Cognition 254 (2025) 105966

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Social perspective-taking influences on metacognition

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ARTICLE INFO

Keywords:
Perspective-taking
Metacognition
Social cognition
Confidence

ABSTRACT

We often effortlessly take the perceptual perspective of others: we represent some aspect of the environment that others currently perceive. However, taking someone's perspective can interfere with one's perceptual processing: another person's gaze can spontaneously affect our ability to detect stimuli in a scene. But it is still unclear whether our cognitive evaluation of those judgements is also affected. In this study, we investigated whether social perspective-taking can influence participants' metacognitive judgements about their perceptual responses. Participants performed a contrast detection task with a task-irrelevant avatar oriented either congruently or incongruently to the stimulus location. By "blindfolding" the avatar, we tested the influence of social perspective-taking versus domain-general directional orienting. Participants had higher accuracy and perceptual sensitivity with a congruent avatar regardless of the blindfold, suggesting a directional cueing effect. However, their metacognitive efficiency was modulated only by the congruency of a seeing avatar. These results suggest that perceptual metacognitive ability can be socially enhanced by sharing perception of the same objects with others.

1. Introduction

People are sensitive to where others are looking. In many situations, successful cooperation or competition requires taking the perceptual perspective of others: to represent some aspect of the environment that others are currently representing. But taking someone's perspective can interfere with one's own perceptual processing, inducing an other-centred, or altercentric, interference. Depending on where they are attending, another person's gaze can either facilitate or impair our ability to detect and discriminate objects in a scene (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010; Seow & Fleming, 2019). Previous studies show that altercentric interference on our perceptual judgements occurs spontaneously and may be involuntary to some extent (Kampis & Southgate, 2020; O'Grady, Scott-Phillips, Lavelle, & Smith, 2020), but whether this type of social influence also extends to the cognitive appraisal of perceptual judgements remains unclear. In this study, we investigate whether social perspective-taking can influence participants' metacognitive evaluation on their perceptual responses, and to what extent sharing perception can enhance metacognitive efficiency.

Metacognition refers to the cognitive processes of evaluating and controlling one's own mental states, including perceptual states (Koriat, 2007; Proust, 2010). Perceptual metacognition is the ability to distinguish between correct and incorrect perceptual judgements: given a particular level of task performance, metacognition is more efficient when there is a close association between the degree of confidence and the accuracy of a perceptual judgement (Fleming & Lau, 2014; Rahnev, 2021). Perceptual metacognition is an essential skill we use every day when, for example, being unsure whether the person you see across the street is your friend, you decide to get closer rather than call them out, or when trusting (or not) your perceptual abilities to drive on a foggy day. In social contexts, we know that perceptual metacognition plays a role in whether we seek advice from others (Pescetelli & Yeung, 2021); during joint decision-making, agreement between one's own decision and another's can boost one's metacognitive efficiency (Pescetelli, Rees, & Bahrami, 2016); and sharing the level of confidence in our own perceptual judgements with others can in turn lead to better joint decisions (Bahrami et al., 2012). There is some evidence that our metacognitive judgements can themselves be socially influenced after making decisions, with people being more confident in their choices after receiving verbal advice (Kaliuzhna, Chambon, Franck, Testud, & Van der Henst, 2012). Eskenazi et al. (2016) found that a task-irrelevant non-verbal eye-gaze social cue shown after a perceptual decision was sufficient to bias participants' confidence ratings on that decision and

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https://doi.org/10.1016/j.cognition.2024.105966
Received 5 January 2024; Received in revised form 20 September 2024; Accepted 23 September 2024
Available online 4 October 2024

that, when informed that the cues reflected the answer of previous participants, it also impaired their metacognitive efficiency. These studies have focused on whether post-decisional social information, either verbal or visual, can affect the original sense of confidence participants had in their decisions. But it is still unclear whether social cues spontaneously gathered concurrently with stimulus information can influence metacognition. Does altercentric interference on perceptual judgements also affect our evaluation of those judgements?

Most studies on altercentric interference have focused on reaction time effects using variations of the dot-counting task, where participants are required to count the number of dots in a scene where a virtual agent has perspectival access to a different number of dots than the participant (Samson et al., 2010). Going beyond reaction time measures, in an innovative study Seow and Fleming (2019) showed that altercentric interference can also affect perceptual sensitivity in a low-contrast detection task. Here, we used this established effect, using a similar first-level perceptual detection task, in order to test second-level metacognitive evaluation. In this pre-registered study (pre-registration available at https://osf.io/sugmb), participants were shown either a Gabor pattern embedded in noise (target present condition) or a noise patch (target absent condition), and asked to report whether they perceived the target Gabor. We manipulated the social condition in which the stimuli were shown, with an avatar whose perspectival orientation was either congruent or incongruent with the stimulus (Fig. 1A). After each trial, participants were asked to rate how confident they were about their response on scale from 1 (low) to 4 (high) (Fig. 1B).

According to the altercentric interference hypothesis, taking the avatar's viewpoint will enhance perceptual processing in the direction of that viewpoint (Kampis & Southgate, 2020; Seow & Fleming, 2019). Moreover, on this hypothesis, altercentric interference reflects a system that is specialised for orienting to perspective-specific over domain-general cues, so that any spontaneous influence of the avatar on perceptual and metacognitive processes would be mediated by a form of mental state attribution, with subjects being sensitive to whether the avatar can see or not (Kampis & Southgate, 2020). An alternative "directional-orienting" hypothesis holds instead that congruency effects (if they are present) are not driven by sensitivity to what the avatar can see, but are instead mediated by a domain-general orienting mechanism, based on low-level directional cues (cf. Heyes, 2014). This orienting mechanism may still be socially-based (for example, tracking head and shoulder directionality), but does not involve any estimation of the avatar's visual state. To arbitrate between these hypotheses, we also manipulated the avatar's visual access by presenting either a seeing avatar or a non-seeing blindfolded avatar (Fig. 1A).

Following the altercentric interference hypothesis, we expected that taking the avatar's perspective would result, first, in greater accuracy in target detection during congruent than incongruent trials and, second, in higher perceptual sensitivity in target detection (d') in congruent than incongruent trials. The altercentric interference hypothesis also predicts that the effect of congruency on accuracy and on d' will be stronger or present only in the seeing condition compared to the non-seeing condition (Seow & Fleming, 2019). The alternative directional-orienting hypothesis predicts that congruency effects on accuracy and sensitivity will not significantly differ between seeing and non-seeing conditions.

Based on previous studies using endogenous attention cueing (Kurtz, Shapcott, Kaiser, Schmiedt, & Schmid, 2017) and post-decision social cues (Eskenazi et al., 2016), we also hypothesise that the mean confidence ratings will be higher for congruent compared to incongruent trials. Following the altercentric interference hypothesis, we expected that the effect of congruency on mean confidence ratings would be stronger in the seeing condition compared to the non-seeing condition. In contrast, the directional-orienting hypothesis predicts no differences between these two conditions. Higher mean confidence ratings do not necessarily lead to better or worse metacognitive efficiency. To quantify and test the effect of congruency on metacognitive judgements, we operationalised metacognitive efficiency using the measure log(M-ratio) = log(meta-d'/d'), where d' refers to the sensitivity in detecting

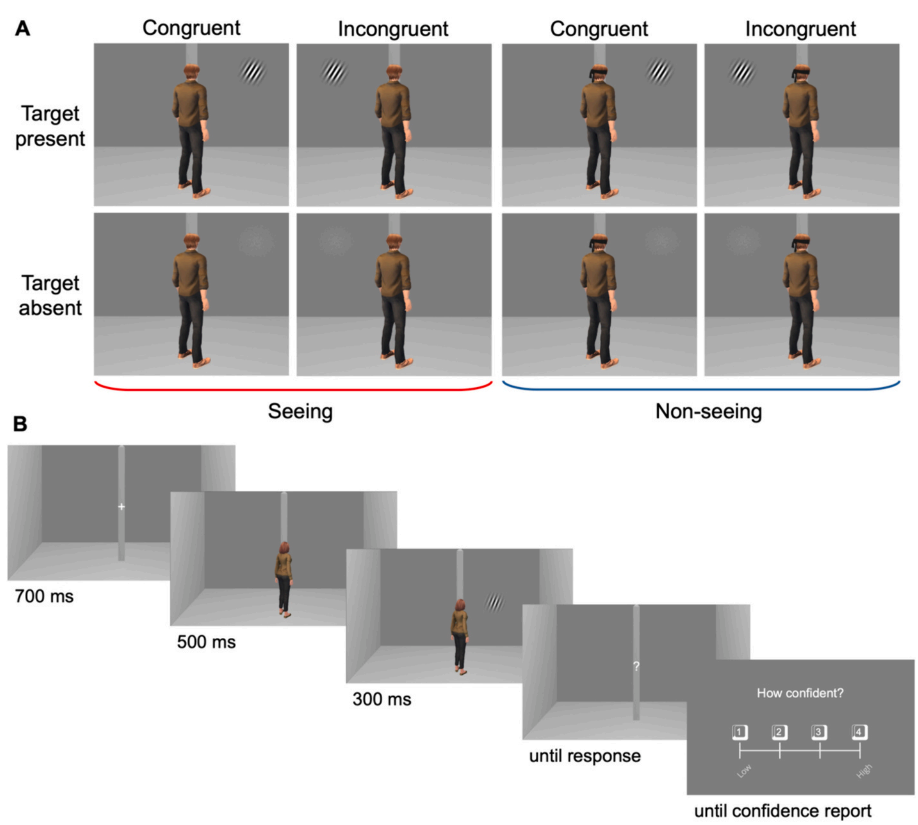

Fig. 1. Stimuli conditions (A), and trial procedure during the main session (B).

the target, and meta-*d'* refers to the *d'* that an ideal observer would have, given the evidence the participant used to report their confidence (Fleming, 2017; Maniscalco & Lau, 2012). This ratio gives an indication of the relative quality of the evidence used for the perceptual response and the metacognitive judgement. An ideal metacognitive observer would base their metacognitive judgement on the same evidence used for their perceptual response (log(M-ratio) = 0).

Congruent altercentric interference has been shown to facilitate higher cognitive processes such as short-term and long-term memory (Gregory & Jackson, 2017; Kampis & Southgate, 2020; Kim & Mundy, 2012). If this facilitation extends to metacognitive judgements, we hypothesise that social perspective congruency fosters optimal metacognition: taking the avatar's perspective enhances a participant's judgement of their available sensory evidence and their detection of errors during congruent trials compared to incongruent trials. This hypothesis predicts that log(M-ratio) would be higher in the congruent than in the incongruent condition. Following the altercentric interference hypothesis, if the influence of congruency on metacognition is due to perspective-taking (being sensitive to what the avatar can and cannot perceive), we expect that this influence will be weaker or not present at all in the non-seeing condition compared to the seeing condition. The directional-orienting hypothesis predicts no differences in congruency effects on log(M-ratio) between the seeing and non-seeing conditions.

We also contrast the altercentric interference hypothesis with what can be called the socially robust metacognition hypothesis. According to this alternative hypothesis, metacognitive efficiency is impervious to social congruency cues. The congruency of perspective-taking may affect perceptual sensitivity, but not higher cognitive processes such as metacognitive judgements. If this is the case, even though we may find differences in perceptual sensitivity between congruency conditions, the metacognitive judgement will operate unbiased between these conditions, making use of the available sensory information without further social influences. While there is no direct experimental precedent for this novel hypothesis, there are recent results showing no effects on cue-target congruency on M-ratio measures in a non-social exogenous attention cueing paradigm (Recht, Mamassian, & de Gardelle, 2022). The socially robust metacognition hypothesis predicts that metacognitive efficiency would not be significantly different between congruency conditions.

2. Materials and methods

2.1. Participants

Our target sample size was 30 participants. Due to the possibility of some participants not meeting the inclusion criteria, we recruited 35 volunteers from the French RISC pool of participants (23 female, M = 30.46 years, SD = 9.58). All participants had normal or corrected-to-normal vision. The study was conducted in accordance with the Declaration of Helsinki and approved by INSERM's ethical evaluation committee (IRB00003888 - N° 18–544-ter - 25.10.2021). All participants gave written informed consent before their participation, and were compensated at the rate of €15 per hour for agreeing to participate.

The sample size was determined by statistical power simulations run in R on a pilot dataset of 8 subjects (see Supplementary Materials for details). We computed the power to detect a significant regression predictor effect and comparison at the standard 0.05 alpha error probability. For a significant main effect of congruency, 80 % power was obtained at 30 participants. For a significant pairwise contrast effect of congruency on at least one of the social conditions (seeing and/or non-seeing avatars), 80 % power was obtained at 24 participants. We had to exclude 3 participants from our target sample size (see Data analysis plan), raising the possibility that such exclusions may have impacted the study's power to detect the effect derived from the pilot dataset. Relatedly, while power calculation derived from pilot data through simulations is considered a reliable approach (Strong & Alvarez, 2019), it has been suggested that power calculations based on pilot data with a small sample size may be biased or imprecise (Albers & Lakens, 2018; Hertzog, 2008). To address these two possibilities, we conducted an after-the-fact power sensitivity analysis based on predetermined smallest effect sizes of independent interest (SESOI) for regressor factors (Kumle, Võ, & Draschkow, 2021; Albers & Lakens, 2018; see Supplementary Materials for details). We found that our study had sufficient sensitivity (over 80 % power) to detect a significant SESOI on metacognitive efficiency of $\beta = 0.27$ for Congruency, and for Social Condition, and a significant pairwise contrast effect of Congruency on at least one of the social conditions. Future studies using a similar power simulation approach should consider the quality of the datasets and effect sizes of interest used for simulation techniques (Strong & Alvarez, 2019).

2.2. Measures

To explore whether any possible individual differences in the effects of the avatar on perceptual performance and on metacognitive ability correlate with individual psychological traits, we also collected and analysed self-reported perspective-taking, empathy, and social anxiety measures, using the Interpersonal Reactivity Index (IRI; Davis, 1983) and the Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987; Fresco et al., 2001). Self-reported perspective taking and empathy scores from the IRI have been found to correlate with altercentric intrusion effects in reaction times, using the dot-counting task (Nielsen, Slade, Levy, & Holmes, 2015). Similarly, generalised and social anxiety traits have been found to correlate both with perspective-taking (Todd & Simpson, 2016) and metacognitive abilities (Rouault, Seow, Gillan, & Fleming, 2018).

The IRI contains 28 Likert-style self-report items rated from 0 (does not describe me well) to 4 (describes me very well). The IRI is designed to produce 4 subscale scores, with 7 items each: personal distress, fantasy, empathic concern, and perspective-taking. Only the last two subscales were administered and analysed here. The LSAS has 24 items describing a situation with 2 subscale scores: how fearful I feel in the situation from 0 (None) to 3 (Severe); and how often I avoid the situation from 0 (never) to 3 (usually). We computed mean scores for each fear and avoidance subscales, and a combined total score. The French versions of the IRI (Gilet, Mella, Studer, Grühn, & Labouvie-Vief, 2013) and the LSAS (Yao et al., 1999) were administered, except for three participants who opted for the English versions. We administered the IRI and LSAS questionnaires online through LimeSurvey (LimeSurvey, 2012), two days before each participant's experimental session.

2.3. Stimuli

The noise patch consisted of a randomly generated white noise of 10 % contrast, modulated by a Gaussian envelope. The target was a Gabor patch made of sinusoidal gratings of 5 degrees of spatial frequency and 30 degrees of orientation, superimposed with 10 % white noise and modulated by a Gaussian envelope. Both noise and Gabor patches subtended 3 degrees of visual angle, and were shown at an eccentricity of 4.5 degrees from fixation. Participants sat at a fixed viewing distance of approx. 60 cm from the computer screen (model BENQ XL2420T 24 in., of 1920 × 1080 pixels resolution, and 60 Hz refresh rate) in a semi-darkened room.

The background on the screen consisted of a frontal view of a 3-D room with a grey back wall divided by a lighter wall. A human avatar, either male or female (avatars were colour-matched and corrected for luminance), would appear in the centre of the screen looking either to the right or to the left. The background was created in Adobe Photoshop CC 2018 and the avatars were created using the avatar customisation tools in the Second Life Viewer software (Version 6.6.4; https://secondlife.com/). The procedure and stimulus presentation were controlled with PsychoPy (Peirce et al., 2019) and Python version 3.6.8.

2.4. General procedure

Two days before the experimental session, each participant was directed to complete an online survey running on LimeSurvey through an anonymised code. The survey included the Perspective-Taking (PT) and Empathetic Concern (EC) subscales of the Interpersonal Reactivity Index (IRI) questionnaire, and the Liebowitz Social Anxiety Scale (LSAS) questionnaire.

The experimental session consisted of a thresholding task, a familiarisation task, and the main task. During the thresholding task, we calibrated the Gabor pattern contrast for each participant using the QUEST procedure (Watson & Pelli, 1983), to estimate a contrast threshold that would yield 75 % accuracy performance during a two-interval forced-choice detection task. We acquired three independent threshold estimates, each consisting of 40 randomly ordered trials. The mean value of these three estimates was used to set the contrast value for the Gabor patch for the rest of the study, which then remained constant, to reduce the risk of inflating the estimates of metacognitive efficiency (Rahnev & Fleming, 2019).

Several studies showing spontaneous perspective-taking, including Seow and Fleming (2019), rely on a mixed-trial design, where participants are required to constantly change between their own and the avatar's perspectives. The motivation for this choice is often to compare altercentric and egocentric interferences. Since we are only interested in possible altercentric interference effects of metacognition, here we used a simplified single-perspective design, with participants asked to reply always from their own perspective during the main task. Single-perspective designs using the dot-counting task tend to elicit altercentric effects only when participants are implicitly prompted to consider the avatar's perspective via instructions or by placing the avatar at or close to fixation (O'Grady et al., 2020). For this reason, prior to the main task, we included a familiarisation task using the typical mixed-trial design requiring participants to take either their own or the avatar's perspective, to habituate them to what the avatar can and cannot see.

In both the familiarisation and main tasks, participants were shown either a Gabor pattern embedded in noise (present condition) or a noise patch (absent condition), and asked to report whether they perceive the target pattern. The familiarisation task consisted of 64 randomly ordered trials in a 2x2x2x2 factorial design crossing presence of Gabor target (present vs absent), avatar direction relative to target position (congruent vs incongruent), perspective (self vs other), and social condition (seeing vs non-seeing). During the familiarisation task, each trial began with a fixation cross presented for 800 ms. The word "YOU" or "THEM" was then shown for 750 ms, indicating the perspective the participant was to take for that trial. The avatar then appeared for 500 ms, with the stimulus (noise patch, or noise superimposed with a Gabor grating) appearing for 300 ms. Participants were asked to indicate with the "up" and "down" arrow keys whether the target was present or absent from the perspective they were instructed to take on that trial.

In the main task, participants performed a total of 448 fully randomised trials (56 trials per condition), shown in four blocks with a short break in between, in a 2x2x2 factorial design where we crossed presence of the Gabor target (present vs absent), avatar direction relative to target position (congruent vs incongruent), and social condition (seeing vs non-seeing) (Fig. 1A). Each congruency level was shown in two variants, according to the stimulus appearing on the right or left side of the screen. In turn, every unique condition was shown with two avatar variants, male or female. Contrary to the familiarisation task, the main task did not include the OTHER condition, and we instructed participants to perform the task from their own perspective. During the main task, each trial began with a fixation cross presented for 800 ms. The avatar then appeared for 500 ms, with the stimulus appearing for 300 ms. After each trial, in addition to indicating with the "up" and "down" arrow keys whether the target was present or absent, participants were asked to rate how confident they were about their response on a 4-point scale (1 = low, 4 = high) (Fig. 1B).

2.5. Data analysis plan

We anticipated that the threshold estimate procedure at the start of the study may not always result in a contrast value yielding mean performance of 75 % accuracy for every participant. Thus, to allow for meaningful interpretation of SDT analysis across conditions, we preregistered to exclude participants from further analysis in case of mean accuracy <55 % or > 95 % correct aggregated across all conditions of the main experiment session. We excluded 5 participants from the sample under these criteria. We further excluded 3 participants from the analysis sample, as they showed extreme outlier results in accuracy, *d'*, and log(M-ratio). These 3 participants were the only ones to show, in two or more conditions with the Gabor target being present (although not when aggregating all 2x2x2 conditions), a pattern of responses with <0.1 proportion correct answers (i.e., completely below chance, or flipped use of response keys), while reporting >3.6 mean confidence in their answers (i.e., over 90 % mean confidence). Although we didn't preregister these exclusion criteria, such patterns of responses strongly suggest that they didn't fully comply with the task instructions, and can lead to unstable estimates of meta-*d'* (Rahnev, 2023). Finally, we preregistered to exclude from the analysis trials with a decision response time lower than 100 ms from stimulus onset, on the basis that trials with shorter response times cannot be genuine responses to the stimuli (Whelan, 2008). The final sample for the analyses had 27 subjects (18 female, $M = 30.52$ years, $SD = 9.28$), from whom we excluded 30 trials due to short response times.

All the analyses were carried out using the R programming language (version 4.0.4). Using lme4 R package (Bates, Mächler, Bolker and Walker, 2015), we ran mixed linear regression models, except for accuracy, where we fitted logistic generalised mixed models, and for reaction times (RT), where we fitted generalised mixed models with an inverse Gaussian distribution on RT data (Lo & Andrews, 2015). We report the results from parsimonious mixed models with best-performing random structures for each measure (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017; Bates, Kliegl, Vasishth and Baayen, 2015). For accuracy, RT, and confidence ratings, we first fitted a mixed model with Congruency, Social condition, Target Presence, and their interaction as fixed factors, with a maximal participant random effects structure (Barr, Levy, Scheepers, & Tily, 2013):

$$\begin{aligned} measure \sim\ & congruency \times socialCondition \times targetPresence + (1 \\ & + congruency \times socialCondition \times targetPresence \mid subjectID) \end{aligned}$$

We then refitted models with simpler random structures, eliminating random effects which didn't lead to a reduction in the BIC criterion, to find the maximal random effects structure for an optimally-performing converging model (Matuschek et al., 2017) (using the Buildmer package in R; see Supplementary Materials for details). 95 % Confidence Interval (CI) reported on the fixed effect parameters were obtained by bootstrapping with 1000 resamples. To test the altercentric interference vs directional-orienting hypotheses, and to allow comparison of our results with previous studies that only analysed trials where the target was present (Seow & Fleming, 2019), we pre-registered to conduct preplanned Bonferroni-corrected pairwise comparisons between the two Congruency levels for each Social condition (seeing and non-seeing) separately. For accuracy, RT, and confidence, these comparisons were done on the target-present subset of the data.

For all SDT-based analyses, we used both target-present and -absent trials. We defined type-1 sensitivity as, $d' = z(H) - z(FA)$ and type-1 criterion bias as $c = -.5(z(H) + z(FA))$, where H is the hit rate (responding "present" when target is present), FA is the false-alarm rate (responding "present" when target is absent), and z is the inverse of the cumulative normal distribution. H and FA rates of 0 and 1 were corrected to $(2N)^{-1}$ and $1 - (2N)^{-1}$, respectively, where N is the number of trials on which the rate is based (Macmillan & Creelman, 2005). We fitted and analysed the measure of metacognitive efficiency log(M-ratio) as the measure of interest since it allows for a log-normal prior in Bayesian estimation, which is appropriate for a ratio parameter like M-ratio, ensuring that increases and decreases relative to the expected value of 1 are given equal weight during parameter estimation (Fleming, 2017). We used the Hierarchical Bayes HMeta-D toolbox (Fleming, 2017) for fitting individual and group-level estimates of log(M-ratio) across the four conditions of interest (Congruency x Social condition). We used this toolbox to sample from the posterior distributions with Markov chain Monte Carlo (MCMC) implemented in JAGS in R, with 3 chains for each parameter, 2000 adaptation steps, 5000 burn-in samples, and 50,000 effective samples. Convergence of all chains was assessed by visually examining trace plots and using the diagnostic $\widehat{R}$ statistic (Gelman and Rubin's potential scale reduction factor; Gelman & Rubin, 1992) for each parameter. Mean $\widehat{R}$ was 1.00, with all $\widehat{R}$ values <1.1, indicating good convergence. For d', c and log(M-ratio) measures, we first fitted a mixed linear model with Congruency, Social condition, and their interaction as fixed factors, with a maximal participant random effects structure:

$$measure \sim congruency \times socialCondition + (1 + congruency \times socialCondition \mid subjectID)$$

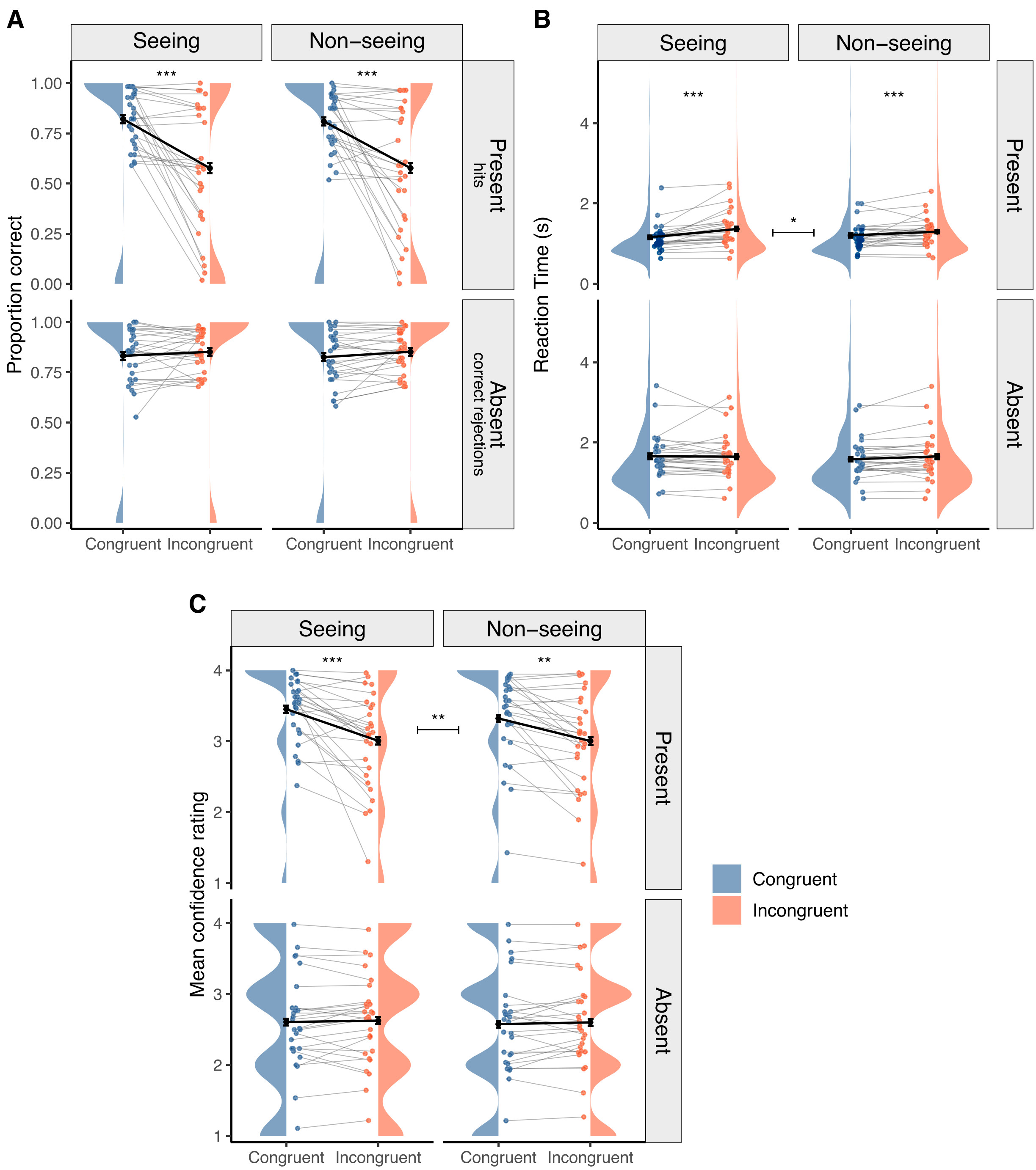

Fig. 2. Effects of congruency (congruent vs incongruent) on mean accuracy (proportion of correct responses) (**A**), mean reaction times (**B**), and mean confidence ratings (**C**) across all conditions. Overall mean in black, with each participant's mean in colours. Distributions are based on single-trial data. Symbols indicate the significance of pairwise comparison z and t-tests (*p < .05, **p < .01, ***p < .001).

We then refitted models with simpler random structures for an optimally-performing converging model and computed 95 % CI of main factors by bootstrapping, as with the accuracy, RT, and confidence analyses. We also pre-registered to conduct pre-planned Bonferroni-corrected pairwise comparisons between the two Congruency levels for the seeing and non-seeing conditions separately. The error bars in the all figures are based on the 95 % CI of the within-participant variability (Cousineau, 2005; Morey, 2008).

3. Results

3.1. Accuracy

For accuracy, the winning logistic generalised mixed model was: $accuracy \sim congruency \times socialCondition \times targetPresence + (1 + congruency + targetPresence | subjectID)$. Holding other predictors constant, participants were overall more accurate in congruent compared to incongruent trials (OR [CI] = 1.97 [1.34, 2.77], $z = 3.64$, $p < .001$); and overall more accurate when the target was absent rather than present (OR [CI] = 0.41 [0.22, 0.8], $z = -2.39$, $p = .02$). We found an interaction between these two predictors, such that the Congruency effect on accuracy was more pronounced in target present rather than absent trials (OR [CI] = 4.02 [3.23, 5], $z = 12.7$, $p < .001$)(see Fig. 2 A). There were no significant main effects for the Social condition predictor nor for its interactions with other predictors (all $ps > 0.4$). Pre-planned comparisons resulted in a significant effect of Congruency both in with seeing (OR [CI] = 4.13 [2.77, 6.15], $z = 6.95$, $p < .001$), and non-seeing avatars (OR [CI] = 3.79 [2.54, 5.64], $z = 6.55$, $p < .001$) (see Fig. 2A).

3.2. Reaction times

For RTs, the optimally converging model was: $RT \sim congruency \times socialCondition \times targetPresence + (1 + congruency | subjectID)$. Keeping all other predictors constant, participants were faster when the target was present (β [CI] = −0.24 [−0.27, −0.21], SE = 0.01, $p < .001$), and when the avatar's orientation was congruent (β [CI] = −0.11 [−0.18, −0.03], SE = 0.03, $p < .001$), with a significant interaction between these conditions, such that participants were faster when the target was both present and congruent with the avatar's orientation (β [CI] = −0.12 [−0.19, −0.06], SE = 0.03, $p < .001$). These effects were qualified by a significant three-way interaction of Congruency x Presence x Social condition (β [CI] = −0.12 [−0.25, 0], SE = 0.05, $p = .01$), showing that, although the congruency boost on RT speed in the target-present trials was significant in both seeing ($z = -5.99$, $p < .001$) and non-seeing ($z = -4.13$, $p < .001$) conditions, this boost was significantly stronger (with shorter RTs) in the seeing compared to the non-seeing condition ($z = -2.39$, $p = .02$)(see Fig. 2B).

3.3. Confidence

For confidence, the optimally converging model was: $confidence \sim congruency \times socialCondition \times targetPresence + (1 + congruency + socialCondition + targetPresence | subjectID)$. Keeping all other predictors constant, participants had higher confidence when the target was present (β [CI] = 0.59 [0.42, 0.77], SE = 0.09, $t(26) = 6.43$, $p < .001$), and when the avatar's orientation was congruent (β [CI] = 0.18 [0.10, 0.26], SE = 0.04, $t(26) = 4.32$, $p < .001$), with a significant interaction between these factors, such that participants were more confident when the target was both present and congruent with the avatar's orientation (β [CI] = 0.4 [0.34, 0.47], SE = 0.03, $t(11954) = 12.54$, $p < .001$). We also observed a significant interaction of Congruency x Social condition (β [CI] = 0.07 [0.01, 0.13], SE = 0.03, $t(11954) = 2.08$, $p = .04$), so that the boosting effect of the congruent avatar orientation on confidence was stronger with a seeing (vs non-seeing) avatar. Pairwise comparisons in the target-present subset of the data showed that the congruency boost on confidence was significant in both the seeing ($t(34.2) = 3.29$, $p = .002$) and the non-seeing ($t(34.2) = 0.21$, $p < .001$) conditions. Following the Congruency x Social interaction, the congruency effect on confidence ratings in the target-present trials was significantly higher in the seeing versus non-seeing condition ($t(11954) = 2.83$, $p = .005$) (See Fig. 2C).

3.4. Sensitivity d' and bias c

The optimal converging regression models for type-1 sensitivity d' and bias c had the form: $measure \sim congruency \times socialCondition + (1 | subjectID)$. The regression analysis revealed a significant effect of Congruency on d', with participants showing a higher d' during the congruent than incongruent condition (β [CI] = 0.76 [0.41, 1.12], SE = 0.18, $t(26) = 4.11$, $p < .001$). There was no significant main effect of Social condition nor of its interaction with congruency (all $ps > 0.5$). Mirroring the accuracy results, pre-planned pairwise comparisons between Congruency levels separately for each Social condition showed that the positive effect of Congruency on d' was significant with both seeing ($t(34.45) = 3.57$, $p < .001$) and non-seeing ($t(34.45) = 4.07$, $p < .001$) avatars (see Fig. 3 A).

We found a similar pattern of results in the regression analysis on criterion bias c, with significant effects of Congruency (β [CI] = −0.43 [−0.66, −0.66], SE = 0.11, $t(26) = -3.96$, $p < .001$) such that participants had a larger bias to respond "present" in the incongruent than the congruent condition. The main effect of Social condition and its interaction with Congruency were not significant (all $ps > 0.5$). Pre-planned pairwise comparisons between Congruency levels run for each Social condition separately showed that the effect of Congruency on c was significant in both the seeing ($t(31.62) = -0.42$, $p < .001$) and non-seeing ($t(31.62) = -0.43$, $p < .001$) conditions (see Fig. 3B).

3.5. Metacognitive efficiency

We estimated group-level log(M-ratio) with a Bayesian hierarchical model fitted for each condition separately, also fitting estimates at the individual level for use in regression analyses (Fleming, 2017). The optimal converging regression model was: $log(Mratio) \sim congruency \times socialCondition + (1 | subjectID)$. We found a significant effect of Congruency, such that participants showed better metacognitive efficiency on trials with congruent avatar orientation (β [CI] = 0.29 [0.1, 0.49], SE = 0.1, $t(78) = 2.95$, $p = .004$)(see Fig. 3C). There was no significant main effect of Social condition (β [CI] = −0.03 [−0.24, 0.14], SE = 0.1, $t(78) = -0.35$, $p = .72$), or the interaction between Congruency and Social condition (β [CI] = 0.32 [−0.06, 0.71], SE = 0.2, $t(78) = 1.63$, $p = .1$). Pre-planned pairwise comparisons revealed that the main effect of Congruency was due to a congruent (vs incongruent) avatar boosting metacognitive efficiency in the seeing condition ($t(78) = 0.45$, $p = .002$), but not in the non-seeing condition ($t(78) = 0.13$, $p = .35$).

Although we did not pre-register to conduct Bayesian inferential analyses, given that the individual log(M-ratio) parameters were fitted using a Bayesian hierarchical model with MCMC sampling, we also obtained a group-level log(M-ratio) estimate that takes into account uncertainty in each individual subject's estimate (Fleming, 2017), and computed the 95 % highest density interval (HDI) for this group-level parameter (Fig. 3D). The HDI represents the 'credible' posterior range within which 95 % of the estimated parameter value falls (Kruschke, 2015). For the seeing condition, the HDI of metacognitive efficiency in congruent trials (HDI = [−0.74, −0.07], $M = -0.39$) was quantitatively higher than that of incongruent trials (HDI = [−1.34, −0.34], $M = -0.83$) in 93 % of the samples ($P(\theta_{incongruent} \leq \theta_{congruent}) = 0.93$). These results provide moderate evidence supporting a difference between Congruency levels, although the classical significance threshold of 95 % was not reached. But in the non-seeing condition, the HDI of metacognitive efficiency in congruent trials (HDI = [−0.98, −0.09], $M = -0.53$) was not quantitatively different from the HDI in incongruent

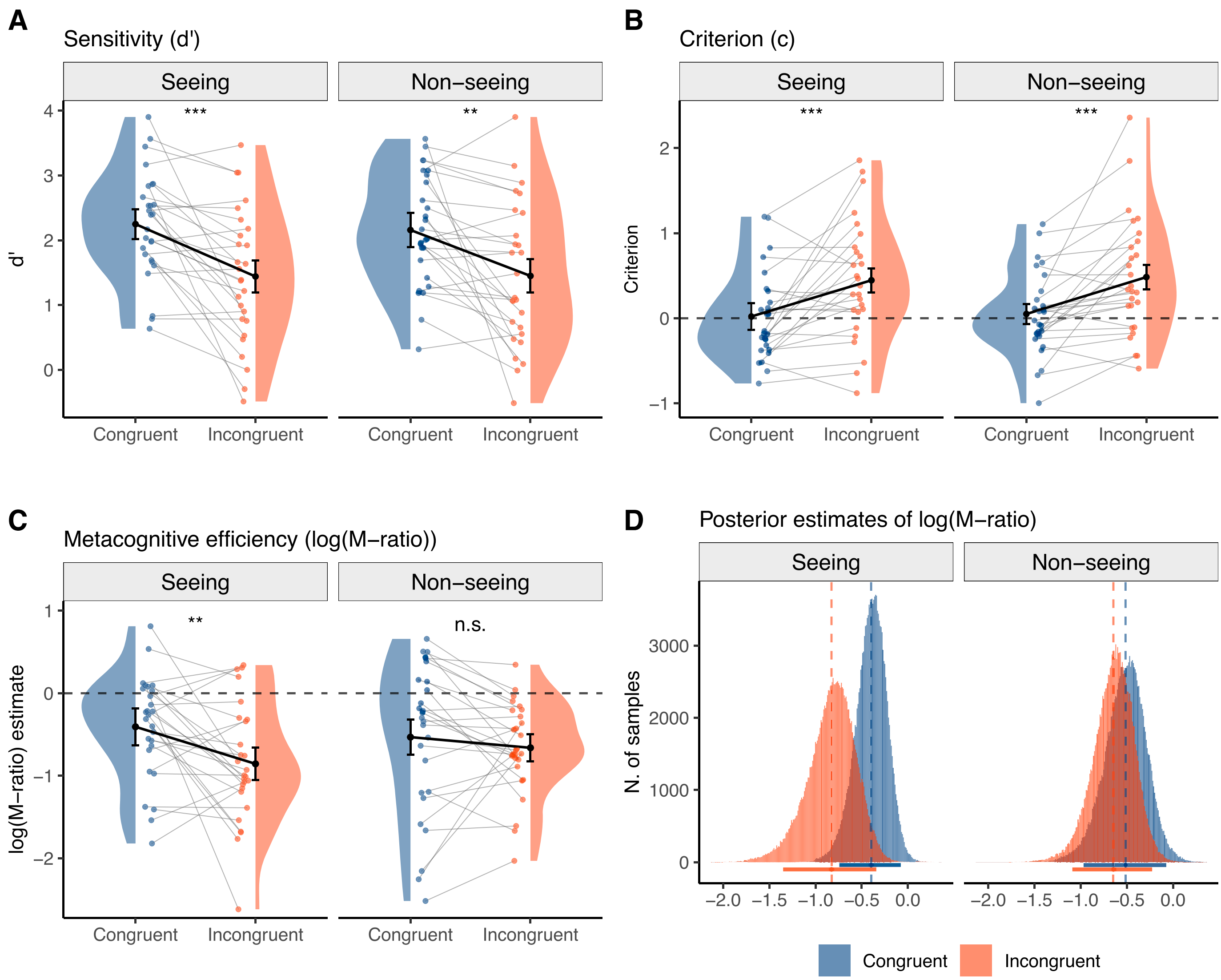

Fig. 3. Effects of congruency (congruent vs incongruent) on mean and individual *d'* (**A**), criterion (**B**) and point log(M-ratio) estimates (**C**) across conditions. Symbols indicate the significance of pairwise comparison *t*-tests (*$p < .05$, **$p < .01$, ***$p < .001$). (**D**) Posterior densities of hierarchical log(M-ratio) estimates. Horizontal lines indicate the highest density interval (HDI) of the distribution, and vertical dotted lines indicate the mean of the distribution.

trials (HDI = [−1.07, −0.23], $M = -0.64$) only in 64 % of posterior samples ($P(\theta_{incongruent} \leq \theta_{congruent}) = 0.64$).

It is known that detection tasks can elicit different behavioural patterns at the metacognitive level depending on whether the subject reported seeing the stimulus or not. Specifically, metacognitive sensitivity is typically impaired during judgements about absence, compared to judgements about presence (Mazor, Friston, & Fleming, 2020; Meuwese, van Loon, Lamme, & Fahrenfort, 2014). It is therefore possible that our experimental manipulations could have impacted metacognitive efficiency differently depending on judgements about presence and absence. We conducted further exploratory analyses (not pre-registered) to test for this possibility. For each experimental condition, we computed two separate group-level log(M-ratio) estimates, one for each response-type (target present, target absent), using the response-conditional variant of the Bayesian hierarchical group model in the HMeta-D toolbox (Fleming, 2017). We also fitted estimates at the individual level for regression analysis, mirroring the procedure above. As expected, participants' metacognitive efficiency was significantly lower in "absent" compared to "present" responses (β [CI] = 2.33 [2.19, 2.47], SE = 0.07, $t(182) = 31.24$, $p < .001$). We also found a main effect of Congruency, so that participants showed higher metacognitive efficiency on trials with congruent avatar orientation (β [CI] = −0.26 [−0.40, −0.11], SE = 0.07, $t(182) = -3.51$, $p < .001$). While the interaction between Response-type and Congruency was only marginally significant, with greater congruency effect in the "absent" responses (β [CI] = 0.25 [−0.02, 0.56], SE = 0.15, $t(182) = 0.25$, $p = .09$), and there was no significant interaction between Response-type and Social condition (β [CI] = 0.02 [−0.3, 0.3], SE = 0.15, $t(182) = 0.11$, $p = .3$), Bayesian inferential analyses on the group-level log(M-ratio) estimates showed a moderately higher congruency difference in posterior samples for "absent" responses in the seeing condition ($P(\theta_{incongruent} \leq \theta_{congruent}) =$ 0.83), than in any other condition (all $P(\theta_{incongruent} \leq \theta_{congruent}) =$ [0.65, 0.69]).

3.6. Trait questionnaires results

We conducted multiple linear regressions to explore the association between psychological traits and the congruency effect on four task-related variables, mean accuracy, *d'*, mean confidence rating, and log (M-ratio) (computed as the difference in each dependent variable between congruent and incongruent conditions). Trait measures of interest were: IRI empathy score, IRI perspective-taking score, LSAS avoidance score, LSAS anxiety score, and LSAS total score. We adjusted for age and gender, so that each regression had the form: $Congruency\ Effect\ on\ DV \sim Trait\ Score + Age + Gender$. To ensure comparability of regression coefficients, each trait measure score was log-transformed to account for skewness and all regressors were *z*-scored. We applied Bonferroni correction for multiple comparisons over the number of dependent variables. We found no significant associations between the congruency effects on task-related variables and any of our trait measures of interest (see Table S1).

4. Discussion

In this study, we investigated whether social perspective-taking influences participants' metacognitive judgements about their own perceptual performance. Specifically, we tested the altercentric hypothesis that sharing perception with a task-irrelevant agent can enhance metacognitive efficiency about perceptual responses. We used an experimental set-up based on previous findings that people's contrast sensitivity can be socially modulated (Seow & Fleming, 2019). Participants performed a contrast detection task, while a task-irrelevant avatar situated in the centre of the screen oriented its perspective either congruent or incongruent with the stimulus location. Participants were then asked to judge their confidence in the accuracy of their response. We also tested whether any effect on metacognitive efficiency was due to taking the perspective of the other agent, or to a directional orienting effect, by measuring the effects on metacognitive judgements of a seeing and a non-seeing blindfolded avatar.

Participants were both faster and more accurate at detecting a present target stimulus when its location was congruent with the avatar's orientation. Orientation congruency also had a boosting effect on participants' sensitivity (*d'*) in detecting the target. Moreover, the congruency effect on accuracy and perceptual sensitivity was significant in both the seeing and non-seeing avatar conditions. These results are in line with the directional orienting hypothesis, suggesting that congruency effects were not sufficiently based on an appraisal of whether the avatar could see the target or not (computing a mental state), but rather on extracting directional features from the avatar. Interestingly, reaction times were significantly faster in the seeing compared to the non-seeing condition. Consistent with the altercentric perspective-taking hypothesis, reaction times, unlike accuracy and sensitivity, were modulated by the avatar's perceptual state. This could indicate that participant's perceptual judgements were indeed sensitive to what the avatar can and cannot see, but not strongly enough to influence their overall accuracy and contrast sensitivity. Alternatively, these results may indicate that the congruency influence on accuracy was different across RT durations. Since shorter RTs often increase the probability of making an error (Heitz, 2014), the speed boost observed in the seeing condition may have negatively affected accuracy, but this effect could have been masked or overcome in turn by the accuracy increase conferred by a congruent avatar. Further exploratory analysis of accuracy in the target-present data revealed a significant three-way interaction between congruency, social condition, and RT, showing that the congruency effect on accuracy varied between the seeing and non-seeing conditions across RT durations (see Supplementary Materials for details). Interaction plots of the regression effects (marginal means) and accuracy rates conditional on RT durations (Fig. S1) show that in the seeing condition, the congruency effect on accuracy (higher accuracy for congruent than incongruent trials) was large for shorter RTs, and became progressively smaller as RTs became longer. In contrast in the non-seeing condition, the congruency effect on accuracy remained comparatively unchanged across RTs. These results align with the hypothesis that the effect of a congruent avatar on accuracy masked or cancelled out the likelihood of errors due to shorter RTs in the seeing condition, but in turn, an incongruent avatar made errors at shorter RTs more likely.

At the perceptual level, our results provide an interesting addition to those of Seow and Fleming (2019), who also compared the effects of seeing and non-seeing avatars, although using a different task design. They reported a significant congruency effect on accuracy and perceptual sensitivity only in the seeing condition, suggesting the effect is due to social perspective-taking. For reaction times, they reported a main effect of congruency, but no differences in this congruency effect between the seeing and non-seeing conditions, suggesting RT is insensitive to shared perception. As we used a different task paradigm, rather than contradicting Seow and Fleming's (2019) results, our findings provide further insight into the enhancement of perceptual processing in different social circumstances. In their study, participants had to switch between their own and the avatar's perspective across trials in a randomised manner. In the present study, participants only performed this version of the task as a familiarisation block of 64 trials. During the main experimental session, participants were not required to switch between perspectives, and were instructed to always respond from their own perspective. These different task designs tend to elicit different behavioural patterns of spontaneous perspective-taking (O'Grady et al., 2020). When testing for the effects of occluding the avatar's vision, previous studies using the dot-counting task with explicit perspective-switching requirements have often found results consistent with the altercentric perspective-taking hypothesis (Baker, Levin, & Saylor, 2016; Furlanetto, Becchio, Samson, & Apperly, 2016), while studies that didn't require perspective-switching have often found results consistent with the directional orienting hypothesis (Cole, Atkinson, Le, & Smith, 2016; Conway, Lee, Ojaghi, Catmur, & Bird, 2017; Langton, 2018; but see, e.g., Experiment 3 in Samson et al., 2010; Surtees, Samson, & Apperly, 2016). However, the precise mechanisms through which these design features elicit or inhibit perspective-taking and/or low-level attention-cueing are still heavily debated and unclear (cf. Rubio-Fernandez, Long, Shukla, Bhatia, & Sinha, 2022; Westra, Terrizzi, van Baal, Beier, & Michael, 2021). O'Grady et al. (2020) suggest that perspective-taking is not purely stimulus driven; rather, participants compute the avatar's perspective rapidly and involuntarily, but only in circumstances where their attentional systems prompts them to. From our study, we can conclude that, in circumstances where the other's spatial perspective remains task-irrelevant during the whole task, their orientation alone is sufficient to modulate perceptual sensitivity. Of course, subjects may still spontaneously engage in computing the visual state of the other's, and our reaction times findings suggest they did so. Our results show that the effects of social perspective-taking can be selectively different across measures of perceptual behaviour. The precise role of different task paradigm requirements that enable or inhibit perspective-taking influences on perceptual sensitivity remains to be determined in future, dedicated studies.

Mirroring the accuracy and sensitivity results, participants' confidence ratings were significantly higher when the avatar's orientation was congruent with a present target. This is not surprising, since level of confidence tends to correlate with accuracy performance (Fleming & Lau, 2014). However, contrary to accuracy and sensitivity but similar to RT results, confidence ratings were significantly higher in the seeing compared to the non-seeing condition. This could suggest that the perceptual perspective of the avatar, and not just its orientation, could affect participant's confidence regardless of their accuracy, that is, their metacognitive bias. To explore this possibility, we re-run the analyses on confidence ratings while controlling for trial-to-trial accuracy (not pre-registered, see Supplementary Materials for details). The congruency influence of the avatar's orientation remained significant, but there was no longer an interaction between congruency and social conditions. These results suggest that the avatar orientation influenced metacognitive bias: a congruently oriented avatar induced a bias to report higher confidence compared to an incongruently oriented one, regardless of the participant's accuracy. However, metacognitive bias was not affected by the avatar's visual state. Given the similar pattern of results between confidence ratings and RT, participants may leverage the elapsed time in their response as a reliability cue to report their degree of confidence, besides their objective accuracy (Kiani, Corthell, & Shadlen, 2014).

Higher confidence ratings do not necessarily lead to better or worse metacognitive efficiency, i.e., being better or worse at distinguishing when one's perceptual judgement is correct or not. We operationalised metacognitive efficiency using the log(M-ratio) measure (Fleming, 2017; Maniscalco & Lau, 2012). In contrast to our accuracy and perceptual sensitivity results, metacognitive efficiency was significantly higher when the avatar's orientation was congruent with the stimulus, but only in the seeing condition. Supplementing these frequentist regression results, Bayesian inference analyses gave moderate evidence for a congruency effect only in the seeing condition. These results provide evidence in line with the altercentric hypothesis: the effects of the avatar's orientation on metacognitive efficiency are modulated by an appraisal of what the avatar can and cannot see. However, as the interaction between congruency and social condition was not significant, we cannot conclude that the effect of congruency in the seeing condition was exclusively driven by computing the avatar's visual state, without any role of low-level directional cueing. Rather, it is likely that metacognitive efficiency was influenced by a mixture of low-level and perspective-specific cues. These results suggest that, when a task-irrelevant avatar's visual perspective is congruent with the subjects', it can boost metacognitive efficiency, and conversely, an incongruent visual perspective can impair metacognition. In our paradigm, then, the metacognitive appraisal of perceptual decisions was modulated to some extent by taking the perspective of the avatar and estimating whether it can also see the target.

Perspective-taking involves shifting attention towards the target of the other's gaze (Kampis & Southgate, 2020), with the other agent acting as an attentional cue even when the shift is mediated by computations of their visual perspective. Previous studies suggest that avatar spatial cuing effects on RT hold only within a critical SOA window between avatar and stimulus presentation of 300 ms to 600 ms (Bukowski, Hietanen, & Samson, 2015; Gardner, Hull, Taylor, & Edmonds, 2018). It is likely that the effects of the avatar on perceptual sensitivity and accuracy would also hold only within this SOA window. These studies only presented seeing avatars, without blindfolds, goggles, or any obstacles to the avatar's vision. It may be possible that the SOAs required for inducing a cuing effect on perceptual sensitivity and accuracy may be different for seeing and non-seeing avatars. This should be systematically studied in future work.

Although taking the avatar's perspective involves shifts in spatial attention, previous studies support the notion that metacognitive ability is stable to manipulations of attentional cues. Using a combination of endogenous and exogenous attentional cues, Landry et al. (2021) found that metacognitive efficiency did not vary between valid and invalid cues. Moreover, in a purely exogenous cueing paradigm, Recht et al. (2022) reported that exogenous cues do not significantly affect metacognitive efficiency. Taken in the context of these findings, the observed boost to metacognitive efficiency with the unoccluded perspective of a congruent (vs incongruent) avatar suggests that socially-specific mechanisms are involved in the modulation of metacognitive ability. The mechanisms by which perspective-taking influences perceptual metacognition are yet to be determined. One tentative hypothesis is that perspective-taking recruits representational and neural machinery that overlaps, or co-opts, machinery that supports the appraisal of one's own perceptual states. This hypothesis is consistent with the proposal that explicit metacognitive abilities share some functional and mechanistic resources with mindreading, the ability to evaluate and understand the mental states of others (Carruthers, 2009; Lombardo et al., 2010; but see Proust, 2012). It has also been proposed that metacognitive systems are functionally involved in, and may even have evolved to facilitate, social coordination and mindreading (Heyes, Bang, Shea, Frith, & Fleming, 2020; Shea et al., 2014). Vaccaro and Fleming's (2018) neuroimaging meta-analysis shows an overlap for metacognition and mindreading capacities in medial prefrontal cortex areas, which may support reflection on others' and one's own mental states. However, the neuroimaging evidence for shared neural mechanisms is still mixed (e.g., Li, Dai, & Jia, 2022). Recent dual-task studies comparing performance on perceptual metacognition and mindreading tasks also report behavioural and computational associations between these abilities (Nicholson, Williams, Lind, Grainger, & Carruthers, 2021; van der Plas et al., 2021), lending support to the proposal of shared meta-representational resources. As social perspective-taking is a minimal form of mindreading that requires the representation of other people's perceptual states (Apperly, 2011; Phillips, 2019), our findings that it can influence metacognitive efficiency during the same task provide a foundation for further studies on the relationship between mindreading and metacognition, and their neural underpinnings.

Perceptual detection tasks are well suited for testing the initial hypothesis that altercentric perspective-taking can influence metacognition, as there are valid answers about the target both from the participant's overall perspective on the scene, and from the avatar's one-sided perspective: either the avatar sees the target or it does not. However, in detection tasks, stimulus evidence can only be properly gathered during target-present trials, not target-absent ones. In perceptual discrimination tasks, in contrast, this asymmetry doesn't exist. The differences between detection and discrimination tasks are reflected at the metacognitive level, with different metacognitive sensitivity (Meuwese et al., 2014) and neural bases of metacognitive judgements between these tasks (Mazor et al., 2020). In line with these studies, our findings show that metacognitive efficiency is substantially lower for judgements of absence than for judgements of presence. A main effect of congruency, keeping other predictors constant, suggests that the effect of avatar orientation generalised across judgement types. However, the effects of seeing vs non-seeing avatars across judgement types were less clear: Bayesian analyses showed a moderately stronger congruency effect in the seeing condition for judgements of absence than for any other condition, suggesting that social perspective congruency may facilitate insight into judgements of absence, although our null regression results do not fully support inferences about the role of perspective-taking across judgement types. As discrimination tasks do not show this asymmetry in responses, future studies should attempt to investigate whether perspective-taking impacts metacognitive judgements in discrimination paradigms.

To conclude, the present study reveals that sharing perception of the same objects with others can affect higher cognitive processes in perceptual decision-making. These findings contribute to the growing research on how an individual's perceptual and cognitive processing of the world is affected by the social context in which these processes occur (Heyes et al., 2020; Kampis & Southgate, 2020). This study provides grounds for future work on metacognition in social domains, and on the interaction between mentalising and metacognition.

CRediT authorship contribution statement

Lucas Battich: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Elisabeth Pacherie:** Writing – review & editing, Methodology, Conceptualization. **Julie Grèzes:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

We have no known conflicts of interest to disclose.

Data availability

The data generated and analysed during the study are openly available at doi:10.17605/OSF.IO/3XP4S. The experiment and analyses were pre-registered at the Open Science Framework (https://osf.io/sugmb).

Acknowledgements

We acknowledge the support of a Fyssen Foundation fellowship grant awarded to L.B., along with support of the French National Research Agency (ANR-23-AERC-0016 awarded to L.B., ANR-20-CE28-0003 awarded to J.G. and E.P, and ANR-10-IDEX-0001-02 PSL* and ANR-17-EURE-0017 FrontCog).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2024.105966.

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