-inconsistent}}$ – $IES_{\text{self-consistent}}$, (3) self-advantage score in situation of competing beliefs = $IES_{\text{other-inconsistent}}$ – $IES_{\text{self-inconsistent}}$. A positive index indicates proneness to egocentric interference, to altercentric interference and to self-advantage on inconsistent trials, respectively. The means were positive for all three scores and the variability was relatively large (see Table S1 in Supplementary Material 5). Furthermore, we computed the total score on the EQ from responses to the 40 experimental items (each item was scored from 0 to 2, maximum score = 80), the score for each subscale of the IRI from responses to 7 items (each item was scored from 0 to 4, maximum score = 28). The total score on the EQ and the four subscales of the IRI showed a reasonable variability and good internal consistency, except for the personal distress subscale from the IRI (see Table S2 in Supplementary Material 5).

3. Results

3.1. Performance in the belief task

The ANOVA on IES showed that the main effects of the visibility condition and of the condition order were not significant, both $Fs < 1$, $p > 0.10$, while the main effects of the target belief and the belief consistency were significant, respectively $F(1, 40) = 13.37$, $p < 0.01$, $g^2_p = 0.25$ and $F(1, 40) = 25.56$, $p < 0.01$, $g^2_p = 0.39$. These effects were qualified by significant two-way interactions: (1) the interaction between the visibility condition and the condition order, $F(1, 40) = 8.41$, $p < 0.01$, $g^2_p = 0.17$, and (2) the interaction between the target belief and the belief consistency, $F(1, 40) = 6.51$, $p = 0.02$, $g^2_p = 0.14$ (see Fig. 2). Importantly, the three-way interaction between the target belief, the belief consistency and the visibility condition was not significant, $F(1, 40) = 2.54$, $p > 0.10$. None of the other interactions was significant, all $Fs < 2.60$, $ps > 0.10$, except for the marginal three-way interaction between the visibility condition, the condition order and the belief consistency, $F(1, 40) = 3.84$, $p = 0.06$, $g^2_p = 0.09$.

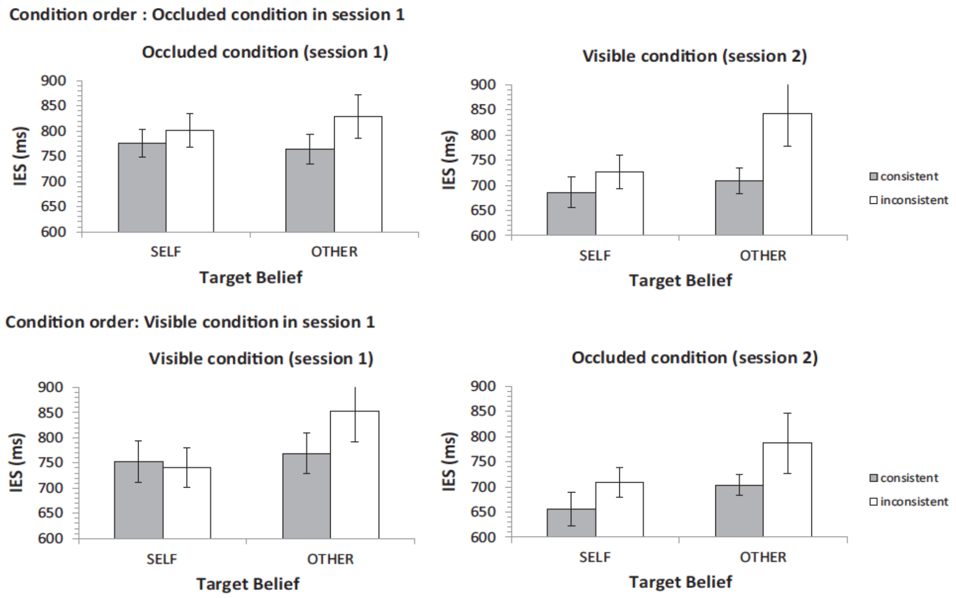

Fig. 2. IES according to the condition order (occluded condition first vs. visible condition first), the visibility condition (occluded vs. visible), the target belief (self vs. other) and the belief consistency (consistent vs. inconsistent). Error bars represent 95% confidence intervals corrected according to Cousineau (2005)'s method.

Post-hoc ANOVAs were carried out to explain the significant interactions. The significant interaction between the target belief and the belief consistency was first explained by the fact that performance was poorer in the inconsistent condition than in the consistent condition for both the other-trials, $F(1, 40) = 17.50$, $p < 0.01$, $g^2_p = 0.30$, and the self-trials, $F(1, 40) = 6.27$, $p = 0.02$, $g^2_p = 0.14$, with a larger consistency effect for the other-trials (mean difference = 91 ms) than for the self-trials (mean difference = 27 ms), $t(41) = 2.58$, $p = 0.01$. This indicates that participants suffered interference from the avatar's belief on the self- trials and that this altercentric interference effect was smaller than the egocentric interference effect shown in the other-trials. The interaction could also be explained by the fact that the effect of the target belief depended on the belief consistency: Performance did not differ significantly between other- and self-trials when beliefs were consistent, $F(1, 40) = 2.41$, $p > 0.10$, while performance was poorer for other-trials compared to self-trials when beliefs were inconsistent, $F(1, 40) = 12.39$, $p < 0.01$, $g^2_p = 0.24$. This indicates equal efficiency to judge the self- versus the other-belief when faced with consistent beliefs and an advantage for judging the self when faced with competing beliefs.

The two-way interaction between the visibility condition and the condition order tended to depend on the belief consistency as indicated by the marginal three-way interaction between the visibility condition, the condition order and the belief consistency. The two-way interaction was indeed significant only for the consistent trials, $F(1, 40) = 18.21$, $p < 0.001$, $g^2_p = 0.313$, and was explained by improvement across sessions. Participants who started with the occluded condition performed better in the visible condition (M = 698 ms, SD = 168) than in the occluded condition (M = 770 ms, SD = 187), $F(1, 20) = 5.97$, $p = 0.02$, while participants who performed the visible condition first performed better in the occluded condition (M = 680 ms, SD = 160) than in the visible condition (M = 761 ms, SD = 169), $F(1, 20) = 15.77$, $p < 0.01$. This suggests that the interaction between the visibility condition and the condition order was driven by general improvement across testing sessions, rather than a carry-over effect specifically driven by one of the visibility conditions. Performance on the inconsistent trials did not improve across sessions (two-way interaction: $F(1, 40) = 2.41$, $p > 0.10$), maybe because the cost of dealing with conflicting beliefs could not be reduced with practice. We also tested whether the belief consistency effect was modulated by the visibility condition and the condition order. This was not the case. The additional ANOVAs with the belief consistency and the visibility condition as repeated factors showed that the main effect of the belief consistency was significant under both condition orders, $F (1, 20) = 17.15$, $p < 0.01$, $g^2_p = 0.46$ and $F(1, 20) = 9.30$, $p < 0.01$, $g^2_p = 0.32$, while the interaction between belief consistency and the visibility condition failed to reach the significance level, $F(1, 20) = 3.11$, $p = 0.09$ and $F(1, 20) = 1.19$, $p > 0.10$.

In sum, altercentric and egocentric interference effects were found, with an asymmetry in favour of the egocentric interference effect. On consistent trials, participants performed equally well on self- and other-trials while on inconsistent trials they showed an advantage for judging the self-trials. Furthermore, the visibility of the critical events did not significantly affect this pattern. Any significant interaction involving this variable appeared instead to be explained by an improvement across sessions, especially for the consistent trials. Bayesian analyses were carried out using JASP 0.8.0.1 (JASP Team, 2016) in order to quantify the extent to which data support a model without the visibility condition against any model with this variable. We included the Target Belief, the Belief Consistency and their interaction as nuisance variables, meaning that these variables were included in all models (including the null model). The Bayes factor (BF_{01}) represents the degree to which the data are more likely under the model with the nuisance variables and without any effect of the visibility condition. Results showed that data are 7 times more likely under the model without the main effect of the visibility condition, $BF_{01} = 7.024$, supporting an absence of main effect of this variable. Including any interaction involving the visibility condition in addition to its main effect led to BF_{01} whose value was even higher (see Table 1). In other words, data were more likely under a model that did not include any effect of the visibility condition.

Table 1
Bayesian ANOVA table.

Models	P(M)	P(M|data)	BF_M	BF_{01}	error%
Null model (incl. TargetBelief, BeliefConsistency, TargetBelief * BeliefConsistency, subject)	0.167	0.822	23.158	1.000	
Visibility	0.167	0.117	0.663	7.024	5.583
Visibility + Visibility * TargetBelief	0.167	0.034	0.176	24.146	4.218
Visibility + Visibility * BeliefConsistency	0.167	0.018	0.092	45.297	3.555
Visibility + Visibility * TargetBelief + Visibility * BeliefConsistency	0.167	0.006	0.030	138.058	5.212
Visibility + Visibility * TargetBelief + Visibility * BeliefConsistency + Visibility * TargetBelief * BeliefConsistency	0.167	0.002	0.012	356.646	5.778

Note: All models include TargetBelief, BeliefConsistency, TargetBelief * BeliefConsistency, subject.

The RTs and percentage of errors (ERR) results - which are in line with the IES results - are presented in Supplementary Material 5 (see also Supplementary Material 6 for raw data).

3.2. Correlations with self-reported measures of everyday life empathy

We expected that performance in the belief task was associated with the EQ, a unidimensional self-reported measure of empathy in everyday life. More particularly, we expected that participants who reported high levels of empathy should be more prone to altercentric interference, less prone to egocentric interference and should show a reduced or no advantage for judging the self-compared to the other-belief in the belief task. The pattern of correlations confirmed these hypotheses: the respondents who scored highly on the EQ were also the ones who were more sensitive to the altercentric interference, $r(42) = 0.37$, $p = 0.02$, who suffered less from egocentric interference, $r(42) = 0.33$, $p = 0.04$, and who showed less self-advantage on inconsistent trials in the belief task, $r(42) = 0.41$, $p < 0.01$ (see upper row of Fig. 3).

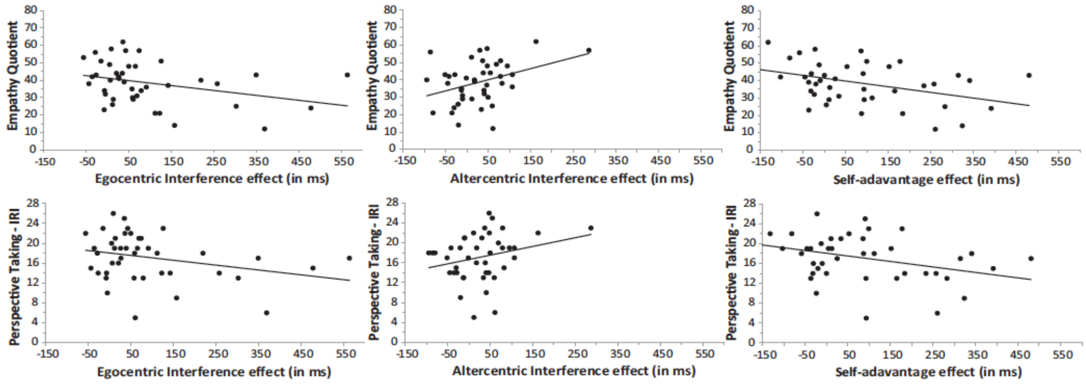

Fig. 3. Correlations between the self-reported measures of empathy and the individual scores in the belief task.

Furthermore, as empathy has been as well theorized as a multidimensional construct, we explored whether distinct components of empathy preferentially correlated with performance in the belief task by using the subscales of the IRI (the perspective taking scale, the fantasy scale, the empathic concern scale and the personal distress scale). As the belief task required the representation of what the other has (and has not) seen, we expected that performance in the belief task should be associated with the score on the perspective taking scale. The pattern of correlations was very similar to the one shown for the EQ (see lower row of Fig. 3) although two of the three correlations failed to reach the significance level. The respondents who scored highly on the perspective taking scale were the ones who showed less self-advantage on inconsistent trials in the belief task, $r(42) = 0.36$, $p < 0.05$, and who tended to suffer less from egocentric interference, $r(42) = 0.29$, $p = 0.06$, and more from altercentric interference, $r(42) = 0.26$, $p = 0.10$. In contrast, no significant correlation was found between the scores on the three other scales and the individual scores in the belief task (all ps > 0.05). Two of them were marginally significant: the correlation between the empathic concern scores and the altercentric interference scores, r(42) = 0.29, p = 0.07, and the correlation between the personal distress scores and the egocentric interference scores, r(42) = 0.26, p = 0.10[1].

In sum, high scores on the EQ and on the perspective taking scale of the IRI were associated with more other-oriented processing and/or less self-oriented processing in the belief task. Amongst the four subscales of the IRI, the perspective taking scale is the only to show a significant correlation with the belief task.

4. Discussion

The present study investigated efficient other-belief processing. We showed that adults track other people's beliefs even when they are instructed to prioritise their own belief and even when information that could boost low-level associations to represent and store belief-like states are not available. Such processing is associated with a global self-reported measure of empathic skills in everyday life and a self-reported measure of one specific empathic skill in everyday life, the perspective-taking ability. We discuss the implications of these findings here below.

4.1. Adults track other people' s beliefs when they have to prioritise their own belief

We demonstrated that performance on self-trials was affected by another person's belief even when the participants knew in advance that they had to judge their own belief. This extends the evidence of altercentric interference that has been previously shown when both self- and other-beliefs were made relevant to compute online because no priority could be assigned before belief-computation (Schuwerk, Döhnel et al., 2014). Furthermore, the finding of altercentric interference in the

[1] This last trend indicates that participants who scored high on the personal distress scale tended to be more egocentric in the belief task, maybe because this scale measures ''self-oriented processing" (Davis, 1980).

present study extends the finding reported by Schneider et al. (2014) that implicit belief tracking is not hindered by the instruction to track reality (i.e., object's location). Indeed, we have shown here that the processing of the irrelevant other-belief is not hindered by the instruction to process the self-belief either. Nevertheless, the altercentric interference effect was smaller than the egocentric interference effect in the present experiment. In combination with the result that participants judged as efficiently the agent's belief as their own belief in the absence of competition (consistent condition), this reduced altercentric interference effect suggests that it is easier to give priority to self-related information and to ignore other-related information than the reverse in a situation of competition. Schuwerk, Döhnel et al. (2014) did not report this self-advantage in situation of conflict probably because, in their study, no priority was given before belief computation. Altogether, these results are consistent with the hypothesis that the relative efficiency of the self vs. the other-belief processing depends on situational factors.

The self-advantage shown in a situation of competing beliefs in the present study fits nicely with the studies showing spontaneous trends to prioritise self-related information (e.g., Sui & Humphreys, 2015) and the recent empirical evidence of greater efficiency to process self-belief compare to other-belief (Bradford, Jentzsch, & Gomez, 2015). We are nevertheless cautious in making direct associations between these results and the present pattern of performance because in Bradford et al.'s study, adult participants were asked to ascribe beliefs about the content of a box (similarly to the smarties task originally developed by Perner, Leekham, & Wimmer, 1987). In such a task, the content of beliefs had to be inferred from the box's appearance. The nature of the computation could thus be very different from the one required by the task used in the present study (inferring beliefs about the location of an object from what the social agent has seen in the box).

4.2. Adults track other people's beliefs even when visual associations are impeded

It has been proposed that implicit belief tracking could be explained by the registration of low-level associations between the social agent and the object (e.g., Apperly & Butterfill, 2009; De Bruin & Newen, 2012, 2014). We tested whether such associative processes were essential for the processing of the irrelevant other-belief in the current study. Participants performed two different versions of the belief reasoning task: one in which the object was visible from the participant's view and one in which it was occluded and its location had to be inferred from indirect cues (the sound of a transfer). Results showed that the visibility of the critical events did not affect the extent to which participants kept tracking the agent's belief. This indicates that the processing of the irrelevant other-belief was not determined by low-level visual associative processes in the present study. This also let open issue as to whether and how the processing of the other person's belief differed in the implicit context (e.g., on the self-trials, when it was irrelevant) compared to in the explicit context (e.g., on the other-trials, when it was relevant). It is important to note that the altercentric effect we evidenced was measured on trials where participants were informed in advance to judge their own belief, the agent's belief being not relevant on those particular trials but nevertheless relevant on other-trials of the task. This task setting probably triggered a form of belief processing that is somewhere in the middle of a continuum between the most extreme form of implicit belief processing (such as the one that likely occurred in the implicit belief-tracking designs used by Kovács et al., 2010; Schneider et al., 2012; Van der Wel et al., 2014) and the most extreme form of explicit belief processing (such as the one that likely occurred on other-belief trials). This means that low-level associative processes may have an impact on the most extreme form of implicit context. This is something worth examining in future research.

4.3. Performance in the belief task relates to self-reported measures of empathy

Significant correlations were found between self-reported measures of empathy and performance in the belief task, providing evidence for the ecological validity of our computerised belief paradigm. High scores on the EQ were associated with less self-oriented processing (in particular, less proneness to egocentric interference and to self-advantage in situation of competing beliefs) and more other-oriented processing (in particular, greater proneness to altercentric interference) in the belief task. A similar pattern of correlations was shown for the perspective taking sub-scale of the IRI. This subscale showed the clearest pattern of associations with performance in the belief task amongst all subscales of the IRI, suggesting an association between the perspective taking ability assessed by this scale and the ability to orient attention toward the other person and take his/her visual/cognitive perspective in the belief task. These results replicate the results that EQ is associated with efficient processing of other people's belief about an object location (Ferguson et al., 2015) and extend them by showing a preferential correlation with the perspective taking sub-scale, which is an assessment of cognitive empathy. Given the size of our sample, correlational analyses should be interpreted with caution and these results should be replicated on a larger sample size. Nonetheless, these findings suggest that investigating inter-individual differences in relation to the efficiency of mentalising is a promising avenue of research.

5. Conclusions

The present study has highlighted that, in a context that enhances the self-other distinction, adults process other people's beliefs even when they can prioritise their own belief at the time of computation. This indicates that the form of belief processing that takes place in such a context operates despite instructions directing attention away from the other person, providing new insights into the ubiquity of efficient belief processing. Furthermore, this implicit belief processing has been shown even when direct visual associations between the belief holder and the belief content are impeded, indicating that implicit belief processing cannot be exclusively explained by low-level associations. The present study also underlines that computerised tasks performed in the lab have some ecological validity, as indicated by the significant correlations between performance on the experimental belief task and self-reported measures of everyday life empathy. This also suggests that these tasks may be utilised to identify specific deficits in clinical populations who suffer from social cognitive disorders. Finally, the present study supports a dynamic view according to which belief processing varies according to situational and dispositional factors.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2017. 06.012.

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