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Evidence that altercentric biases in a continuous false belief task depend on highlighting the agent's belief

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A B S T R A C T

As social beings, we excel at understanding what other people think or believe. We even seem to be influenced by the belief of others in situations where it is irrelevant to our current tasks. Such *altercentric* interference has been proposed to reflect implicit belief processing. However, in which situations altercentric interference occurs and to what extent it is automatic or dependent on the relevance of the belief in context are open questions. To investigate this, we developed a novel task testing whether participants show an altercentric bias when searching for an object in a continuous search space (a 'sandbox'). Critically, another agent is present that holds either a true or a false belief about the object location, depending on condition. We predicted that participants' search for the object would deviate from its actual location in direction of where the agent believed the object to be. Further, we tested how this altercentric bias would interact with an *explicit* belief reasoning version of the task, where participants are asked where the agent would look for the object. In two large, preregistered studies ($N = 113$ and $N = 157$), we found evidence for an altercentric bias in participants' object search. Importantly, this bias was only present in participants who conducted the explicit before the implicit task and started the experiment with the false belief condition. These findings indicate that altercentric biases depend on the relevance of the other's belief in the context of the task, suggesting that spontaneous belief processing is not automatic but context dependent.

As social beings, one of our central cognitive abilities is understanding what other people think or believe, referred to as Theory of Mind (ToM) (Premack & Woodruff, 1978). Previous studies found that we do not only deliberately reason about others' perspectives, but also seem to be influenced by their perspective in situations where it is irrelevant to or even disruptive of our current tasks (El Kaddouri, Bardi, de Bremaeker, Brass, & Wiersema, 2020; Freundlieb, Kovács, & Ágnes M.], & Sebanz, N., 2018; Freundlieb, Sebanz, Kovács, & Ágnes, 2017; Kovács, Melinda, Téglás, & Endress, 2010; Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010; van der Wel, Sebanz, & Knoblich, 2014; Ward, Ganis, & Bach, 2019). For instance, participants were slower at correctly responding to the number of items in a scene when another person was present who could only see a subset of these items (Marshall, Gollwitzer, & Santos, 2018; Samson et al., 2010). Such *altercentric biases* have not only been observed for incongruent visual perspectives (Freundlieb et al., 2017; Freundlieb et al., 2018; Samson et al., 2010; Ward et al., 2019), but also when someone is present who has a false belief about the items (El Kaddouri et al., 2020; Kovács et al., 2010; van der Wel et al., 2014). These biases have been assumed to occur automatically and outside of voluntary control (Kovács et al., 2010; Samson et al., 2010). It has further been proposed that altercentric biases reflect implicit, automatic ToM processes that may provide a fast and efficient route to understanding others' mental states (Apperly & Butterfill, 2009). However, findings in the context of visual perspective

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taking have challenged whether altercentric biases are indeed automatic or whether they may depend on context (Holland, Shin, & Phillips, 2021), but this is unclear for belief processing. Further, it is unknown how altercentric biases relate to explicit mental state reasoning. Understanding this relation may inform the debate about the nature of these biases and their dependence on explicitly processing the other's mental states. In the present study, we set out to investigate this in the context of reasoning about false beliefs.

False beliefs, as opposed to an agent's visual perspective, do not necessarily reflect reality but are non-factive and thus require the ability to consider mental states independently of reality (Dennett, 1978) and beyond visible cues (such as an agent's line of sight). Hence, understanding others'false beliefs is considered a critical test of ToM (Dennett, 1978). Whether others' false beliefs lead to altercentric biases, and under which circumstances they do so, is therefore important for the question of whether these biases reflect implicit and automatic ToM processes. While the majority of studies reporting altercentric biases found them in the context of visual perspective taking, a few studies have also observed such biases when an agent had a false belief about an object (Kovács et al., 2010; van der Wel et al., 2014). Specifically, Kovács et al. (2010) showed that participants were faster at detecting a ball, surprisingly revealed behind an occluder, when another agent was present who falsely believed that the ball should be behind the occluder. Similarly, when asked to move their mouse cursor to an object, revealed in one of two locations, participants' response trajectories deviated in the direction of where an agent falsely believed the object to be (van der Wel et al., 2014). These studies were taken as evidence that we automatically compute others' beliefs, even in situations where their belief is entirely irrelevant to our current tasks (Kovács et al., 2010). This interpretation was questioned by a series of studies suggesting that the effect resulted from attentional processes specific to the task design (Phillips et al., 2015), but this suggestion was not confirmed by a follow-up study (El Kaddouri et al., 2020). Together with recent null-findings in implicit ToM paradigms (Haskaraca, Proft, Liszkowski, & Rakoczy, 2023; Poulin-Dubois et al., 2018), this raises the question how robust altercentric biases stemming from belief processing are, including new experimental scenarios. Here, we therefore developed a new task to test whether altercentric biases are also observed in a completely different setting, not in participants' reaction times, but in their search location for an object buried in the ground.

A further open question is to what extent altercentric biases occur fully automatically, independent of the relevance of the other agent, or their belief, for the task. Originally, these biases were proposed to be automatic and triggered by the mere presence of an agent, even if the agent was entirely irrelevant to participants' task (Kovács et al., 2010). In the context of visual perspective taking, however, recent studies indicate that altercentric biases may depend on contextual factors, such as participants' intention and attention, guided by task instructions or properties of the agent (Holland et al., 2021). For example, when controlling for lower-level explanations, such as directional cueing, altercentric biases only occurred when participants' attention was directed to the agent's visual perspective beforehand (Conway, Lee, Ojaghi, Catmur, & Bird, 2017; Holland et al., 2021; O'Grady, Scott-Phillips, Lavelle, & Smith, 2020). This raises the question of whether, in the critical case of false belief understanding, altercentric biases indeed occur automatically, independent of the relevance of the agent for the task (as argued by Kovács et al. (2010)), or rely on highlighting the agent's belief.

A related question is whether altercentric biases depend on, and interact with, explicit processing of an agent's belief. The relation between altercentric biases (or more generally implicit or spontaneous forms of mental state processing) and explicit mental state attribution has been a matter of intense debate. While some researchers have argued that the same core ToM processes are used when a person spontaneously or explicitly processes an agent's belief (Leslie, 2005; Onishi & Baillargeon, 2005), others have proposed that implicit and explicit belief processing rely on different systems (Apperly & Butterfill, 2009; Grosse Wiesmann, Friederici, Singer, & Steinbeis, 2020; Grosse Wiesmann, Schreiber, Singer, Steinbeis, & Friederici, 2017). Specifically, implicit ToM was proposed to constitute a fast and efficient system whereas explicit ToM is more flexible but cognitively effortful (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013). A distinct developmental trajectory, as well as behavioral and neural dissociations between implicit and explicit ToM tasks, support this proposal (Clements & Perner, 1994; Grosse Wiesmann et al., 2020; Grosse Wiesmann, Friederici, Singer, & Steinbeis, 2017; Grosse Wiesmann, Schreiber, et al., 2017). Although these studies suggest that implicit and explicit ToM tasks measure different processes, it is an open question whether and how these processes interact. Further, previous studies on the relation of implicit and explicit ToM focused on non-verbal action prediction as measure of implicit ToM, but the question has not been addressed for altercentric biases. Yet, the question is particularly relevant for this case as altercentric biases occur in situations where the attention is on a different task and not on the agent's mental states, highlighting the question of whether these mental states need to be processed explicitly for the bias to occur.

Inspired by Bernstein, Thornton, and Sommerville (2011), we presented participants with videos of agents hiding objects in a continuous search area, for example, in the sand. In the agent's absence, the participant watched the object being moved to a different location in the sand. In the original task, by Bernstein et al. (2011), participants were asked where the agent would search for the object, as in a classic explicit false belief task. Interestingly, participants responses systematically deviated toward the actual object location, that is, they displayed an egocentric bias (Bernstein et al., 2011; Sommerville, Bernstein, & Meltzoff, 2013), although this effect was not replicated in a recent study (Haskaraca et al., 2023). Here, we adapted this task to incorporate an implicit version. The implicit ToM task was exactly the same as the explicit task, except that, in the end, participants were asked where the object was, instead of where the agent would search for it. Based on previous altercentric findings, we predicted that participants' search locations would now deviate toward where the agent falsely believed the object to be. That is, they would manifest an altercentric bias in their search location. To assess potential influences of explicit belief processing on such an implicit manifestation of belief processing, the two versions of the sandbox task were presented in counterbalanced order across participants.

In the implicit task, we hypothesized an altercentric bias when participants searched for the object. In the explicit task, in which participants reported where the agent would search, we expected to replicate the previously reported egocentric bias (Bernstein et al., 2011; Sommerville et al., 2013). Since an egocentric bias impedes the ability to reason about other people's beliefs, it has been interpreted as a negative measure of explicit belief reasoning (Sommerville et al., 2013). We thus predicted that, if altercentric biases were related to explicit belief reasoning, we would find a negative correlation between the altercentric and the egocentric biases. Further, if altercentric biases depend on, or are enhanced by, explicit belief processing, conducting the explicit ToM task first, may impact the altercentric bias in the subsequent implicit version of the task.

1. Experiment 1

1.1. Material & methods

This study was pre-registered at AsPredicted (https://aspredicted.org/AIP_UVS) and all analyses were conducted according to this preregistration unless explicitly stated otherwise.

1.1.1. Participants

A total sample of $N = 113$ adults (resulted from a Bayesian sequential testing scheme, details see Section 1.1.5.1) were included in the present study (Mean (M) = 28.44 years, median = 25, range = 19.0–65.0, 72 female). Six additional participants were excluded due to technical errors. From the total sample of N = 113, N = 16 participants were excluded from the implicit task analyses and N = 19 from the explicit task analyses due to non-meaningful task compliance (see Section 1.1.4). Thus, the final sample for the implicit task consisted of N = 97 adults (from which 48 started with the implicit task and 49 with the explicit task) and N = 94 adults for the explicit task (from which 40 started with the implicit task and 54 with the explicit task). The study was conducted online and approved by the local ethics committee. Participants were recruited from an internal database via email. Participants provided informed consent by button press and were compensated monetarily for their time (3,50€ for participation and an additional 2€ if they answered correctly at least 75 % of the time).

1.1.2. Materials

The task was based on the paper and pencil version of the Sandbox task from Coburn, Bernstein, and Begeer (2015). An online version was built and recorded with the platform Labvanced (Finger, Goeke, Diekamp, Standvoß, & König, 2017). Participants were presented with four different videos, each featuring a change of location scenario (a squirrel hiding a nut, a boy hiding a sieve, a girl hiding a ball, and a seagull hiding a twig) as described in more detail in Section 1.1.3.

1.1.3. Experimental design

In each trial, participants saw a video in which an agent buried an object at location 1, which was then blown to location 2 by the wind (see Fig. 1). In false belief (FB) trials, the agent turned away from the scene before the wind relocated the object and thus did not see the location change. In true belief (TB) trials, the agent faced the scene and thus observed the location change. The wind was chosen to relocate the object in order to avoid introducing a second agent (or agent-like self-propelled movements) as their belief may also have elicited a bias counteracting the bias from the primary agent. At the end of each video the participants needed to respond to a test question. In the implicit task, participants were asked, "Where is the object?" and thus needed to indicate where the object was by mouse click. In the explicit task the test question was, "Where will the agent search?". Here, participants had to reason about the agent's belief, rather than base their answer on their own knowledge of the object location. A 20-s distractor task was displayed between the location change video and the test question. Then, participants were asked to search for and click a six-pointed star amongst five-pointed stars as fast as they could.

There were 4 different pairs of hiding locations (two per scenario). For each pair, once the object was moved from left to right and once from right to left. This led to a total of eight different location changes. The distance between the location pairs was approximately 360 pixels (see Appendix A, Table A.1) and the middle of the screen was always crossed during the relocation. The hiding locations and scenarios were the same in FB and TB trials to allow direct comparability.

The experiment consisted of 16 trials in total, eight trials of the implicit task and eight trials of the explicit task that were presented in separate blocks, in counterbalanced order across participants. Within each task block, there were four false belief and four true belief trials featuring the four different change of location scenarios, also presented in blocks in counterbalanced order across participants. This led to a 2 × 2 within-subject design with the factors task (implicit/explicit) and belief (true/false). We chose a block design to present the tasks and the belief trials to ensure that participants understood the task and did not get confused by having to switch between tasks. Before each task block participants completed two familiarization trials in which the respective task (implicit or explicit) and the distractor task were introduced separately. The sandbox familiarization trials consisted of the same hiding scenario and the same task as in the test trials, but without a change of location to avoid showing any of the experimental conditions beforehand. The total study duration was approximately 20 min.

1.1.4. Data preprocessing

Participants responded via mouse click and response coordinates were recorded with the online platform Labvanced using the in-house *design unit*. This particular unit was utilized because participants completed the study on screens of different sizes and the experiment was always presented in full screen mode. In line with our preregistered criteria, responses that followed any technical errors or that were outside of the hiding terrain (i.e., in the sky) were excluded, as were participants who reported comprehension difficulties. To assess whether any observed biases were driven by small deviations or by "errors", incorrect answers were defined as searches closer to the incorrect than to the correct location.

In the implicit task, participants were asked to point to the location where the object was. The distance to the actual object location, projected to the line directly connecting the actual and the believed object location, was calculated. This distance was defined to be positive when participants deviated from the actual object location in direction of the believed location and negative when they deviated in the other direction. The altercentric bias was then defined as difference between this deviation in the FB trial minus the deviation in its matched control TB

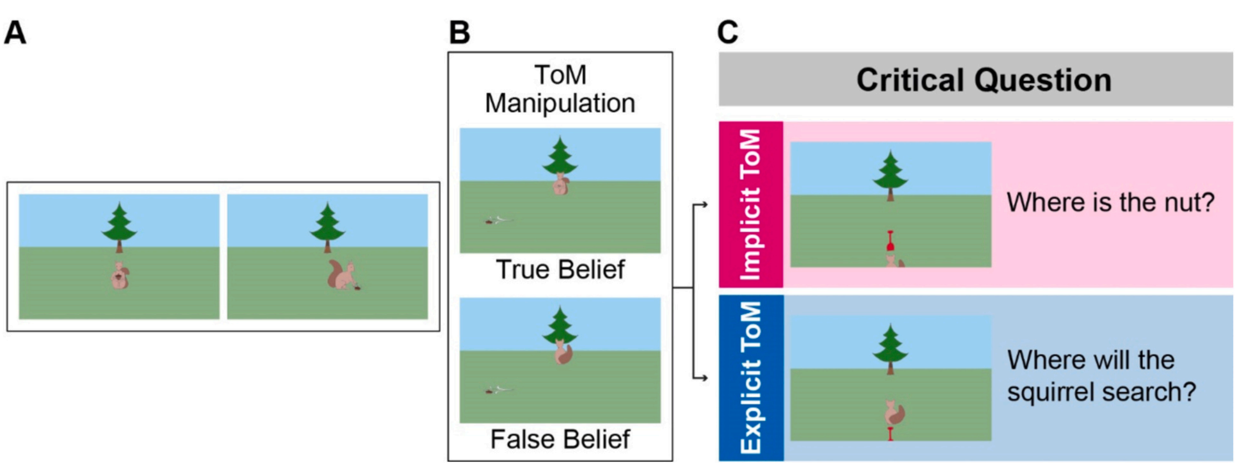

Fig. 1. Example trial and overview of the experimental paradigm.
The squirrel buried a nut at location 1 (A). Then, the nut was blown to location 2 by the wind (B), while the squirrel was watching (B, TB - upper image) or not (B, FB - lower image). At the end of each story participants were asked a test question that depended on the task (C). In the implicit task, they were asked "Where is the nut?" and thus needed to indicate where the object was. In the explicit task, in turn, they were asked: "Where will the squirrel search?" and thus needed to indicate where the squirrel believed the object to be.

trial. Thus, the altercentric bias was positive when participants deviated more in direction of the believed location in the FB than in the TB condition.

In the explicit task, participants were asked to point to the location where the agent believed the object to be. The distance to the believed location projected to the line directly connecting the believed and the actual object location, was calculated. Again, this distance was defined to be positive when participants deviated in the direction of the actual object location and negative if they deviated in the other direction. The egocentric bias was again defined as difference between this deviation in the FB trial and its matched control TB trial. Thus, the egocentric bias was positive, if participants deviated more in direction of the actual object location in the FB than in the TB condition.

The altercentric and egocentric biases were averaged across trials and the subject means were entered in the statistical analyses. Since these means were not normally distributed as indicated by q-q-plots (see Appendix B, Fig. B.1), whenever possible, we used non-parametric equivalents to our planned analyses as pre-registered. Since the ANOVA is fairly robust to violations of the normality assumption (Blanca, Alarcón, Arnau, Bono, & Bendayan, 2017; Schielzeth et al., 2020), we decided to move forward with our original analysis plans in this case (details see Results Section 1.2).

1.1.5. Bayesian framework

We applied Bayesian statistics in all our analyses, which has the advantages of allowing quantification of evidence both for or against a given hypothesis and data collection until the desired level of evidence is reached (Wagenmakers et al., 2018). In Bayesian inference, prior probability distributions need to be specified for all parameters involved. Since there was no a priori information about the effects available, following common practice, we used uninformed priors, so-called *default* priors, in all our analyses (Rouder, Morey, Speckman, & Province, 2012). With these priors, the marginal likelihood given the observed data can be calculated for different models and these models can be contrasted with the Bayes Factor (BF). The BF_{10} sets the evidence for the alternate model (denoted with subscript 1) in contrast to the evidence for the null model (denoted with subscript 0). For instance, a BF_{10} of 3 means that the data were three times more likely under the alternate model than under the null model. Although the BF assesses evidence on a continuous scale, there is a widely accepted classification scheme: Evidence for the alternate model is considered anecdotal for a BF_{10} between 1 and 3, moderate for a BF_{10} between 3 and 10, strong for a BF_{10} greater than 10, very strong for a BF_{10} greater than 30, and extreme for a BF_{10} greater than 100. Conversely, evidence for the null model is considered anecdotal for a BF_{10} between 1 and 1/3, moderate for a BF_{10} between 1/3 and 1/10, strong for a BF_{10} smaller than 1/10, very strong for a BF_{10} smaller than 1/30, and extreme for a BF_{10} smaller than 1/100. Typically, only Bayes Factors greater than 3 or smaller than 1/3 are interpreted as evidence. All Bayesian analyses were conducted using JASP version 0.16.0.0 (JASP Team, 2021). Annotated .jasp files, including distribution plots, data, and input options, will be made available at OSF upon acceptance of the manuscript.

1.1.5.1. Sequential testing. With Bayesian Statistics it is possible to apply a sequential testing strategy, i.e., to continue data collection until the desired level of evidence for or against a specific effect of interest is found (K. Mani & Kalpana, 2016; Mani et al., 2021). This has the advantage of ensuring sufficient power in an efficient testing design (Mani et al., 2021). As preregistered, we continued data collection in the present study until the Bayes Factor testing for a positive altercentric bias in the implicit task reached either 3 or 1/3, corresponding to moderate evidence for or against this hypothesis. To control for false positives and negatives, a minimum of 60 participants was collected. This minimal number was determined by means of power simulations using the R packages 'Superpower' version 0.1.0 (Lakens & Caldwell, 2021) and 'BayesFactor' version 0.9.12–4.2 (Morey & Rouder, 2015) assuming an effect size of 0.3 (Cohen's d) with a standard variation of 0.1.

This sequential testing strategy led to $N = 97$ participants for the implicit task. The stopping criterion was already reached after 62 participants, but due to the email recruitment and automated online testing, the data collection could not be stopped immediately, so that data from 35 additional participants was collected. Here, we report the data of the full sample as the data without the additional participants yields similar results (see Appendix C). Fig. 2 illustrates the development of the Bayes Factor with increasing number of participants.

1.2. Results

1.2.1. Implicit task

To test whether there was a positive altercentric bias in the implicit task we performed a directed Bayesian one sample Wilcoxon signed rank test >0, which also served as the stopping criterion for the sequential testing approach. This test yielded moderate evidence for a positive altercentric bias in the entire sample ($BF_{10} = 5.68$, Wilcoxon signed rank test statistic (W) = 2980, Wilcoxon test convergence measure[2] ($\hat{R}$) = 1.00, N = 97, M = 19.02, standard deviation (SD) = 70.37, see Fig. 3A).

To test for effects of task order (implicit or explicit task first) and order of the belief conditions (false or true belief first), we ran a Bayesian ANOVA with the factors task order (implicit first/explicit first) and belief order (TB first/FB first). This analysis yielded moderate evidence against a main effect of belief order ($BF_{10} = 0.22$, error 2.45 %, model including task order and belief order against model including task order only). The Bayes Factors remained inconclusive for the factor task order ($BF_{10} = 0.45$, error 5.58 %, model including task order and belief order against model including belief order only) and the interaction ($BF_{10} = 1.45$, error 1.87 %, full model against model including task order and belief order).

To test for potential effects of task order, we had also pre-registered an analysis that only included data of participants who completed the implicit before the explicit task. In contrast to the entire sample, this analysis remained inconclusive ($BF_{10} = 0.41$, W = 660, $\hat{R} = 1$, $N = 48$, M = 9.76, SD = 66.56). To resolve this contrast, we therefore also analyzed the data of participants who did the implicit task only after the explicit task in addition to our preregistered analysis. As for the entire sample, we found moderate evidence for a positive altercentric bias in this group ($BF_{10} = 7.79$, W = 847, $\hat{R} = 1$, $N = 49$, M = 28.09, SD = 73.46). Thus, there was only evidence for an altercentric bias in participants who conducted the implicit task after they had completed the explicit task (see Fig. 3B).

To follow up on this finding, we exploratorily ran separate post-hoc Bayesian Wilcoxon signed rank tests for the four subgroups that received different task orders (implicit/explicit first and true belief/false belief first respectively, see Fig. 3C). These yielded strong evidence for an altercentric bias only in participants who had done the explicit task before the implicit and who started both tasks with the false belief condition ($BF_{10} = 24.95$, W = 295, $\hat{R} = 1$, $N = 27$, M = 42.83, SD = 68.31). For participants who did the implicit task first and started with the false belief condition, moderate evidence against an altercentric bias was found ($BF_{10} = 0.21$, W = 145, $\hat{R} = 1$, $N = 24$, M = −1.50, SD = 51.75). For the two other groups, the Bayes Factors remained inconclusive (explicit before implicit and true belief before false belief: $BF_{10} = 0.43$, W = 145, $\hat{R} = 1$, $N = 22$, M = 10.00, SD = 77.05, implicit before explicit and true belief before false belief: $BF_{10} = 0.79$, W = 187, $\hat{R} = 1$, N = 24, M = 20.98, SD = 78.18).

[2] This measure is a ratio comparing the between- and within-chain variance of the estimates. Values less than or equal to 1 indicate convergence.

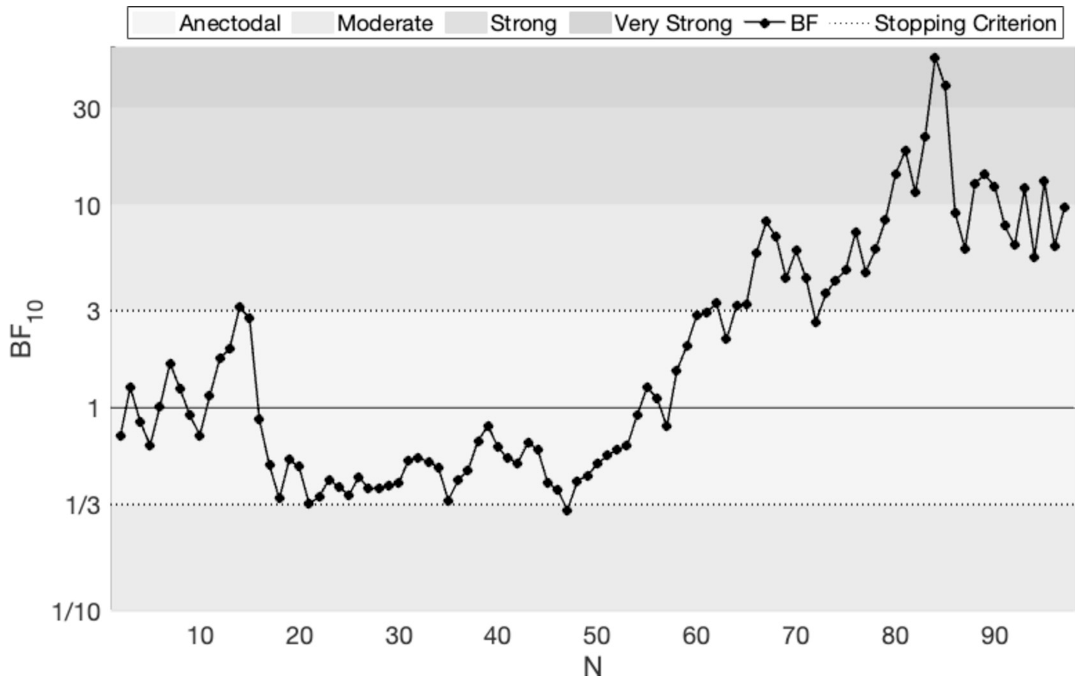

Fig. 2. Results of the sequential testing.
Illustration of the development of the Bayes Factor of a Wilcoxon signed rank test testing for a positive altercentric bias in the implicit task with increasing number of participants. The dotted lines illustrate the stopping criterion, the different stages of evidence for or against an effect are highlighted in different shades of grey.

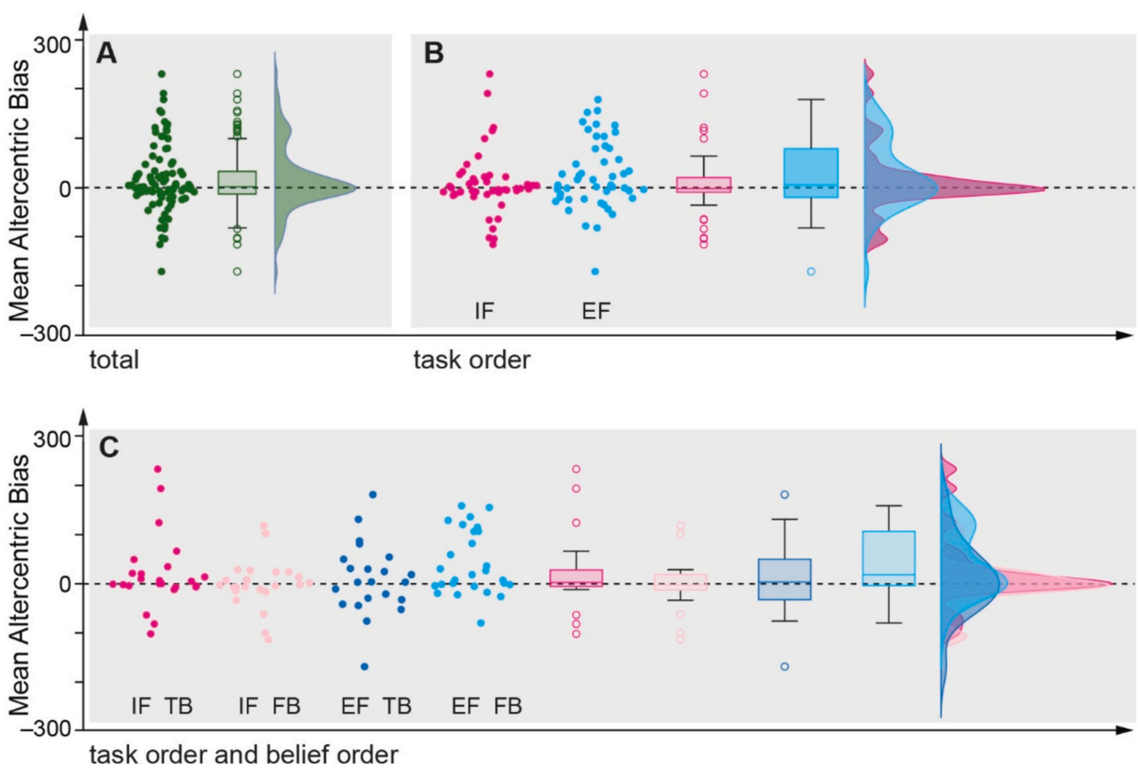

Fig. 3. Experiment 1: Mean altercentric bias in the implicit task.
A. Mean altercentric bias in the implicit task for all participants (green). B. Separated by task order: In pink, participants who did the implicit task before the explicit task (IF = implicit first), in blue, participants who did the explicit task first (EF = explicit first). C. Separated by task order and belief order: In dark pink, participants who did the implicit task before the explicit task and the false belief condition before the true belief condition (IF FB = implicit first and false belief first), in light pink, participants completing the implicit task first and the true belief condition first (IF TB = implicit first and true belief first), in dark blue, explicit task first and the false belief condition first (EF FB = explicit first and false belief first), in light blue, explicit task first and the true belief condition first (EF TB = explicit first and true belief first).

To test whether the observed altercentric bias reflected smaller deviations from the correct object location or was driven by trials in which the participants searched on the wrong side of the search area (i.e., closer to the believed than to the real object location), we repeated the main analyses including only those trials in which participants searched on the correct side of the screen. This yielded evidence against an altercentric bias ($BF_{10} = 0.29$, $W = 2662$, $\hat{R} = 1$, $N = 97$, $M = 1.91$, $SD = 23.96$), which was confirmed in all four subgroups (with inconclusive evidence for the explicit first and false belief first group, details see Appendix D, Table D.1). This suggests that the observed altercentric bias was driven by trials in which participants searched closer to the believed than to the actual object location.

Furthermore, we examined potential gender effects with a Bayesian Mann Whitney *U* Test, which yielded moderate evidence against an effect ($BF_{10} = 0.32$, $W = 1240$, $\hat{R} = 1$, $N_{male} = 36$, $N_{female} = 61$, $M_{male} = 26.21$, $M_{female} = 14.78$, $SD_{male} = 70.44$, $SD_{female} = 70.57$).

Finally, to determine whether there was an effect of the different hiding scenarios, we ran two separate Bayesian repeated measures ANOVAs, one including the factor 'agent' with four levels (i.e., squirrel, seagull, boy, girl) and one including the factor 'location' with four levels (i.e., for each possible location, details locations see Appendix A, Table A.1). This yielded very strong evidence against an effect of agent ($BF_{10} = 0.02$, error = 0.85 %) and strong evidence against an effect of location ($BF_{10} = 0.04$, error = 0.62 %) on the altercentric bias.

1.2.2. Explicit task

To test whether there was a positive egocentric bias in the explicit task, we performed a directed Bayesian one sample Wilcoxon signed rank test >0. This test yielded moderate evidence against a positive egocentric bias ($BF_{10} = 0.17$, $W = 2280$, $\hat{R} = 1$, $M = 5.08$, $SD = 63.20$, see Fig. 4A).

To examine effects of task order and order of belief condition, we conducted an ANOVA with the factors task order (implicit first/explicit first) and belief order (false belief first/true belief first). This yielded moderate evidence against an effect of task order ($BF_{10} = 0.22$, error = 2.74 %, model including belief order and task order against model including only belief order), inconclusive evidence for an effect of the order of belief condition ($BF_{10} = 0.42$, error 2.04 %, model including belief order and task order against model including only task order), and moderate evidence against an interaction between the factors ($BF_{10} = 0.29$, error = 2.89 %, full model against model including only the main effects).

Looking at the data of participants who did the explicit task first and participants who did the implicit task first separately yielded moderate evidence against a positive egocentric bias for both groups (explicit first: $BF_{10} = 0.21$, $W = 745$, $\hat{R} = 1$, $N = 54$, $M = 4.78$, $SD = 52.73$, implicit first: $BF_{10} = 0.25$, $W = 439$, $\hat{R} = 1$, $N = 40$, $M = 5.48$, $SD = 75.79$, see Fig. 4B).

As for the implicit task, in addition to our preregistration, we tested the subgroups depending on the order in which they had seen the conditions (implicit/explicit task first and false belief first/true belief first) with separate Bayesian Wilcoxon signed rank tests. This confirmed moderate evidence against an egocentric bias in both subgroups (implicit and explicit first) that started the task with the true belief condition (implicit first and true belief first: $BF_{10} = 0.23$, $W = 87$, $\hat{R} = 1$, $N = 18$, $M = -5.27$, $SD = 61.67$, explicit first and true belief first: $BF_{10} = 0.16$, $W = 214$, $\hat{R} = 1$, $N = 30$, $M = -1.37$, $SD = 41.47$). Evidence remained inconclusive in the groups that started with the false belief condition (implicit first and false belief first: $BF_{10} = 0.43$, $W = 145$, $\hat{R} = 1$, $N = 22$, $M = 14.27$, $SD = 86.08$, explicit first and false belief first: $BF_{10} = 0.51$, $W = 171$, $\hat{R} = 1$, $N = 24$, $M = 12.46$, $SD = 64.25$, see Fig. 4C).

As before, we repeated our main analyses excluding trials in which participants searched on the wrong side of the screen (i.e., indicated that

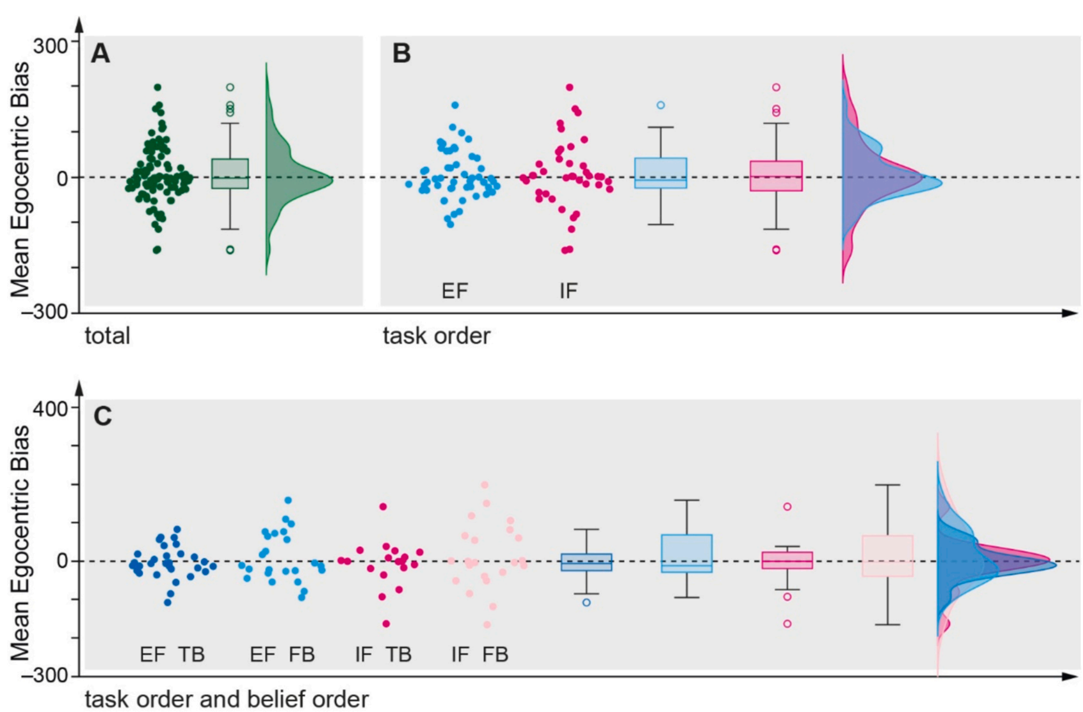

Fig. 4. Experiment 1: Mean egocentric bias in the explicit task.
A. Mean egocentric bias in the explicit task for all participants (green). B. Separated by task order: In blue, participants who did the explicit task before the implicit task EF = explicit first), in pink, participants who did the implicit task first (IF = implicit first). C. Separated by task order and belief order: In dark blue, participants who did the explicit task before the implicit task and the false belief condition before the true belief condition (EF FB), in light blue, participants completing the explicit task first and the true belief condition first (EF TB), in dark pink, implicit task first and the false belief condition first (IF FB), in light pink, implicit task first and the true belief condition first (IF TB).

the agent would search closer to the real object location than where the agent believed the object to be). This confirmed the evidence against an egocentric bias in the entire data set ($BF_{10} = 0.04$, $W = 1641$, $\hat{R} = 1$, $M = -7.56$, $SD = 36.81$) as well as in all groups (with inconclusive evidence in the implicit and true belief first group, details see Appendix D, Table D.2.

There was moderate evidence against an effect of gender (Bayesian Mann Whitney *U* Test: $BF_{10} = 0.23$, $W = 950$, $\hat{R} = 1$, $N_{male} = 30$, $N_{female} = 64$, $M_{male} = 4.14$, $M_{female} = 5.51$, $SD_{male} = 56.87$, $SD_{female} = 66.38$).

Finally, as for the implicit task, we analyzed the effects of the different hiding scenarios with two separate Bayesian repeated measures ANOVAs, one with the factor agent and one with the factor location. These yielded moderate evidence for an effect of agent ($BF_{10} = 3.51$, error = 3.27 %) and moderate evidence against an effect of location ($BF_{10} = 0.32$, error = 1.32 %). Pairwise post-hoc analyses of the different agents against each other showed evidence that the egocentric bias was smaller for the squirrel than for the seagull ($BF_{10} = 4.03$, $W = 1315$, $\hat{R} = 1.02$, $M_{squirrel} = -14.96$, $M_{seagull} = 38.49$, $SD_{squirrel} = 92.30$, $SD_{seagull} = 152.83$). The other pairwise comparisons between the agents yielded evidence against a difference or remained inconclusive (details see Appendix E, Table E.1). To follow-up on this effect, we additionally examined the agents in separate Wilcoxon signed rank tests. This revealed strong evidence against an egocentric bias in trials with the squirrel, the boy, or the girl as agent (squirrel: $BF_{10} = 0.04$, $W = 1475$, $\hat{R} = 1$, $N = 94$, $M = -16.17$, $SD = 91.67$; boy: $BF_{10} = 0.07$, $W = 1967$, $\hat{R} = 1$, $N = 94$, $M = 8.12$, $SD = 99.76$; girl: $BF_{10} = 0.05$, $W = 1725$, $\hat{R} = 1$, $N = 93$, $M = -6.05$, $SD = 102.25$), while evidence remained inconclusive for trials with the seagull as agent ($BF_{10} = 1.41$, $W = 2592$, $\hat{R} = 1$, $N = 93$, $M = 38.14$, $SD = 152.03$).

1.2.3. Relation between the altercentric and the egocentric bias

Finally, a Bayesian correlation analysis between the two biases revealed moderate evidence against a correlation ($BF_{10} = 0.15$, $r = -0.04$).

A repeated measures Bayesian ANOVA with the factors task (implicit/explicit) and belief (FB/TB) showed moderate evidence for an effect of task ($BF_{10} = 8.78$, error = 5.78 %, $N = 78$, model including belief, task and subject against model including only belief and subject) in that participants' biases were greater in the implicit than in the explicit task. Evidence remained inconclusive for the factor belief ($BF_{10} = 1.34$, error = 2.84 %, $N = 78$, model including belief, task, and subject against model including only task and subject) and the interaction of task and belief ($BF_{10} = 1.59$, error = 61.80 %, $N = 78$, full model against model including belief, task and subject).

1.3. Discussion Experiment 1

Experiment 1 provides evidence that participants' search for an object, buried in the sand, was biased by where another person believed the object to be. That is, they systematically deviated from the object's real location in the direction of where another person had last seen the object. This was the case even though the person was irrelevant to the object search task. Similar altercentric biases had previously been observed in participants' reaction times when asked to detect objects that another person either could not see (Freundlieb et al., 2017; Freundlieb et al., 2018; Marshall et al., 2018; Samson et al., 2010; Ward et al., 2019) or had a false belief about (Kovács et al., 2010). These findings have been interpreted as evidence that we automatically process others' mental states, even when these are entirely irrelevant to our tasks. In the present study, however, altercentric biases only occurred when participants had been asked to reason about the agent's belief explicitly in a previous task, that is, in a situation where the agent's belief was relevant in the context of the task. Specifically, in the explicit task, participants were asked to indicate where the agent would search for the object, rather than where the object really was. Previous studies who had used a similar sandbox explicit belief reasoning task had reported that participants were systematically biased by where they knew the object to be (Bernstein et al., 2011; Coburn et al., 2015; Sommerville et al., 2013). Here, however, we did not replicate such an egocentric bias but found evidence against it.

The observed order effect, where only participants who conducted the explicit task before the implicit task showed an altercentric bias in their object search, challenges the interpretations that altercentric biases occur automatically. Previous studies had concluded that humans are influenced by the belief of others, even if they are entirely irrelevant to their task. Our findings, however, suggest that for an altercentric bias to occur the agent's belief needs to be relevant for the context of the task.

Our new continuous measure also allowed us to investigate whether altercentric biases result in small deviations from the actual object location or whether more radical memory errors are introduced, with participants misremembering the object closer to where the other believes it to be than where it really is. Note that remembering the last object location was not an easy task because of the 20 s distractor task between object hiding and search task, where participants had to perform an unrelated visual search task, so that larger memory errors occurred across all conditions. Importantly, however, these larger memory errors (defined as searching closer to the believed than the actual object location) occurred systematically more often in the false belief than the true belief condition, driving the observed altercentric bias. That the memory errors occurred systematically for the false belief and less for the true belief condition suggests that, under high memory load, the presence of another agent with a false belief can cause us to misremember locations where the agent believes the object to be, rather than where it really is. This memory bias could serve as an alternative way of taking other's beliefs into account in situations with high cognitive load, and little capacity for explicit Theory of Mind processes. As such, altercentric memory biases may provide an efficient route to understanding others when time and cognitive resources are constrained.

An alternative explanation for our pattern of findings may be that some participants, who did the explicit belief reasoning task first, got confused and continued doing the explicit task instead of the object search task in the second block, leading them to indicate the completely wrong side of the screen in the false belief trials of the object search task. If this were the case, our altercentric biases would be driven by a few participants with many large memory errors. However, the majority of participants did make memory errors ($N = 26$ of 49 participants made at least one error in either a false or a true belief trial, $N = 21$ participants made at least one error in a false belief trial) and the errors were randomly distributed over the false belief trials (see Appendix F, Fig. F.1). Further, none of the included participants chose the wrong location in more than 2 of the 4 false belief trials. Finally, we used a block design with extensive instructions and practice trials before the implicit block to facilitate task comprehension. Our false and true belief trials were closely matched, with the agent present in both conditions and similar highlighting of the object relocation by ostensive verbal narration, ensuring that participants would not have missed the relocation. These reasons make it unlikely that participants did not understand the task instructions.

Nevertheless, to confirm that the observed memory errors and order effects truly reflected an altercentric bias and did not result from misunderstanding or mixing up the task instructions, we sought to replicate the findings from Experiment 1 in a second experiment. In this experiment, we added task comprehension questions at the beginning of each block to ensure that participants had indeed understood and were doing the new task.

2. Experiment 2

2.1. Material & methods

The procedures in Experiment 2 were exactly the same as in Experiment 1, except for an additional comprehension question at the beginning of the explicit task block and the implicit task block to verify that participants understood the task instructions correctly. Here, we therefore only describe what differed from Experiment 1. Experiment 2 was pre-registered at AsPredicted (https://aspredicted.org/789_DV4).

2.1.1. Participants

A total sample of N = 157 adults (resulting from a Bayesian sequential testing scheme, details see Section 1.6.1) were included in the present study (Mean (M) = 37.86 years, median = 36, range = 20–74, 97 female). N = 22 participants were excluded due to technical errors. N = 30 participants were excluded due to task comprehension difficulties (N = 18 did not answer the control questions correctly and 12 additional participants reported difficulties understanding the task after the experiment). An additional N = 22 participants needed to be excluded because they started the experiment again, after already participating, while N = 34 participants were excluded from the implicit task analyses and N = 33 from the explicit task analyses due to non-meaningful task performance (as defined in Section 1.1.4). This led to N = 157 participants for the implicit task and N = 158 participants for the explicit task.

2.1.2. Materials

The materials were the same as in Experiment 1.

2.1.3. Experimental design

The experimental design was the same as in Experiment 1, with the addition of a comprehension question after the instruction of each task and before participants started doing the test trials. Participants were asked where they needed to click in the following task and were presented with the options "Where the object is" and "Where the agent will search". If they did not answer correctly (for the explicit task: N = 67, for the implicit task: N = 20), they received the feedback to read the instructions carefully one more time and were asked again after the familiarization trials. Participants who still did not answer correctly were excluded (due to miscomprehension of the explicit task: N = 17, due to miscomprehension of the implicit task: N = 2). As we aimed to replicate the findings of the altercentric bias in experiment 1, we focused in experiment 2 on the subgroup who conducted the explicit task before the implicit task. As such, all participants started with the explicit task and we only counterbalanced the order of belief condition (true belief first and false belief first).

2.1.4. Data processing

Data preprocessing and analysis were the same as in Experiment 1.

2.1.5. Bayesian framework

We applied Bayesian statistics in all our analyses (for details see Section 1.1.5).

2.1.5.1. Sequential testing. As in Experiment 1, we continued data collection until the Bayes Factor testing for a positive altercentric bias in the implicit task reached either 3 or 1/3. To control for false positives and negatives, a minimum of 140 participants was collected. These criteria were preregistered and determined by means of power simulations using the R packages 'Superpower' version 0.1.0 (Lakens & Caldwell, 2021) and 'BayesFactor' version 0.9.12–4.2 (Morey & Rouder, 2015) assuming an effect size of 0.25 with a standard deviation of 0.12 as observed in study 1. This sequential testing strategy led to N = 157 participants for the implicit task. See Appendix G, Fig. G.1 illustrating the development of the Bayes Factor with increasing number of participants.

2.2. Results

2.2.1. Implicit task

As in experiment 1, we tested for an altercentric bias with and without errors included, i.e., trials in which participants searched on the wrong side of the screen. When looking at the entire sample, moderate evidence against a positive altercentric bias was found for both (Wilcoxon signed rank test with errors: BF_{10} = 0.29, W = 6877, $\hat{R}$ = 1.00, N = 157, M = 7.98, SD = 67.64; without errors: BF_{10} = 0.12, W = 6322, $\hat{R}$ = 1.00, N = 157, M = 0.60, SD = 24.39, see Fig. 5A). As participants only showed an altercentric bias in experiment 1 when they did the false belief before the true belief trials, we also looked at this subgroup of participants separately. This yielded no evidence for an altercentric bias when errors were included (BF_{10} = 0.35, W = 1756, $\hat{R}$ = 1.00, N = 78, M = 7.83, SD = 65.22), but moderate evidence for an altercentric bias when excluding errors (BF_{10} = 3.17, W = 1911, $\hat{R}$ = 1.01, N = 78, M = 6.22, SD = 23.14, see Fig. 5B; sequential testing: see Appendix G, Fig. G.2) replicating the order effect of experiment 1. This suggests that, after adding control questions to check for task comprehension, the observed altercentric bias stemmed from small deviations in the participant responses and was not driven by trials in which participants searched closer to the believed than to the actual object location. As in experiment 1, altercentric biases where only observed when the participants started with the false belief condition and not when they did the true belief condition first (with errors: BF_{10} = 0.26, W = 1731, $\hat{R}$ = 1.00, N = 79, M = 8.12, SD = 70.37, without errors: BF_{10} = 0.05, W = 1283, $\hat{R}$ = 1.00, N = 79, M = −4.95, SD = 24.46, see Fig. 5B).

As before, we examined potential gender effects with a Bayesian Mann Whitney *U* Test, which yielded moderate evidence against an effect for both data sets without and with errors (without errors: BF_{10} = 0.18, W = 2604.5, $\hat{R}$ = 1.04, N_{male} = 53, N_{female} = 98, M_{male} = 0.94, M_{female} = 0.74, SD_{male} = 24.77, SD_{female} = 24.81; with errors: BF_{10} = 0.28, W = 2247.5, $\hat{R}$ = 1.03, N_{male} = 53, N_{female} = 98, M_{male} = −1.14, M_{female} = 10.77, SD_{male} = 63.16, SD_{female} = 70.49).

Finally, to check whether there was an effect of the different hiding scenarios for the altercentric bias, we ran the two separate Bayesian repeated measures ANOVAs with the factors 'agent' and 'location'. As in experiment 1 this yielded strong evidence against an effect of agent when analyzing the data with errors (BF_{10} = 0.12, error = 0.70 %) and moderate evidence for an effect of agent (without errors: BF_{10} = 4.05, error = 1.06 %, details see Appendix H, Tables H.1 and H.2). There was no effect of location (without errors: BF_{10} = 0.28, error = 0.72 %, with errors: BF_{10} = 0.08, error = 0.59 %) on the altercentric bias.

2.2.2. Explicit task

As in experiment 1, we tested for a positive egocentric bias in the explicit task with and without including errors. This yielded evidence against a bias in both samples (Wilcoxon signed rank test with errors: BF_{10} = 0.04, W = 4172, $\hat{R}$ = 1.07, N = 158, M = −20.63, SD = 66.70; without errors: BF_{10} = 0.03, W = 3805, $\hat{R}$ = 1.01, N = 158, M = −12.19, SD = 31.99), replicating the results of experiment 1.

As for experiment 1, we tested the subgroups depending on the order

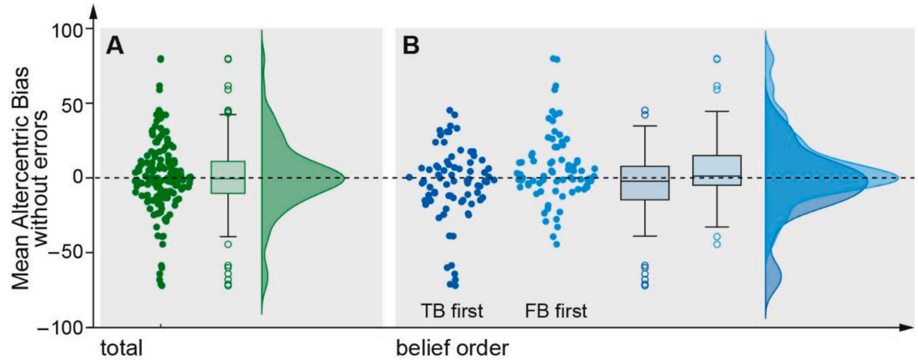

Fig. 5. Experiment 2: Mean altercentric bias in the implicit task.
A. Mean altercentric bias in the implicit task for all participants (green). B. Separated by belief order: in dark blue, true belief condition first (TB = true belief), in light blue, the false belief condition first (FB = false belief). All participants started with the explicit task.

in which they had seen the conditions (false belief first/true belief first). This confirmed evidence against an egocentric bias in both subgroups (true belief first: $BF_{10} = 0.04$, W = 1141, $\widehat{R} = 1.01$, N = 79, M = −20.85, SD = 66.23, false belief first: $BF_{10} = 0.05$, W = 1055, $\widehat{R} = 1.01$, N = 79, M = −20.40, SD = 67.59). The same was found when excluding errors (true belief first: $BF_{10} = 0.05$, W = 969, $\widehat{R} = 1.04$, N = 79, M = −12.99, SD = 34.41, false belief first: $BF_{10} = 0.04$, W = 953, $\widehat{R} = 1.01$, N = 79, M = −11.39, SD = 29.57).

A Bayesian Mann Whitney *U* test provided no evidence for an effect of gender ($BF_{10} = 0.94$, W = 2178, $\widehat{R} = 1.03$, $N_{male} = 55$, $N_{female} = 99$, $M_{male} = -33.34$, $M_{female} = -14.24$, $SD_{male} = 66.87$, $SD_{female} = 67.03$).

Finally, as in experiment 1, we analyzed the effects of the different hiding scenarios. These yielded moderate evidence against an effect of location ($BF_{10} = 0.23$, error = 0.57 %) and very strong evidence for an effect of agent ($BF_{10} = 59.48$, error = 0.89 %) replicating the effect observed in experiment 1 (see Appendix I, Tables I.1 and I.2 for post-hoc analyses of the different agents).

2.2.3. Relation between the altercentric and the egocentric bias

As in experiment 1, a Bayesian correlation analysis yielded moderate evidence against a correlation between the two biases (without errors: $BF_{10} = 0.15$, $r = -0.07$, with errors: $BF_{10} = 0.22$, $r = 0.10$).

Similar to experiment 1, the Bayesian ANOVA with the factors task (implicit/explicit) and belief (FB/TB) showed evidence for an effect of task and the interaction of task and belief, whereas the analysis for the factor belief remained inconclusive (details see Appendix J, Tables J.1 and J.2).

2.3. Discussion Experiment 2

In experiment 1, we observed an altercentric bias in participants who did an explicit belief reasoning task before the implicit object search task. This altercentric bias was driven by large memory errors in false belief trials, i.e. by participants searching closer to the location where the agent believed the object to be than the location where the object actually was. Thus, it could have been the result of participants confusing the task instructions of the implicit (searching for the object) and the explicit task (indicating where the agent believed the object to be). To ensure that this was not the case, we aimed to replicate the effect in an independent sample in experiment 2, firmly controlling for task comprehension by adding comprehension questions and feedback after the task instructions. Indeed, we were able to replicate the altercentric bias observed in experiment 1 in this independent sample. In fact, in this sample, the altercentric bias was only evident when errors were excluded, i.e. trials in which participants searched closer to the believed than the actual location. Thus, in experiment 2, the altercentric bias was driven by small deviations in participant responses from the correct location in the direction of where the other person falsely believed the object to be. Thus, this rules out the notion of task confusion. The fact that we only found an altercentric bias when excluding errors can be attributed to the fact that errors in experiment 2 were rare (see Appendix K, Fig. K.1 for details of error distribution in experiment 2) and, by definition, much bigger than the small deviations generating the effect. As in experiment 1, we only found an altercentric bias when participants started with the false belief condition. Order effects like this have already been observed in previous research (Dörrenberg, Rakoczy, & Liszkowski, 2018; Kampis, Kovács, & Melinda, 2022).

3. General discussion

Across two pre-registered experiments ($N = 113$ and $N = 157$), we found evidence that participants are influenced in their object search by the false belief of others. The results of experiment 1 revealed that this altercentric bias only appears when the participants conducted a task where they needed to explicitly reason about another person's false belief before they did the object search task. This altercentric bias in participants' object search was replicated in an independent sample in experiment 2, where all participants started with the explicit belief reasoning task. Furthermore, we replicated an order effect of the belief condition in both experiments. Namely, altercentric biases were only elicited when the agent directly had a false belief and not when the true belief control condition was shown first. In neither of the two experiments were we able to replicate a previously observed egocentric bias (Bernstein et al., 2011; Coburn et al., 2015; Sommerville et al., 2013) when asking participants where another person with a false belief would search for the object.

The observed altercentric bias in participants' search location extends previous studies reporting altercentric biases in participants' reaction times in object detection or recognition in the presence of an agent with a different perspective (El Kaddouri et al., 2020; Freundlieb et al., 2017; Freundlieb et al., 2018; Marshall et al., 2018; Samson et al., 2010). Most of these studies found altercentric biases in the context of visual perspective taking, that is, when the other agent could not see some of the objects present in the scene or saw them from a different viewing angle (Freundlieb et al., 2017; Freundlieb et al., 2018; Marshall et al., 2018; Samson et al., 2010; Ward et al., 2019). While, in visual perspective taking, an alternative explanation is that these biases result from directional cueing, without the need to compute the others' perspective (Heyes, 2014; Michael et al., 2018; Santiesteban, Catmur, Hopkins, Bird, & Heyes, 2014), false belief situations are considered a critical test of mental state attribution (Dennett, 1978). Only a few previous studies have found altercentric biases in the context of false belief processing (El Kaddouri et al., 2020; Kovács et al., 2010; van der Wel et al., 2014) and some alternative explanations have been discussed (Phillips et al., 2015). Our findings of an altercentric bias in response to an agent's false belief, in an entirely new setting and with a new measure thus supports the notion that altercentric biases genuinely result from processing others' mental states.

Further evidence that altercentric biases involve processing others' mental states comes from the order effects we observed. Participants only showed an altercentric bias if they had to reason about the agent's belief explicitly in a previous task, but not if they started with the object search task without mention of the agent. The fact that doing the explicit belief reasoning task first seemed necessary for the altercentric bias to occur challenges previous interpretations of this bias as automatic and triggered by the mere presence of an agent, even when entirely irrelevant to the task (Kovács et al., 2010). Rather, the order effect suggests that for an altercentric bias to occur, the agent's belief needs to have been relevant. In the strongest interpretation of these findings, it may be necessary to process an agent's belief explicitly for an altercentric bias to occur, which would question the implicit nature of these biases. Alternatively, it may also be sufficient to highlight the agent or their beliefs, for example in a previous task, without the need for participants to explicitly process this belief during the object search task. This interpretation also pertains to the mechanisms underlying the observed priming effect. One possibility is that the explicit task increased attention to the agent and their perspective, leading to potentially stronger encoding of the hiding event cued by the agent's attention (as argued, e.g., by Grosse Wiesmann & Southgate, 2021; Southgate, 2020 in the developmental context). As a consequence, this remembered location may interfere with the memory of the later observed current object location (Heller & Brown-Schmidt, 2023). Another possibility is that reasoning about the agent's belief in a previous task may cue or enhance belief processing in future tasks. Stronger (explicit) belief processing in the implicit task may then lead to interference between one's own and the other's belief. Without such priming, in turn, participants may not process the agent's perspective and thus not show any biases from this perspective. One way of obtaining insight into which of these mechanisms underlie the observed priming effect would be to test children before and after they develop the ability to explicitly reason about the belief of others, considered to develop around 4 years. If merely directing the attention is the cause of the effect, then children who do not yet possess explicit reasoning abilities may also show altercentric biases after highlighting the agent's perspective. In contrast, if the capacity and extent to which the agent's belief is explicitly processed underlies the priming effect, only children who are already capable of explicit reasoning should show such an order effect. Indeed, a recent study provides evidence that only children passing standard false belief tasks show altercentric biases in the Sandbox task (Speiger et al., 2024). In that study, children passing standard FB tasks showed the same order effect observed in adults in the present study. That is, children were only influenced by the other's belief when they were asked to explicitly reason about another person's belief in a previous task. This supports the account that the observed order effect reflects an enhancement of belief processing through previous priming. In any case, our results indicate that the occurrence of altercentric biases depend on the relevance or salience of the agent and do not occur automatically, independent of context and task relevance. O'Grady et al. (2020) differentiate between automatic and spontaneous processes. The former take place independently of intentional and attentional factors and cannot be inhibited. The latter can occur rapidly and involuntarily but are mediated by the attentional system. Our findings suggest that altercentric biases may be a spontaneous but not necessarily automatic process. However, it remains open for future research to determine which exact contextual factors are necessary to elicit an altercentric bias. Specifically, it should be clarified whether explicit belief reasoning must be performed beforehand, if emphasizing the relevance of the agent is required, or if simply directing attention to the agent is sufficient.

When comparing the presentation of the altercentric bias in experiment 1 and 2 we find an interesting difference. In experiment 1 the altercentric bias manifested itself in larger memory errors, systematically emerging more in trials where the other person had a false belief than in true belief trials. This suggests that, under high memory load, the presence of another agent with a false belief can cause us to misremember locations, where the agent believes the object to be, rather than where it really is. Whereas, when we tried to minimize these large memory errors, by adapting task instructions and adding comprehension questions in experiment 2, further emphasizing the participant's own perspective, participants indeed made less errors overall (both in true belief and false belief trials) and the altercentric bias instead presented itself in small systematic deviations from the correct location in direction of where the other person falsely believes the object to be. In fact, another recent study with pre-school children also shows that altercentric biases can present both in small deviations and in large memory errors (Speiger et al., 2024). These different expressions of the altercentric bias could serve as alternative ways of taking others' beliefs into account. For example, in situations of little time or high cognitive load, when there is little capacity for explicitly reasoning about other's beliefs separately from our own, such biases may highlight the location considered by the other through memory errors, or help prepare for potential actions of the other by deviating in the appropriate direction.

The observed dependence of altercentric biases on an a prior explicit belief reasoning task also explains why a recent study (Haskaraca et al., 2023) did not find an altercentric bias across three experiments using a similar paradigm but no explicit task before an object search task. In 2 out of 3 experiments by Haskaraca et al., participants only performed an implicit (object search) task, without previously doing in explicit belief reasoning task. Accordingly, in line with our findings, no altercentric bias was observed. Only in experiment 3 did Haskaraca et al. (2023) use a within subject-design where the same participants participated in the explicit and the implicit version of the task. In that study, only $N = 27$ participants received an explicit belief reasoning task before they did the altercentric task. Based on the effect size we found in our first study (0.25), Haskaraca et al. (2023) only had a power of 35 % to detect an existing altercentric bias. It is therefore not surprising that they did not find an altercentric bias, which we detected due to our Bayesian sequential testing approach, leading to much larger sample sizes with sufficient power. This highlights the importance of large sample sizes and efficient sampling designs to study phenomena like altercentric biases.

Our finding of the dependence of altercentric biases on highlighting the agent's belief is in line with visual perspective taking studies showing that altercentric interferences, when responding to the number of dots a participant could see, depended on the relevance of the other's perspective in the context of the task (Holland et al., 2021; O'Grady et al., 2020). Further, our findings are consistent with prior studies demonstrating that altercentric biases depend on the nature of the agent (e.g. humans or animals, animated or real) and the salience of their perspective (Bardi, Desmet, & Brass, 2019; Ferguson, Brunsdon, &

Bradford, 2018; Pesimena, Wilson, Bertamini, & Soranzo, 2019; Schneider, Lam, Bayliss, & Dux, 2012; Xiao, Fan, Zhang, & Zhou, 2022; Ye, Furumi, Da Catarino Silva, & Hamilton, 2021; Zhou, Peng, Li, Deng, & Chen, 2022). This context dependency of social biases is also supported by findings that the perspective of participants can successfully be shifted toward one's own or the other's perspective depending on the instruction, and further, that egocentrism can be decreased accordingly (Eyal, Steffel, & Epley, 2018; Kampis & Southgate, 2020).

In contrast to the altercentric bias in participants' own object search, we found evidence against an egocentric bias in our studies when participants were asked to indicate where the agent would search for the object. This was consistent across two independent experiments with large samples ($N = 113$ and $N = 157$) with a Bayesian sequential testing approach that ensured sufficient power to provide statistical evidence against the effect. The lack of an egocentric bias was observed consistently, regardless of task order or whether participants first experienced the agent with a false or a true belief. This non-replication of the original sandbox task (Bernstein et al., 2011; Coburn et al., 2015; Sommerville et al., 2013) is in line with other recent non-replications of the egocentric bias across five independent experiments using a similar paradigm (Haskaraca et al., 2023; Samuel, Legg, Lurz, & Clayton, 2018). When interpreting the lack of an egocentric bias in our study, it is important to consider two aspects of our explicit task that differed from the original sandbox task. While the original sandbox studies used a memory control condition, asking participants whether they remembered where the object had originally been (Bernstein et al., 2011; Sommerville et al., 2013), we used a true belief control condition to match the altercentric task. That is, in our control condition, similar to the false belief condition, participants were asked where the agent would search for the object, and the only difference was that the agent had seen the object relocation. As the egocentric bias in our studies is computed as the difference between participants' deviation in the false belief and the true belief condition, this difference may have explained the discrepancy between our own and the original findings. Second, while the original studies used live sandbox and paper-pencil versions of the task (Bernstein et al., 2011; Coburn et al., 2015; Sommerville et al., 2013), we used a digital version, which may have led to differences between the findings. However, the other recent non-replications of the sandbox task used the original control condition and partly also paper-pencil versions like the original task and were nevertheless unable to replicate the egocentric bias (Haskaraca et al., 2023; Samuel et al., 2018). Together, this suggests that egocentric biases in adults' search may not be as robust as previously thought. Future research will therefore need to follow up on the robustness of this phenomenon across different task settings and contexts.

With regard to the magnitude of the altercentric and the egocentric biases in other tasks, such as the dot perspective task (Samson et al., 2010), it is important to consider that these tasks investigated perspective taking rather than belief understanding. It is very plausible that one's own immediate visual perception dominates over another person's computed perspective. In the case of beliefs, in contrast, neither of the two representations has the immediacy of perception and so the relevance of egocentric biases may very well differ from the case of perspective taking. In addition, the dot perspective and other perspective taking tasks, have used reaction time as a measure of altercentric biases, whereas our paradigm uses distances in space. It is very likely that participants will be slowed down in their visual judgements when competing salient visual stimuli are present, whereas this may be quite different in our task.

Given the absence of an egocentric bias in the explicit task, it is not surprising that we found no relation between this measure in the explicit task and the altercentric bias in the implicit task. Future research should investigate the correlation between ego- and altercentric biases with paradigms that reliably elicit both (e.g., Samson et al., 2010).

Despite not finding an overall egocentric bias, we found evidence for an effect of agent on this measure in both experiments. Specifically, in experiment 1 participants showed more egocentric bias (corresponding to worse explicit false belief performance) for the seagull compared to the human agents and the squirrel. Speculatively, the degree to which participants were egocentric depended on the nature of the agent. The seagull might not have been perceived as a relevant agent to humans, potentially impeding explicit false belief reasoning. However, the squirrel, who was the most prominent agent in both studies, as it was used in all introduction videos and familiarization trials, yielded the most precise answers in the false belief trials and thus the smallest egocentric bias. A similar effect was found in the altercentric bias as well where the bias was primarily present for the girl. Given that most participants were female, the perspective of the girl might have been more prompting than the perspective of the other agents. Hence, in both social biases, the relevance of the agent seems to have played a role in the degree to which they emerged. These agent effects are in line with a study showing that only dog owners but not the control group showed an altercentric bias when the agent was a dog (Bardi et al., 2019).

4. Conclusion

In sum, our study provides evidence for an altercentric bias in participants' object location memory, when an agent's false belief about the object's location had been the explicit target of a previous task. These findings support the idea that false belief processing can indeed lead to altercentric biases, but only when the agent's belief was relevant for a previous task. This suggests that such biases may not reflect fully automatic belief processing but, instead, depend on context.

CRediT authorship contribution statement

Marie Luise Speiger: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Katrin Rothmaler:** Writing – original draft, Validation, Supervision, Investigation, Formal analysis, Data curation. **Ulf Liszkowski:** Writing – review & editing, Conceptualization. **Hannes Rakoczy:** Writing – review & editing, Conceptualization. **Charlotte Grosse Wiesmann:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare no competing interests.

Data availability

The JASP files used for analyzing the data, including the corresponding datasets, are available upon request from the corresponding author. Please contact Marie Luise Speiger at speiger@cbs.mpg.de for access.

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None.

Appendix A

Table A.1
Hiding location pairs.

Location 1	Location 2
146	506
294	651
187	546
238	596

The direction of change was shown from left to right and from right to left in all pairs. Distance between the locations is approximately 360 Pixel. The presented screen width was 800 Pixel.

Appendix B

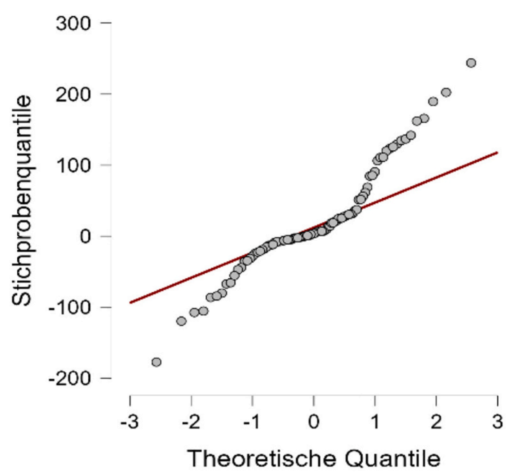

Fig. B.1. Experiment 1: QQ-plot mean altercentric bias.

Appendix C

Main results of analyses with reduced samplesize based on sequential testing approach of experiment 1.

Table C.1
Experiment 1: Bayesian one sample Wilcoxon signed rank test > 0 for altercentric and egocentric bias.

	BF_{+0}	W	Rhat	N	M	SD
Mean Altercentric Bias	3.26	1245.00	1.00	62	17.82	65.76
Mean Egocentric Bias	0.47	1028.00	1.00	59	10.01	69.02

Table C.2
Experiment 1: Bayesian ANOVA with belief and task order for altercentric and egocentric bias.

		BF_{+0}	Error %
	Belief order	0.39	1.63
Mean Altercentric Bias	Task order	1.37	1.44
	Interaction Belief*Task	0.48	2.36
	Belief order	0.49	2.39
Mean Egocentric Bias	Task order	0.33	1.63
	Interaction Belief*Task	0.36	1.55

Table C.3
Experiment 1: Bayesian one sample Wilcoxon signed rank test > 0 of altercentric and egocentric bias.

	BF_{+0}	W	Rhat	N	M	SD
Implicit First: Mean Altercentric Bias	0.41	660.00	1.00	48	9.76	66.56
Explicit First: Mean Altercentric Bias	2.91	1245.00	1.00	62	17.82	65.76
Explicit First: Mean Egocentric Bias	0.45	1028.00	1.00	54	−11.20	34.86
Implicit First: Mean Egocentric Bias	0.25	439.00	1.00	40	5.48	75.79

Appendix D

Table D.1
Experiment 1: Bayesian Wilcoxon signed rank test > 0 of altercentric bias without errors in separate subgroups.

	BF_{+0}	W	Rhat	N	M	SD
Implicit First	0.18	613.00	1.00	48	0.71	20.80
Explicit First	0.44	723.00	1.00	49	3.09	26.87
Explicit First and True Belief First	0.22	135.00	1.00	22	−1.77	26.20
Explicit First and False Belief First	0.85	237.00	1.00	27	7.05	27.24
Implicit First and True Belief First	0.27	162.00	1.00	24	0.89	23.01
Implicit First and False Belief First	0.20	149.00	1.00	24	0.52	18.82

Table D.2
Experiment 1: Bayesian Wilcoxon signed rank test > 0 of egocentric bias without errors in separate subgroups.

	BF_{+0}	W	Rhat	N	M	SD
Implicit First	0.15	402.00	1.00	40	−2.65	39.19
Explicit First	0.05	441.00	1.01	54	−11.20	34.86
Explicit First and True Belief First	0.09	167.00	1.00	30	−8.54	37.87
Explicit First and False Belief First	0.07	64.00	1.00	24	−14.52	31.17
Implicit First and True Belief First	1.28	119.00	1.00	18	6.68	19.30
Implicit First and False Belief First	0.12	93.00	1.00	22	−10.28	49.15

Appendix E

Table E.1
Experiment 1: Mean egocentric bias pairwise post-hoc tests separated by agent.

		BF_{+0}	Error %
Squirrel	Seagull	4.025	0.007
	Boy	0.431	0.046
	Girl	0.138	0.114
Seagull	Boy	0.410	0.048
	Girl	2.766	0.010
Boy	Girl	0.196	0.087

Appendix F

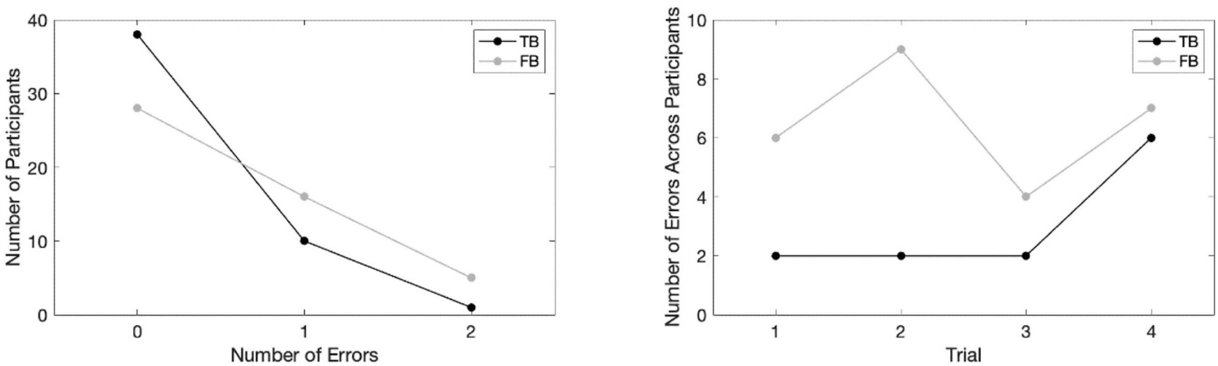

Fig. F.1. Experiment 1: Error distribution in the implicit task of participants starting with the explicit task.
On the left: Number of errors over participants in the implicit task seperated for true belief (TB) condition and false belief (FB) condition. On the right: number of errors across participants per trial seperated for TB and FB blocks in the implicit task.

Appendix G

Results of the Sequential Testing Approach in experiment 2.

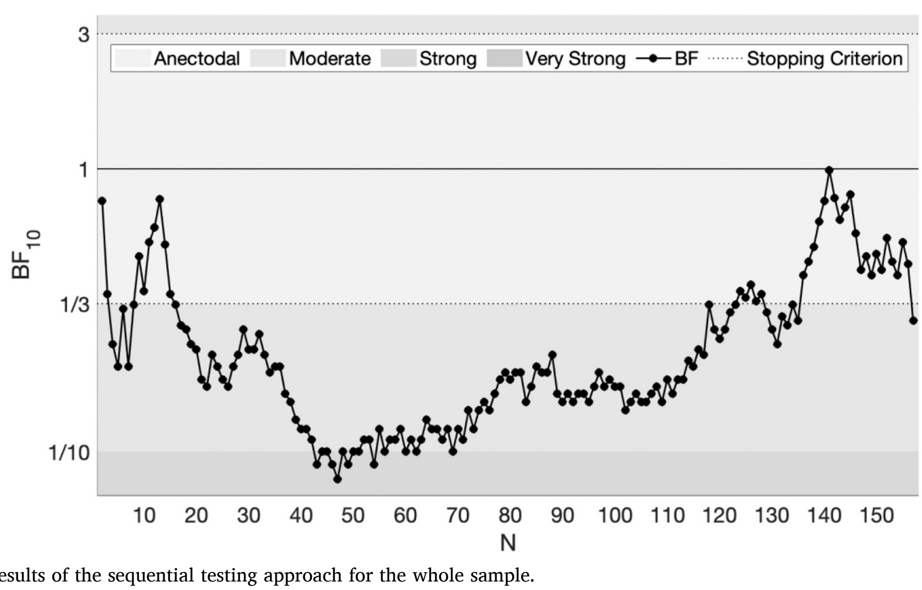

Fig. G.1. Experiment 2: Results of the sequential testing approach for the whole sample.
Illustration of the development of the Bayes Factor of a Wilcoxon signed rank test testing for a positive altercentric bias in the implicit task with increasing number of participants. The dotted lines illustrate the stopping criterion, the different stages of evidence for or against an effect are highlighted in different shades of grey.

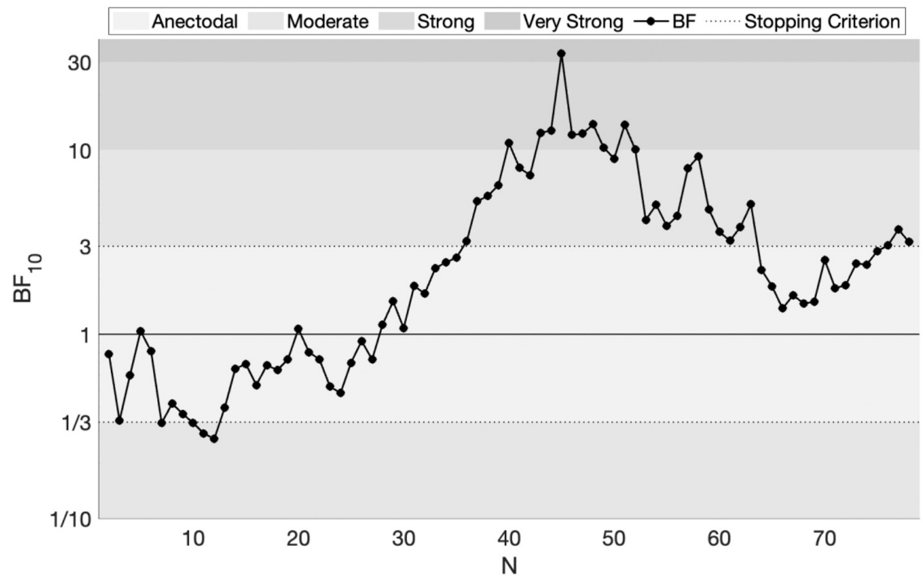

Fig. G.2. Experiment 2: Results of the sequential testing approach for false belief first condition without errors.
Illustration of the development of the Bayes Factor of a Wilcoxon signed rank test testing for a positive altercentric bias in the implicit task for participants starting with the false belief condition, excluding trials were the participant's answer was closer to the believed than to the actual location, with increasing number of participants. The dotted lines illustrate the stopping criterion, the different stages of evidence for or against an effect are highlighted in different shades of grey.

Appendix H

Post-hoc analyses effect of agent on the altercentric bias in experiment 2.

Table H.1
Experiment 2: Mean altercentric bias without errors pairwise post-hoc tests separated by agent.

		BF_{+0}	Error %
Squirrel	Seagull	0.14	0.12
	Boy	0.11	0.14
	Girl	10.13	0.00
Seagull	Boy	0.13	0.13
	Girl	1.10	0.21
Boy	Girl	6.94	0.00

Table H.2
Experiment 2: Bayesian Wilcoxon signed rank test > 0 of altercentric bias without errors separate by agent.

	BF_{+0}	W	Rhat	N	M	SD
Squirrel	0.03	3893	1.00	102	−5.82	35.49
Seagull	0.09	4984.5	1.00	102	−1.39	44.60
Boy	0.05	4579.5	1.00	102	−4.48	31.93
Girl	3.80	5338	1.01	102	12.15	50.77

Appendix I

Experiment 2: Post-hoc tests of ANOVA with the factor agent in the explicit task.

Table I.1
Experiment 2: Mean egocentric bias pairwise post-hoc tests separated by agent.

		BF_{+0}	Error %
Squirrel	Seagull	37.42	0.00
	Boy	20.70	0.00
	Girl	0.46	0.05
Seagull	Boy	0.09	0.21
	Girl	0.78	0.03
Boy	Girl	0.45	0.05

Table I.2
Experiment 2: Bayesian Wilcoxon signed rank test > 0 of egocentric bias separate by agent.

	BF_{+0}	W	Rhat	N	M	SD
Squirrel	0.03	3293	1.01	158	−53.15	157.15
Seagull	0.09	6048.50	1.00	158	−1.69	104.80
Boy	0.05	5764	1.00	158	−2.11	115.45
Girl	0.02	3605	1.01	158	−25.55	111.77

Appendix J

Experiment 2: Bayesian ANOVA and descriptives with the factors task and belief in the explicit task.

Table J.1
Experiment 2: Bayesian ANOVA for the mean egocentric bias without errors with the factors task and belief.

		BF_{+0}	Error %
Mean Egocentric Bias	Task	8.07	21.32
	Belief	2.03	18.85
	Interaction Task*Belief	19.89	8.98

Table J.2
Experiment 2: Descriptives mean egocentric bias without errors separated by task and belief.

Task	Belief	N	Mean	SD
Implicit	TB	138	1.90	23.14
	FB	138	2.55	22.66
Explicit	TB	138	1.60	20.15
	FB	138	−7.66	25.63

Appendix K

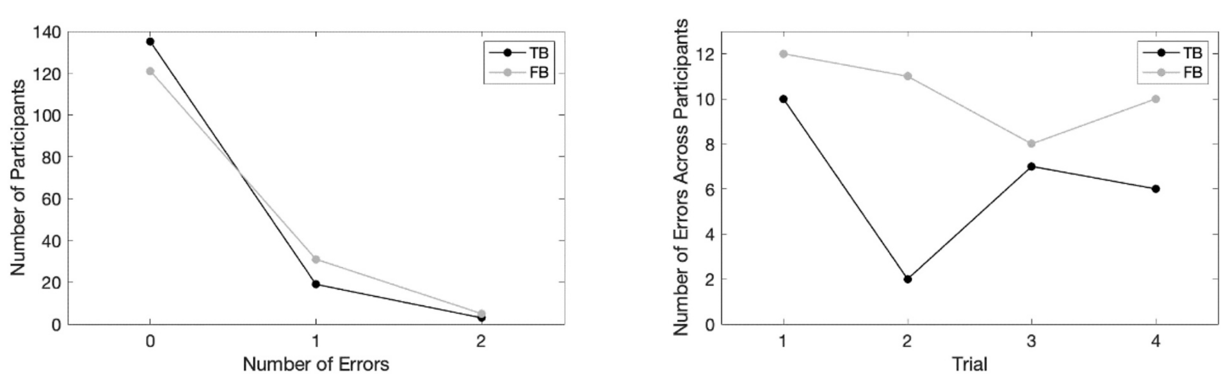

Fig. K.1. Experiment 2: Error distribution in the implicit task.
On the left: Number of errors over participants in the implicit task seperated for true belief (TB) condition and false belief (FB) condition. On the right: number of errors across participants per trial seperated for TB and FB condition in the implicit task.

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