

# Projection inferences: On the relation between prior beliefs, at-issueness, and lexical meaning

Word count (excluding Abstract, Supplements, and References): x,xxx words

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## Abstract

Research to date has shown that projection inferences, that is, inferences that the speaker believes utterance content contributed in the scope of an entailment-canceling operator, are modulated by a number of factors, including interpreters' *prior beliefs* about the content, the extent to which the content is *at-issue* with respect to the Question Under Discussion, as well as the *lexical meaning* of expressions associated with the content. Theoretical models of projection inferences differ with respect to whether these factors are taken to interact or to independently modulate projection inferences. This paper reports the result of two experiments designed to investigate the relation between prior beliefs, at-issueness, and lexical meaning for projection inferences in American English. The contents under investigation are contributed by the clausal complements of clause-embedding predicates, which differ in lexical meaning. The experiments suggest that (I) the effect of prior beliefs on projection persists across predicates, (II) the effect of at-issueness on projection varies by predicate, (III.a) prior beliefs and at-issueness do not interact in modulating projection, and (III.b) there is no effect of prior beliefs on at-issueness. We show that there is no projection analysis on the market that is able to capture these results, and point out important areas for future research on projection inferences.

**Keywords:** Projection inferences; prior beliefs; at-issueness; lexical meaning of clause-embedding predicates; American English

# 1 Introduction

Projection inferences are interpreter-side inferences that the speaker believes content that is contributed by an expression in an entailment-canceling environment, such as polar questions (see, e.g., Kiparsky and Kiparsky 1970; Potts 2005). For instance, from Scott’s utterance of the polar question in (1), interpreters may infer that Scott believes the content of the complement (CC) of *know*, that Julian dances salsa.

- (1) Scott: “Does Cole know that Julian dances salsa?”

Prior research has found that projection inferences are modulated by a number of factors. One factor is the lexical meaning of the expression associated with the projective content: It has long been observed, for example, that the projection inference is stronger in (1), where the clause *Julian dances salsa* is embedded under *know*, than in a variant of (1) where the same clause is embedded under *discover* (e.g., Karttunen 1971; Tonhauser et al. 2018; Degen and Tonhauser 2022). Another factor are interpreters’ prior beliefs about the content (e.g., Mahler 2020; Degen and Tonhauser 2021): For instance, the projection inference in (1), that Scott believes that Julian dances salsa, is stronger if interpreters know that Julian is Cuban (and know that Scott knows this, too) than if they know that Julian is German (and know that Scott knows this, too). A third factor is the status of the content with respect to the Question Under Discussion (QUD, Roberts 2012), that is, the at-issueness of the content (e.g., Simons et al. 2010; Cummins and Rohde 2015; Tonhauser 2016; Tonhauser et al. 2018; Djärv and Bacovcin 2017, 2020): The projection inference in (1) is stronger if (1) is taken to address a question about Scott’s mental state than if (1) is taken to address the question of whether Julian dances salsa.

While much progress has been made on understanding which factors modulate projection inferences, understanding the relation between these factors is important for the formulation of theories of projection inferences. There is, however, little research to date on the relations between these factors and, where there is research, there is disagreement.

**(I) Prior beliefs and lexical meaning.** Degen and Tonhauser 2021 found that prior beliefs modulate projection for the CCs of the 20 clause-embedding predicates they investigated. As their analyses did not consider the lexical meanings of the clause-embedding predicates, an open question is whether there is an effect of prior beliefs on projection across clause-embedding predicates.

**(II) At-issueness and lexical meaning.** Different assumptions are made in the literature about the relation between lexical meaning and at-issueness. On the one hand, Tonhauser et al.’s 2018 Gradient Projection Principle holds that the more not-at-issue a content is, the stronger the projection inference is. Empirical evidence for the Gradient Projection Principle, which is assumed to hold for any content, was provided in Tonhauser et al. 2018 for a variety of contents associated with English expressions (see also Tonhauser 2016). On the other hand, there is research that suggests that there is by-expression variation in the effect of at-issueness on projection (e.g., Djärv and Bacovcin 2017, 2020; Mahler, de Marneffe, and Lai 2020). Specifically, this research suggested that the effect of at-issueness on projection is sensitive to whether the clause-embedding predicate is ‘factive’ (like *know*) or ‘nonfactive’ (like *think*). The results of the experiments reported on in Djärv and Bacovcin 2017, 2020 and Mahler et al. 2020 suggest that the Gradient Projection Principle holds for factive predicates, but that there is either the opposite effect for nonfactive predicates (Djärv and Bacovcin 2017, 2020) or no effect for nonfactive predicates (Mahler et al. 2020). These results are further complicated by recent experimental research that challenged the assumed categorical distinction between factive and nonfactive predicates (e.g., de Marneffe et al. 2019; Degen and Tonhauser 2022). In short, there is need for further investigations of the relation between at-issueness and predicate meaning in modulating projection.

**(III) Prior beliefs and at-issueness.** There is also disagreement in the literature about the relation between prior beliefs and at-issueness. Models of projection inferences developed within the Rational Speech Act (RSA) framework take the two factors to independently modulate projection (Qing, Goodman, and Lassiter 2016; Stevens, de Marneffe, Speer, and Tonhauser 2017; Warstadt 2022; Pan and Degen 2023). These models reflect the broader assumption of RSA models of utterance interpretation that the two factors are independent: Interpreters' prior beliefs about content are modeled as affecting interpretation directly, whereas at-issueness affects the speaker's production model and therefore only enters interpretation indirectly, via consideration of the speaker model (for background on the RSA framework see, e.g., Degen 2023). On the other hand, prior beliefs and at-issueness are not independent according to Tonhauser et al.'s 2020 Non-redundancy Principle for At-issue Content, which holds that the more an interpreter takes a content to be a priori true (i.e., before observing an utterance), the less likely it is that they take the speaker to have intended for the content to be at-issue. For (1), this principle leads one to expect that the more an interpreter is a priori committed to Julian dancing salsa, the less likely it is that Scott's utterance is taken to address the question of whether Julian dances salsa.

This paper reports the results of an experiment designed to investigate the relations between lexical meaning, interpreters' prior beliefs, and at-issueness in modulating projection inferences, by addressing the research questions in (2).

## (2) Research questions

- (I) Prior beliefs and lexical meaning:** Is there an effect of prior beliefs on projection across clause-embedding predicates, that is, across lexical meanings?
- (II) At-issueness and lexical meaning:** Is it the case that content that is more not-at-issue is more projective for all clause-embedding predicates (as expected under Tonhauser et al.'s 2018 Gradient Projection Principle) or only for factive predicates, with the opposite effect for nonfactive predicates (as suggested in Djärv and Bacovcin 2017, 2020)?
- (III) Prior beliefs and at-issueness:**
  - a.** Is it the case that the prior probability and at-issueness of content do not interact in modulating projection inferences (as assumed in most RSA models of projection inferences)?
  - b.** Is it the case content is more not-at-issue the higher its prior probability (as expected from Tonhauser et al.'s 2020 Non-redundancy Principle for At-issue Content)?

The contents whose projection is investigated are the CCs of 20 English clause-embedding predicates. By including predicates that have traditionally been considered factive, predicates that have traditionally been considered factive, as well as predicates with unclear classifications, our experiment allows us to investigate the interaction between lexical meaning, prior beliefs, and at-issueness in modulating projection. The results of Exp. 1 (presented in section 2) suggests that (I) the effect of prior beliefs on projection persists across predicates, (II) the effect of at-issueness on projection varies by predicate, (III.a) prior beliefs and at-issueness do not consistently interact in modulating projection, and (III.b) there is no consistent effect of prior beliefs on at-issueness. These four results are replicated in Exp. 2, presented in section 3. We discuss the implications of these results for theories of projection in section 4, and conclude in section 5.

## 2 Experiment 1

Exp. 1 was designed to investigate the relation between interpreters' prior beliefs about content, content's at-issueness, and lexical meaning in modulating projection. Participants rated the prior probability, at-issueness, and projection of 20 contents of clausal complements of 20 clause-embedding predicates.

## 2.1 Methods

**Participants.** 600 participants with U.S. IP addresses and at least 99% of previous HITs approved were recruited on Amazon’s Mechanical Turk platform (ages: 18-73, median: 38.5). They were paid \$2.20.

**Materials and procedure.** The prior probability, at-issueness, and projection of the contents of 20 clauses were measured in three separate blocks. Prior probability was manipulated by pairing each of the 20 clauses (e.g., *Julian dances salsa*) with two facts between participants: The content of each clause was expected to have a higher prior probability in the presence of one fact (e.g., *Julian is Cuban*) than of the other (e.g., *Julian is German*). See Supplement A for the full set of 20 clauses and facts, and Supplement C for evidence that the facts successfully manipulated the prior probability of the respective contents.

In the prior block, which was the prior block in Degen and Tonhauser 2021, the 20 clauses were realized as the complements of *How likely is it that...?* questions. As shown in Fig. 1a, each target item consisted of one of the two facts for that clause and the *How likely is it that...?* question. Participants read the fact and assessed the prior probability of the content, given the fact. They gave their responses on a slider marked ‘impossible’ at one end (coded as 0) and ‘definitely’ at the other (coded as 1).

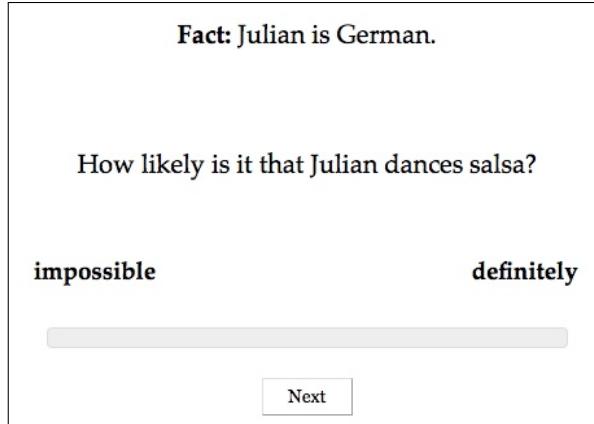
In the at-issueness and projection blocks, target items consisted of a fact and a polar question that was uttered by a named speaker, as in Fig. 1c and Fig. 1d, respectively. The polar questions were formed by realizing the 20 clauses as the complements of the 20 clause-embedding predicates in Fig. 1b, which are the same predicates as in Degen and Tonhauser 2021, 2022. Participants were told to imagine that they are at a party and that, on walking into the kitchen, they overhear somebody ask somebody else a question. At-issueness was measured using the ‘asking whether’ diagnostic (as in Tonhauser et al., 2018): Participants were asked to rate whether the speaker was asking about the CC, taking into consideration the fact. They gave their responses on a slider marked ‘yes’ at one end (coded as 0) and ‘no’ at the other (coded as 1). Greater not-at-issueness of the CC with respect to the implicit QUD should result in higher slider ratings. Projection was measured using the ‘certain that’ diagnostic (as in, e.g., Tonhauser et al. 2018; Mahler 2020; Degen and Tonhauser 2022): Participants were asked to rate whether the speaker was certain of the CC, taking into consideration the fact. They gave their responses on a slider marked ‘no’ at one end and ‘yes’ at the other. In contrast to the at-issueness block, ‘no’ was coded as 0 and ‘yes’ as 1, so that greater projection of the CC should result in higher slider ratings.

The at-issueness and projection blocks also included 6 control trials each, which functioned as attention checks: The contents of these items were expected to be at-issue and not to project. The same 6 contents were also used to form 6 filler trials in the prior block. These filler items were not used to assess participants’ attention. For the full set of control and filler items see Supplement A.

Each participant’s set of items was semi-randomly generated: First, the 20 clauses were randomly paired with the 20 predicates. Then, one random half of the items was assigned the respective clause’s higher-probability fact, and the other half its lower-probability fact. Participants completed a total of 78 trials: 20 target trials in each block, 6 control trials in the projection and at-issueness blocks each, and 6 filler trials in the prior block. Each participant completed the same filler and control trials. To measure the prior probability of the contents, the prior block was presented first to all participants. The projection and at-issueness blocks were then presented in random order. Within blocks, trial order was randomized.

After completing the experiment, participants filled out a short optional demographic survey. To encourage truthful responses, participants were told that they would be paid no matter what answers they gave in the survey.

**Data exclusion.** Data was excluded based on self-declared non-native speaker status and other criteria shown in Supplement B, leaving 10,100 data points from 505 participants (ages 20-73; mean age: 39.5).



(a) Target trial in prior block ('impossible'/low prior coded as 0, 'definitely'/high prior coded as 1).

*acknowledge, admit, announce, be annoyed, be right, confess, confirm, demonstrate, discover, establish, hear, inform, know, pretend, prove, reveal, say, see, suggest, think*

(b) 20 clause-embedding predicates in the at-issueness and projection blocks.

**Fact (which Scott knows): Julian is German.**

Scott asks: "*Did Cole suggest that Julian dances salsa?*"

Is Scott asking whether Julian dances salsa?

no   yes

Next

(c) Target trial in at-issueness block ('no'/not-at-issue coded as 1, 'yes'/at-issue coded as 0).

**Fact (which Scott knows): Julian is German.**

Scott asks: "*Did Cole suggest that Julian dances salsa?*"

Is Scott certain that Julian dances salsa?

no   yes

Next

(d) Target trial in projection block ('no'/no projection coded as 0, 'yes'/projection coded as 1).

Figure 1: Sample target trials and clause-embedding predicates in Exp. 1.

## 2.2 Statistical analysis

To address the research questions in (2), we want to know for each lexical meaning (contributed by a clause-embedding predicate) whether there is an effect of prior probability on projection (research question I), whether there is an effect of at-issueness on projection (research question II), whether there is an effect of the interaction of prior probability and at-issueness on projection (research question III.a), and whether there is an effect of prior probability on at-issueness (research question III.b). To address these questions, we fit two types of models to the data. All analyses were conducted in R (R Core Team 2016, version 4.3.1) using

RStudio (version 2023.12.0+369).

First, to address questions (I), (II) and (III.a), we fit 20 Bayesian mixed-effects beta regression models, one for each clause-embedding predicate, with weakly informative priors using the ‘*brms*’ package (Bürkner 2017). The models predicted certainty ratings<sup>1</sup> (measuring projection) from a centered fixed effect of asking-whether rating (measuring at-issueness), a centered fixed effect of prior probability rating, and their interaction. The models included a random by-item intercept (where an item is a complement clause) and a random by-item slope for the fixed effect of asking-whether and prior probability rating.<sup>2</sup>

Second, to address question (III.b), we fit 20 Bayesian mixed-effects beta regression models, one for each clause-embedding predicate, with weakly informative priors using the ‘*brms*’ package. The models predicted asking-whether ratings (measuring at-issueness) from a centered fixed effect of prior probability rating. The models included a random by-item intercept (where an item is a complement clause) and a random by-item slope for the fixed effect of prior probability rating.

To facilitate the interpretation of the models, they did not include a fixed effect of block or an interaction between a fixed effect of block and the other fixed effects. To investigate the role of block order, we conducted auxiliary analyses on the two subsets of the data that differ in whether the projection block preceded the at-issueness block (proj/ai) or followed it (ai/proj). (The prior block always came first.)

Hypothesis testing was conducted to investigate the effects of interest, that is (I) whether there was an effect of prior beliefs on projection for each of the clause-embedding predicates/lexical meanings, (II) whether there was an effect of at-issueness on projection for each of the clause-embedding predicates/lexical meanings, (III.a), whether there was an effect of the interaction between prior beliefs and at-issueness on projection for each for each of the clause-embedding predicates/lexical meanings, and (III.b) whether there was an effect of prior beliefs on at-issueness for each of the clause-embedding predicates/lexical meanings. Table 1a reports, for each of the four hypotheses, whether there was evidence for an effect, whether the effect was positive or negative, and the Bayes factor of the evidence. Full model outputs are provided here: [LINKTOFULLMODELOUTPUTSFOREXP1MODELS](#)

## 2.3 Results and discussion

Fig. 2 shows participants’ ratings for the full dataset. The corresponding figures for the two subsets ‘proj/ai’ and ‘ai/proj’ are provided in Supplement D.

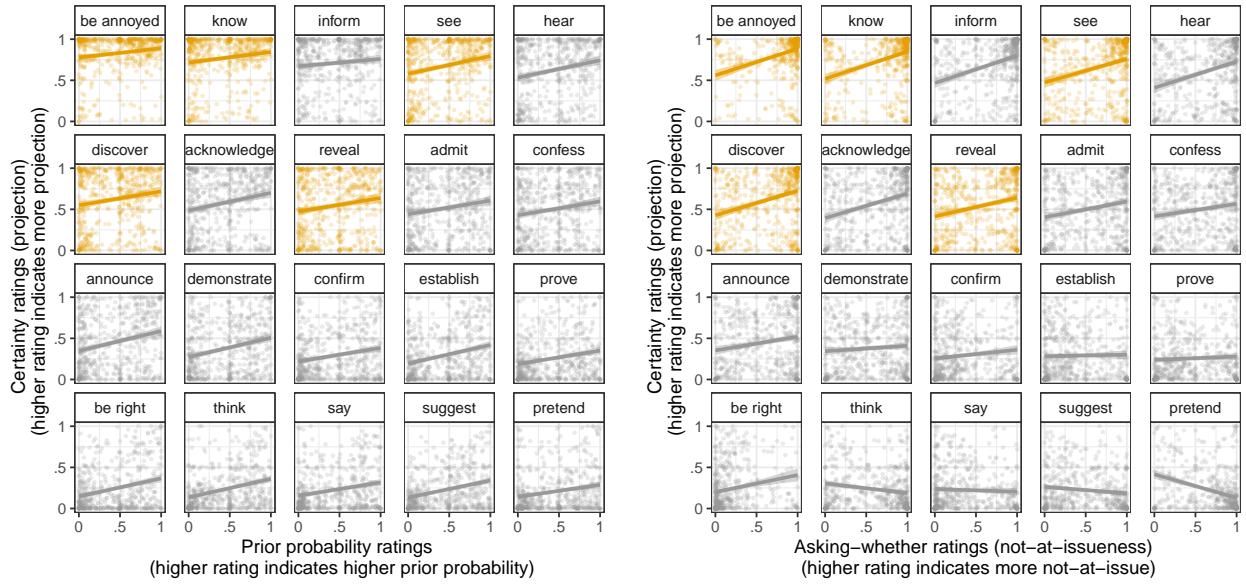
**(I) The relation between prior beliefs and lexical meaning in modulating projection.** Recall that Degeen and Tonhauser 2021 observed a positive effect of prior probability on projection: The higher an interpreter’s prior belief in a content, the more the interpreter takes the speaker to believe in the content. This result is replicated in the current experiment: As shown in Fig. 2a, which shows participants’ prior probability ratings against their certainty ratings (measuring projection) by clause-embedding predicate,<sup>3</sup> there is a positive effect for each predicate, suggesting that the higher an interpreter’s prior belief about content, the more the content projects.

These observations were supported by the models fitted to the full dataset and to the ‘proj/ai’ subset: As shown in Table 1a, there is at least strong evidence for a positive effect of prior probability on certainty ratings (measuring projection) for each predicate in the full dataset as well as in the proj/ai subset. In the ai/proj subset, there is at least strong evidence for a positive effect for 14 of the 20 predicates. For

<sup>1</sup>To model the certainty ratings using a beta regression, the ratings were first transformed from the interval [0,1] to the interval (0,1) using the method proposed in Smithson and Verkuilen 2006. In the models for research question (III.b), the asking-whether ratings were also transformed in this way.

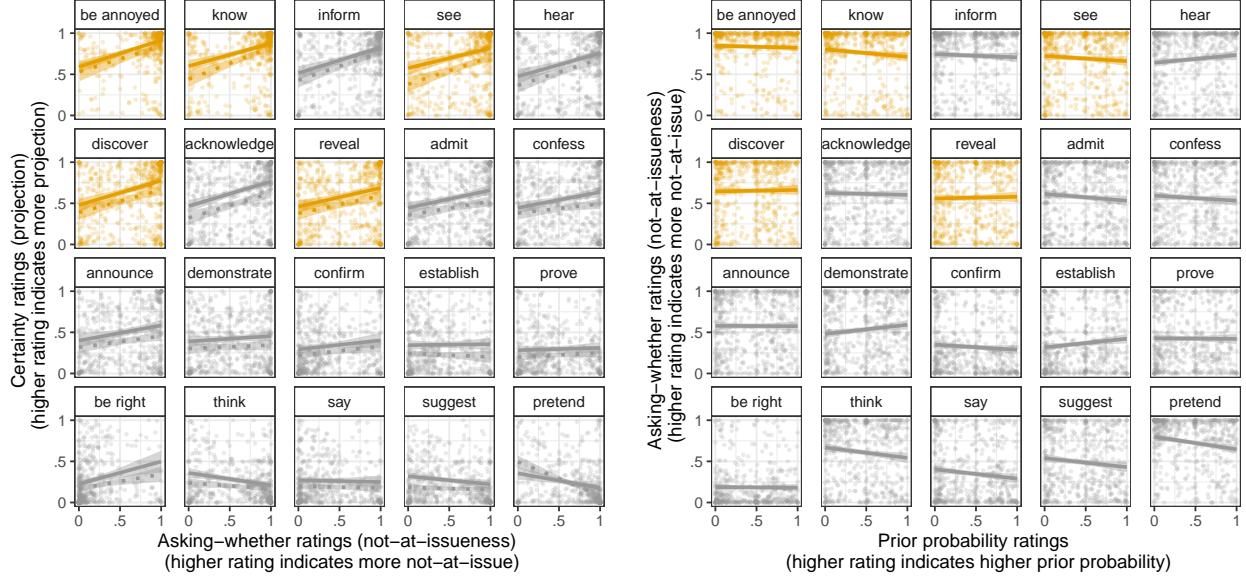
<sup>2</sup>By-participant random effects were not included here or in the models for research question (III.b) because each participant saw each predicate only once.

<sup>3</sup>The predicates are ordered in Figs. 2 and 3 by the strength of the projection of the CC in the respective experiment.



(a) Certainty against prior probability ratings.

(b) Certainty against asking-whether ratings.



(c) Certainty against asking-whether ratings by high prior probability fact (solid line: —) and low prior probability fact (dotted line: ···).

(d) Asking-whether against prior probability ratings.

Figure 2: Participants' ratings in Exp. 1 (full dataset) by predicate: (a) certainty ratings (measuring projection) against prior probability ratings, (b) certainty ratings (measuring projection) against asking-whether ratings (measuring projection), (c) certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by high and low prior probability fact, (d) asking-whether ratings (measuring at-issueness) against prior probability ratings. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

4 predicates, namely *discover*, *acknowledge*, *reveal* and *say*, there is only weak to moderate evidence for a positive effect. Furthermore, there is no evidence for an effect for *be annoyed* and weak to moderate evidence for a negative effect for *inform*.

One possible explanation for this difference between the ‘proj/ai’ and ‘ai/proj’ datasets is that the effect of prior beliefs on projection is an artifact of the design of Exp. 1, such that participants’ certainty ratings on the projection block are artificially influenced by their prior belief ratings, but only when the prior block immediately precedes the projection block. Another possible explanation is that the effect of prior beliefs on projection is real, but when the at-issueness block directly precedes the projection block, participants’ attention is drawn to the question of what the speaker is asking about, thereby drawing resources away from integrating information from the prior. One way of distinguishing these explanations is to collect certainty ratings from a set of participants who do not provide prior belief ratings and to use a separate group’s prior belief ratings as a predictor of these certainty ratings. This is what we will do in Exp. 2, which is reported on in the next section. Preliminary support for the latter explanation comes from Degen and Tonhauser’s 2021 Exp. 2, which suggested that there is an effect of prior beliefs on projection even when the prior belief ratings were collected from a different set of participants than the projection ratings.

**(II) The relation between at-issueness and lexical meaning in modulating projection.** Recall that Tonhauser et al.’s 2018 Gradient Projection Principle leads us to expect a positive effect of not-at-issueness on projection for all predicates. Djärv and Bacovcin’s 2020 analysis, on the other hand, predicts a positive effect only for factive predicates and no effect for nonfactive ones. Fig. 2b shows participants’ certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by clause-embedding predicate: There is a positive correlation for most predicates (e.g., *know*, *inform*, *announce*, *acknowledge*), which suggests that for these predicates there is a positive effect of not-at-issueness on projection. There is a negative correlation for other predicates (e.g., *pretend*, *think*), which suggests that for these predicates there is a negative effect of not-at-issueness on projection (or: a positive effect of at-issueness on projection). Finally, there appears to be no correlation for a third group of predicates (e.g., *prove*, *confirm*). These observations suggest that there is by-predicate variation in the effect of at-issueness on projection.

The observations were supported by the models. As shown in Table 1a, there is very strong to extreme evidence for a positive effect of asking-whether rating (measuring at-issueness) on certainty ratings (measuring projection) for 13 of the 20 predicates in the full dataset and the two subsets: *be annoyed*, *know*, *inform*, *see*, *hear*, *discover*, *acknowledge*, *reveal*, *confess*, *admit*, *announce*, *confirm* and *be right*. For *demonstrate*, there is very strong to extreme evidence for a positive effect in the full dataset and the proj/ai subset, but no evidence for an effect in the ai/proj dataset. This suggests that, for these 14 predicates, the more not-at-issue the CC is, the more it projects.

For *think*, *suggest* and *pretend*, there is at least strong evidence for a negative effect of at-issueness on projection in the full dataset, though the three predicates differ in the strength of this evidence in the two subsets: For *suggest* it is merely weak to moderate in both subsets, for *think* it is weak to moderate in one subset and very strong to extreme in the other, and it is very strong to extreme in both subsets for *pretend*. This suggests that, for *pretend*, *think* and possibly also *suggest*, the more at-issue the CC is, the more it projects. For the remaining 3 predicates (*establish*, *prove*, *say*), the models fit to the three datasets only provide at most weak to moderate evidence for a (positive or negative) effect of at-issueness in the full dataset, and no clear support in the two subsets. This suggests that, for these 3 predicates, there is no effect of at-issueness on projection.

The observations are neither completely predicted by the Gradient Projection Principle (which does not lead us to expect predicates with a non-positive effects) nor by Djärv and Bacovcin’s 2020 analysis (which does not lead us to expect nonfactive predicates with positive effects).

**(III.a) The relation between prior beliefs and at-issueness in modulating projection.** Recall that extant RSA models of projection inferences assume no relation between prior beliefs and at-issueness in modulating projection. Fig. 2c shows participants' certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by prior probability and by predicate. There does not seem to be an interaction for most predicates (e.g., *be annoyed*, *discover*), but some predicates seem to exhibit an interaction (e.g., *see*, *pretend*).<sup>4</sup>

Overall, the models fit to the full dataset and the two subsets do not support the assumption of a systematic relation between prior beliefs and at-issueness in modulating projection. As shown in Table 1a, for 12 of the 20 predicates, there is at most weak to moderate evidence for an effect of the interaction in all three datasets (namely *know*, *discover*, *reveal*, *admit*, *confess*, *announce*, *demonstrate*, *confirm*, *establish*, *prove*, *think*, *suggest*). For five predicates, there is strong to extreme evidence for an effect in one of the three datasets, but at most weak to moderate evidence in the other two (*inform*, *acknowledge*, *be right*) or very strong to extreme evidence for an effect of the opposite polarity in another dataset (*be annoyed*, *hear*). Thus, for 17 of the 20 predicates, the data do not support the assumption of a systematic relation between prior beliefs and at-issueness in modulating projection. The only three predicates for which the models support the assumption of a consistent effect are *see* (strong evidence for a negative effect in the full dataset), *say* (strong evidence for a positive effect overall), and *pretend* (very strong to extreme evidence for a positive effect overall).

These results provide some support for the assumption made in extant RSA models that there is no relation between prior beliefs and at-issueness in modulating projection (Qing et al. 2016; Stevens et al. 2017; Warstadt 2022; Pan and Degen 2023). However, if the effects for *see*, *say* and *pretend* replicate in Exp. 2, analyses will need to allow for individual predicates to exhibit an interaction between prior beliefs and at-issueness in modulating projection.

**(III.b) The relation between prior beliefs and at-issueness.** Recall that Tonhauser et al.'s 2020 Non-redundancy Principle for At-issue Content predicts a positive effect of prior beliefs on not-at-issueness. Fig. 2d shows participants' asking-whether ratings (measuring at-issueness) by their prior probability ratings. While there does not seem to be a correlation for many of the 20 predicates, there may be a weakly positive one for *hear* and *demonstrate*, and a negative one for predicates like *think*, *say*, *suggest* and *pretend*.

These observations are supported by the models. As shown in Table 1a, for 8 of the 20 predicates, there is either no evidence for an effect of prior beliefs on at-issueness or only weak to moderate evidence in all three datasets (namely *inform*, *see*, *discover*, *acknowledge*, *reveal*, *admit*, *announce*, *be right*). For *hear* and *demonstrate*, there is very strong to extreme evidence for a positive effect of prior beliefs on at-issueness in the full dataset, and at least strong evidence for a positive effect in one of subsets. For *be annoyed*, *know*, *admit*, *think*, *say*, *suggest* and *pretend*, there is at least strong evidence for a negative effect in the full dataset and one of the two subsets. These results suggest that the effect of prior beliefs on at-issueness exhibits by-predicate variation. That there is either no evidence for an effect or at least strong evidence for a negative effect for 15 of the 20 predicates does not support Tonhauser et al.'s 2020 Non-redundancy Principle for At-issue Content, which leads one to expect a positive effect.

### 3 Experiment 2

The results of Exp. 1 provide novel insights into the relation between prior beliefs, at-issueness and lexical meaning in modulating projection inferences, as well as on the relation between prior beliefs and at-issueness. But the result for the research question (I) also gave rise to the question of whether the effect of

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<sup>4</sup>Whereas Fig. 2c groups the prior belief ratings by the binary prior probability classification (higher vs. lower prior probability), the models do not assume this classification as participants' prior belief ratings may not align with this binary classification.

Effect	Data	be annoyed	know	inform	see	hear	discover	acknowledge	reveal	admit	confess	announce	demonstrate	confirm	establish	prove	be right	think	say	suggest	pretend
(I): prior on projection	full																				
	proj/ai																				
	ai/proj																				
(II): not-at-issue on projection	full																				
	proj/ai																				
	ai/proj																				
(IIIa): prior:not-at-issue on projection	full																				
	proj/ai																				
	ai/proj																				
(IIIb): prior on not-at-issueness	full																				
	proj/ai																				
	ai/proj																				

(a) Results of Exp. 1

Effect	Data	be annoyed	know	inform	see	hear	discover	acknowledge	reveal	admit	confess	announce	demonstrate	confirm	establish	prove	be right	think	say	suggest	pretend
(I): mean prior on projection	full																				
	proj/ai																				
	ai/proj																				
(II): not-at-issue on projection	full																				
	proj/ai																				
	ai/proj																				
(IIIa): mean prior :not-at-issue on projection	full																				
	proj/ai																				
	ai/proj																				
(IIIb): mean prior on not-at-issueness	full																				
	proj/ai																				
	ai/proj																				

(b) Results of Exp. 2

Table 1: Summary of the results of Exps. 1 and 2. The ‘Effect’ column identifies the research question and the hypothesized effect, and the ‘Data’ column whether the model was fit to the full dataset (‘full’) or a subset with a particular block order (‘proj/ai’, ‘ai/proj’). Predicates are ordered by mean projection in Exp. 1 with factive predicates in orange. Color coding indicates whether the effect was positive (red) or negative (blue), and the Bayes factor of the evidence for the effect: : 21+ (“very strong to extreme evidence”), : 11-20 (“strong evidence”), : 2-10 (“weak to moderate evidence”). White indicates that there was no evidence for an effect.

prior beliefs on projection real or merely an artifact of the within-participant design of Exp. 1. Exp. 2 allows us to investigate this open question and also investigate whether the by-predicate variation observed for the other three effects replicate. Exp. 2 had the same design as Exp. 1 except that there was no prior block. To investigate the relation between prior beliefs, at-issueness, and lexical meaning in modulating projection inferences, we added to Exp. 2 the mean prior probability ratings of the 40 content/fact combinations collected in three previous experiments, namely Exp. 1, the prior block of Exp. 1 in Degen and Tonhauser 2021, and Exp. 2a in Degen and Tonhauser 2021.

### 3.1 Methods

**Participants.** 600 participants with U.S. IP addresses and at least 99% of previous HITs approved were recruited on Amazon’s Mechanical Turk platform (ages: 19-73, median: 37.5). They were paid \$2.20.<sup>5</sup>

**Materials and procedure.** Exp. 2 differed from Exp. 1 only in that there was no prior block. As in Exp. 1, each participant’s set of items was semi-randomly generated: First, the 20 clauses were randomly paired with the 20 predicates. Then, one random half of the items was assigned the respective clause’s higher-probability fact, and the other half its lower-probability fact. Participants completed a total of 52 trials: 20 target trials in each block, and 6 control trials in the projection and at-issueness blocks each. Each participant completed the same control trials. The projection and at-issueness blocks were presented in random order.

**Data exclusion.** Data was excluded based on self-declared non-native speaker status and other criteria shown in Supplement B, leaving 10,160 data points from 508 participants (ages 19-73; mean age: 38.3).

### 3.2 Statistical analyses

To address the research questions in (2), we fit the almost same two types of models to the data as with Exp. 1 (see section 2.2): The only difference was that there was no centered fixed effect of prior probability rating, but a centered fixed effect of *mean* prior probability rating, aggregated by content/fact combination from the three experiments mentioned at the beginning of section 2.

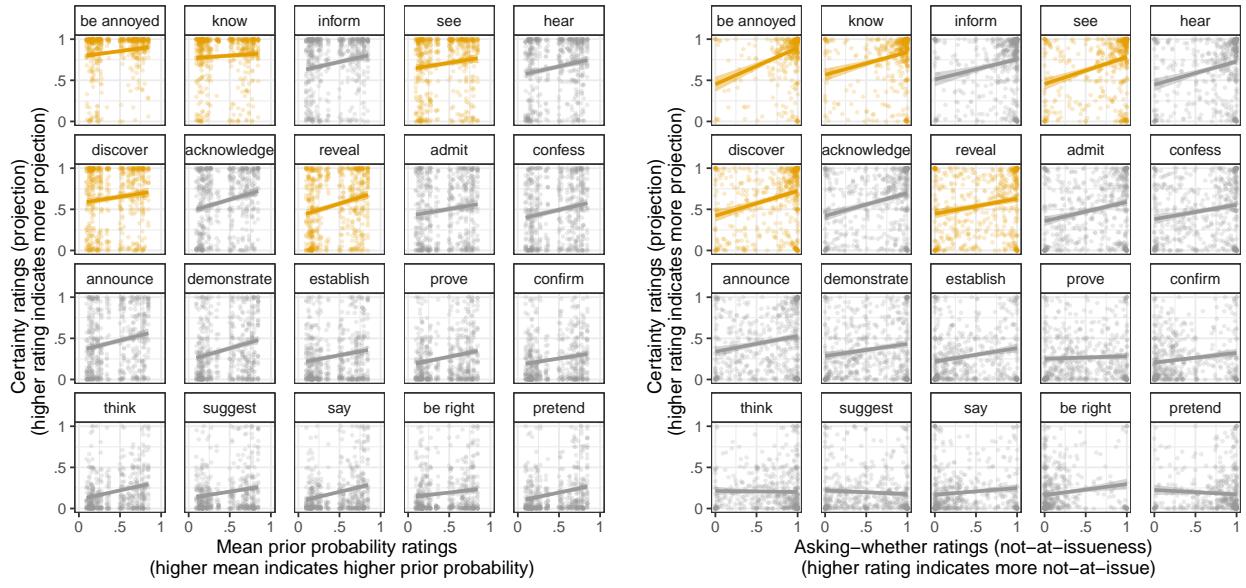
Hypothesis testing was conducted to investigate the effects of interest, that is (I) whether there was an effect of mean prior beliefs on projection for each of the clause-embedding predicates/lexical meanings, (II) whether there was an effect of at-issueness on projection for each of the clause-embedding predicates/lexical meanings, (III.a), whether there was an effect of the interaction between mean prior beliefs and at-issueness on projection for each of the clause-embedding predicates/lexical meanings, and (III.b) whether there was an effect of mean prior beliefs on at-issueness for each of the clause-embedding predicates/lexical meanings. Table 1b reports, for each of the four hypotheses, whether there was evidence for an effect, whether the effect was positive or negative, and the Bayes factor of the evidence. Full model outputs are provided here: [LINKTOFULLMODELOUTPUTSFOREXP2MODELS](#)

### 3.3 Results and discussion

Fig. 3 shows participants’ ratings for the full dataset. The corresponding figures for the two subsets ‘proj/ai’ and ‘ai/proj’ are provided in Supplement E.

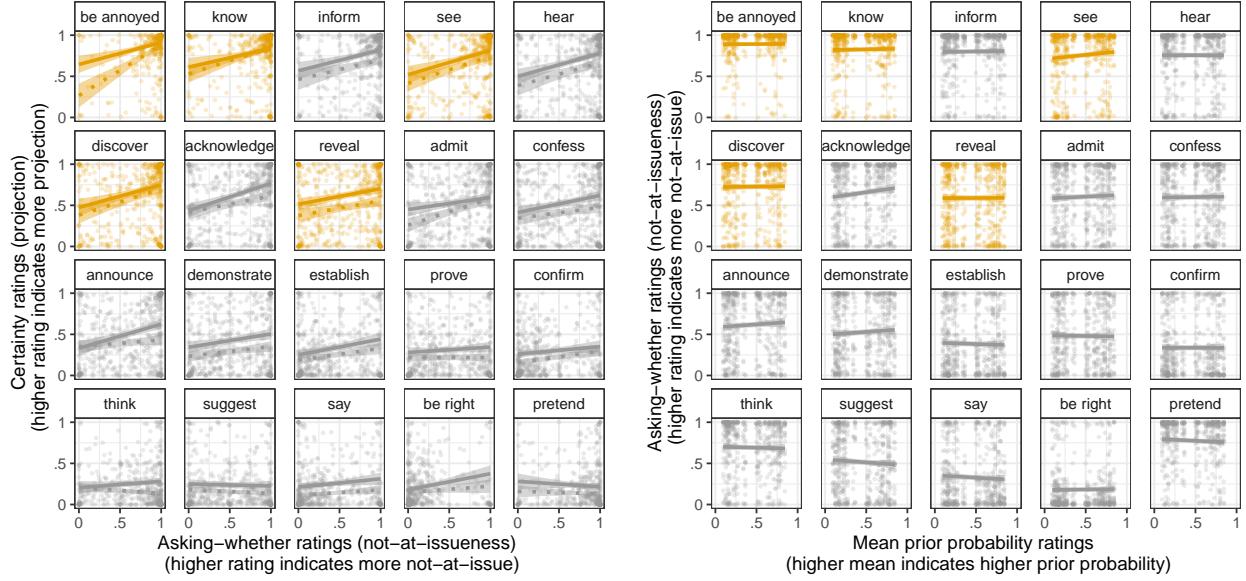
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<sup>5</sup>92 individuals participated in both experiments. Since the experiments were run four months apart (Exp. 1: December 16, 2019; Exp. 2: August 21, 2019), it is unlikely that these participants’ responses were primed by their prior participation.



(a) Certainty against mean prior probability ratings.

(b) Certainty against asking-whether ratings.



(c) Certainty against asking-whether ratings by higher prior probability fact (solid line: —) and lower prior probability fact (dotted line: ···).

(d) Asking-whether against mean prior probability ratings.

Figure 3: Participants' ratings in Exp. 2 (full dataset) by predicate: (a) certainty ratings (measuring projection) against mean prior probability ratings, (b) certainty ratings (measuring projection) against asking-whether ratings (measuring projection), (c) certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by higher and lower prior probability fact, (d) asking-whether ratings (measuring at-issueness) against mean prior probability ratings. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean in Exp. 2, with purportedly factive predicates in orange.

**(I) The relation between prior beliefs and lexical meaning in modulating projection.** Fig. 3a shows, for each predicate, participants' certainty ratings for the content/fact combinations against the mean prior probability ratings for the content/fact combinations that were collected from a different set of participants. As shown, there is a positive correlation between mean prior probability ratings and certainty ratings for each predicate. These observations were supported by the models fit to the full dataset and for the 'proj/ai' dataset: As shown in Table 1b, there is at least strong evidence for a positive effect of mean prior probability ratings on certainty ratings (measuring projection) for each predicate in the full dataset as well as in the proj/ai subset (except for *admit*, where the evidence is weak to moderate). In the ai/proj subset, the evidence is merely weak to moderate for a positive effect for *see*, *discover*, *announce*, *confirm* and *be right*, and for a negative effect for *know*.

This observation suggests that the effect of prior beliefs on projection observed in Exp. 1 was not an artifact of the within-participant design of that experiment. Rather, the results of Exps. 1 and 2 support the assumption that participants integrate their prior beliefs about content when giving certainty ratings, regardless of whether they were asked to give prior probability ratings in an earlier block (Exp. 1) or not (Exp. 2). The fact that in both Exps. 1 and 2 the evidence for a positive effect of prior beliefs on projection is weaker in the 'ai/proj' blocks than in the 'proj/ai' blocks further suggests that when participants' attention is drawn to the question of what the speaker is asking about, integrating information from their prior beliefs into their certainty ratings is more challenging than if they give certainty ratings before giving asking-whether ratings. In sum, the results of Exps. 1 and 2 support the hypothesis that participants' prior beliefs about content modulate their projection ratings across the 20 predicates under investigation.

**(II) The relation between at-issueness and lexical meaning in modulating projection.** Fig. 3b shows participants' certainty ratings (measuring projection) against asking-whether ratings (measuring not-at-issueness) by clause-embedding predicate: There is a positive correlation for most predicates (e.g., *know*, *inform*, *announce*, *acknowledge*), which suggests that for these predicates there is a positive effect of not-at-issueness on projection. There are also predicates for which there is no correlation (e.g., *think*, *suggest*, *pretend*). In contrast to Exp. 1, there are no predicates for which there is a clearly negative correlation. These observations again suggest that there is by-predicate variation in the effect of at-issueness on projection, though the variation is not identical to that of Exp. 1.

The observations were supported by the models. There is at least strong evidence for a positive effect of asking-whether rating (measuring at-issueness) on certainty ratings (measuring projection) for 12 of the 20 predicates in the full dataset and the two subsets: *be annoyed*, *know*, *inform*, *see*, *hear*, *discover*, *acknowledge*, *admit*, *confess*, *announce*, *demonstrate* and *confirm*. For an additional 5 predicates, namely *reveal*, *establish*, *prove*, *be right* and *say*, there is at least strong evidence for a positive effect in the full dataset, and at least strong evidence in one of the subsets. This suggests that, for these 17 predicates, the more not-at-issue the CC is, the more it projects. The models of Exp. 1 support the assumption of a negative effect of projection on at-issueness only for *suggest*, where there is very strong to extreme evidence for a negative effect in the full dataset and in the 'ai/proj' subset. For *think* and *pretend*, the results of Exp. 2 do not support the assumption of an effect of at-issueness on projection.

Comparing the results of Exp. 2 to those of Exp. 1, we find that there are 14 predicates for which there is evidence for a positive effect of at-issueness on projection in both experiments, namely *be annoyed*, *know*, *inform*, *see*, *hear*, *discover*, *acknowledge*, *reveal*, *admit*, *confess*, *announce*, *demonstrate*, *confirm* and *be right*. These predicates include those with the highest certainty ratings (that is, the predicates whose CCs are most projective), which suggests that Tonhauser et al.'s 2018 Gradient Projection Principle generally holds for CCs that are relatively projective. At the same time, the fact that it also holds for *be right*, a predicate whose CC is only weakly projective, suggests that other factors may also modulate whether the Gradient Projection Principle holds. For the remaining 6 predicates, the results of Exp. 1 do not replicate in

Exp. 2. For 2 of these predicates, the polarity of the effect stayed the same but the evidence was stronger in Exp. 2 than in Exp. 1 (*prove*, *suggest*), and for the other 4 the polarity of the effect changed (namely *establish*, *think*, *say* and *pretend*). We conclude from the results of Exps. 1 and 2 that the observations are neither completely predicted by the Gradient Projection Principle (which does not lead us to expect predicates with a non-positive effects) nor by Djärv and Bacovcin's 2020 analysis (which does not lead us to expect nonfactive predicates with positive effects).

Why might Exps. 1 and 2 partially differ with respect to the effect of at-issueness on projection? One difference between the two experiments is that Exp. 1 but not Exp. 2 included a prior probability block. While it is possible that the presence of this block affected participants' ratings on the projection and at-issueness blocks, it is not clear why such an effect would primarily be observed for the predicates whose CCs are least projective among the 20. An observation that may be relevant for developing a hypothesis (and, hence, future investigations of at-issueness) is that prior probability and certainty ratings are more stable across experiments than asking-whether ratings: In a by-experiment comparison of the three types of ratings, the Spearman rank correlation was at least .98 for the mean prior probability ratings of the 40 by-content/fact combinations, it was .85 for the mean certainty ratings of the 800 by-predicate/content/fact combinations, but it was only .72 for the mean asking-whether ratings of the 800 by-predicate/content/fact combinations. (See Supplement F for details.) It is possible that asking-whether ratings are more susceptible than the other two ratings to the ways in which participants might enrich the context in which they interpret the stimuli or to the (implicit) prosody with which they read the stimuli. These possibilities must be considered in future research on at-issueness.

**(III.a) The relation between prior beliefs and at-issueness in modulating projection.** Fig. 3c shows participants' certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by mean prior probability and by predicate.<sup>6</sup> For some predicates, there does not seem to be an interaction (e.g., *inform*, *see*, *hear*), while there appears to be one for others (e.g., *be annoyed*, *admit*, *announce*).

Overall, the models fit to the full dataset and the two subsets do not support the assumption of a systematic relation between prior beliefs and at-issueness in modulating projection across the 20 predicates. For 9 of the 20 predicates, there is either no evidence for an effect or only weak to moderate evidence for an effect in all three datasets (namely *know*, *see*, *hear*, *discover*, *reveal*, *demonstrate*, *establish*, *prove*, *pretend*). For the three predicates *be annoyed*, *confess* and *suggest* the overall evidence is inclusive. Finally, there are 8 predicates for which there is at least strong evidence for an effect in the full dataset and one of the subsets: This effect is positive for *inform*, *acknowledge*, *announce*, *be right* and *think*, and negative for *admit*, *confirm* and *say*. While the results for these 8 predicates may be taken to suggest that there is an interaction between prior beliefs and at-issueness in modulating projection, it is important to note that none of these effects were observed in Exp. 1. Furthermore, none of the effects observed in Exp. 1 replicated in Exp. 2: Whereas the results of Exp. 1 suggested a negative effect for *see* and a positive effect for *say* and *pretend*, the results of Exp. 2 do not support an effect for *see* and *pretend*, and they support a negative effect for *say*.

We suggest that the results of Exps. 1 and 2 taken together provide support for the assumption made in extant RSA models that there is no relation between prior beliefs and at-issueness in modulating projection (Qing et al. 2016; Stevens et al. 2017; Warstadt 2022; Pan and Degen 2023).

**(III.b) The relation between prior beliefs and at-issueness.** Fig. 3d, which shows participants' asking-whether ratings (measuring at-issueness) by the mean prior probability ratings, does not suggest that there is a correlation for most of the 20 predicates. This observation is supported by the models. For 15 of the 20 predicates, there is at most weak to moderate evidence for an effect of mean prior beliefs on at-issueness

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<sup>6</sup>Whereas Fig. 3c groups the mean prior belief ratings by the binary prior probability classification (higher vs. lower prior probability), the models do not assume this classification.

(namely *know*, *inform*, *hear*, *discover*, *reveal*, *confess*, *announce*, *demonstrate*, *confirm*, *establish*, *prove*, *be right*, *think*, *say*, *pretend*). For the remaining 5 predicates, there appears to be at least some evidence for an effect, but none of these were observed in Exp. 1: For instance, whereas there is very strong to extreme evidence for a positive effect for *see* in the full dataset and the ‘ai/proj’ subset, there was at most weak to moderate evidence for a negative effect in Exp. 1; similarly, whereas there is at least strong evidence for a positive effect for *acknowledge* in the full dataset and the ‘proj/ai’ dataset, there was no evidence for an effect in Exp. 1. Furthermore, none of the effects observed in Exp. 1 for *hear*, *demonstrate*, *be annoyed*, *know*, *admit*, *think*, *say*, *suggest* and *pretend* replicate in Exp. 2: For all of these predicates, there is at most weak to moderate evidence for an effect of the same polarity in Exp. 2 in the full dataset.

We suggest that the results of Exps. 1 and 2 taken together provide support for the assumption that there is no systematic effect of prior beliefs on at-issueness, contrary to the positive effect that is expected under Tonhauser et al.’s 2020 Non-redundancy Principle for At-issue Content.

## 4 General discussion

This paper has reported the results of two experiments designed to investigate interactions between three factors that have been shown in prior research to modulate projection, namely prior beliefs, at-issueness, and lexical meaning. Taken together, the results of Exps. 1 and 2 suggest the following answers to the research questions:

- (I) Prior beliefs and lexical meaning:** Is there an effect of prior beliefs on projection across clause-embedding predicates, that is, across lexical meanings?

Answer: Yes, there is a systematic effect of prior beliefs on projection across the meanings of the 20 clause-embedding predicates investigated such that the higher an interpreter’s prior beliefs in the CC, the more the CC is taken to project.

- (II) At-issueness and lexical meaning:** Is it the case that content that is more not-at-issue is more projective for all clause-embedding predicates (as expected under Tonhauser et al.’s 2018 Gradient Projection Principle) or only for factive predicates (as suggested in Djärv and Bacovcin 2017, 2020 and Mahler et al. 2020)?

Answer: There is by-predicate variation in the effect of at-issueness on projection. While the CCs of most predicates are more projective, the more they are not-at-issue, there are also predicates that do not show this positive effect. This result is neither completely predicted by the Gradient Projection Principle (which does not lead us to expect predicates with a non-positive effect) nor by Djärv and Bacovcin 2020 (which does not expect nonfactive predicates with a positive effect).

- (III) Prior beliefs and at-issueness:**

- a. Is it the case that the prior probability and at-issueness of content do not interact in modulating projection inferences (as assumed in most RSA models of projection inferences)?

Answer: Yes, the results of Exps. 1 and 2 did not establish systematic evidence for an interaction between prior probability and at-issueness on projection.

- b. Is it the case content is more not-at-issue the higher its prior probability (as expected from Tonhauser et al.’s 2020 Non-redundancy Principle for At-issue Content)?

Answer: No, the results of Exps. 1 and 2 did not establish systematic evidence for an effect of prior probability on at-issueness.

There is currently no analysis of projection on the market that can capture (I) the systematic effect of prior beliefs on projection and (II) the by-predicate variation in the effect of at-issueness on projection. In the remainder of this section we consider analyses that are among the strongest contenders.

## 4.1 Heim 1983 and Djärv and Bacovcin 2020

The analysis proposed in Djärv and Bacovcin 2020 is an extension of Heim 1983, where presuppositions are specified in the lexical entries of the triggering expressions. For clause-embedding predicates, this means that the CCs of factive predicates are lexically specified as presupposed, whereas the CCs of nonfactive predicates are not. Because presuppositions must be satisfied in the input context before the utterance is interpreted, these analyses predict that the CCs of factive predicates project from under entailment-canceling operators, either because they are already entailed by the input context or because they are accommodated into the input context. Presuppositions are locally accommodated (in the local context of the entailment-canceling operator) only if global accommodation into the input context would result in inconsistency.

Djärv and Bacovcin 2020 supplement Heim's 1983 analysis by proposing that prosody provides a cue to the QUD addressed by the utterance. Specifically, they propose that utterances of clause-embedding predicates with focus on the subject of the embedded clause, as in (3a), give rise to the QUD inference that somebody has the property denoted by the verb phrase of the embedded clause but it is not known who. On the other hand, the variant with focus on the embedding predicate, as in (3b), gives rise to the QUD inference that the attitude holder has some relationship with the embedded proposition.

- (3) Djärv and Bacovcin 2020, 73
- a. John might've discovered that [Anna]<sub>F</sub> left town.  
QUD inference: Somebody left town but it is not known who.
  - b. John might've [discovered]<sub>F</sub> that Anna left town.  
QUD inference: John has some relationship with the proposition that Anna left town.

Djärv and Bacovcin 2020 assume that the strength of the projection inference observed for utterances of sentences with focused clause embedding predicates, as in (3b), provides a baseline against which the effect of focus on the embedded subject, as in (3a), can be evaluated. Their analysis predicts that this effect of focus differs for factive and nonfactive predicates: For factive predicates, the QUD inference (specifically, that it is not known who left town) weakens the projection inference triggered by the factive predicate (that Anna left town). For nonfactive predicates, on the other hand, the QUD inference (specifically, that somebody left town) strengthens an inference to the truth of the CC (no projection inference is lexically triggered).<sup>7</sup>

Djärv and Bacovcin 2020 do not explicitly relate their proposal to at-issueness, but one might assume that the CC is at-issue in utterances of sentences in which the embedded subject is focused, as in (3a), whereas it is not-at-issue when the embedding predicate is focused, as in (3b). Under this interpretation, Djärv and Bacovcin's 2020 extension of Heim's 1983 analysis predicts that when the CC of a factive predicate is at-issue, it is less projective, whereas the opposite effect is expected for nonfactive predicates. We now consider whether Heim 1983 and Djärv and Bacovcin 2020 capture the results of our experiments.

**(I) The relation between prior beliefs and lexical meaning in modulating projection.** Neither analysis predicts the effect of prior beliefs on projection across the 20 clause-embedding predicates, for two reasons. The first reason is that neither analysis makes predictions about the projection of the majority of the 20 predicates, namely the 15 nonfactive ones (see Degen and Tonhauser 2022 for extensive discussion). The second reason is that prior beliefs do not play a role in either analysis. At best, one can imagine an extension on which presupposition accommodation is sensitive to the strength of the prior belief in the presupposition. Specifically, one might assume that the lower the prior belief in the presupposition, the more likely is not accommodated globally, but locally. This extension would, however, constitute a major change for these

<sup>7</sup>The results of Exp. 1 reported on in Djärv and Bacovcin 2020 support this analysis for the three verbal nonfactive predicates investigated, but not for the three adjectival nonfactive predicates, where this effect of subject focus was not observed.

analyses, where global accommodation taken to be the default, and local accommodation is only licensed if global accommodation of the presupposition leads to inconsistency.

**(II) The relation between at-issueness and lexical meaning in modulating projection.** Djärv and Bacovcin's 2020 extension of Heim 1983 does not predict the observed by-predicate variation in the effect of at-issueness on projection. This is because our experiments suggest that greater not-at-issueness results in greater projection not just for the CCs of factive predicates but also for several nonfactive predicates. While Djärv and Bacovcin's 2020 analysis correctly predicts the pattern observed for factive predicates, they predict the opposite of what is observed for many of the nonfactive predicates we investigated.

In sum, Heim 1983 and the extension in Djärv and Bacovcin 2020 correctly predict that the CCs of factive predicates project and that greater not-at-issueness leads to greater projection for these predicates. These analyses do not, however, predict that the CCs of nonfactive predicates may also be projective, that greater not-at-issueness may also lead to greater projection for nonfactive predicates, and they also do not predict the effect of prior beliefs on projection for the CCs of clause-embedding predicates.

## 4.2 Abrusán 2011, 2016, and Simons et al. 2017

Abrusán 2011, 2016 and Simons et al. 2017 do not assume that presuppositions are lexically specified. In Abrusán 2011, 2016, a lexical entailment of an uttered sentence is a presupposition if it is about a time that is not the event time of the matrix predication and it is not at-issue with respect to the QUD addressed by the utterance. For instance, the CC of B's utterance in (4), that Phil's ballet class is canceled, is predicted to be a presupposition (and therefore project) because it is a lexical entailment of sentence embedded under the epistemic modal and it is not at-issue with respect to A's interrogative utterance.

- (4) Adapted from Simons et al. 2017, 188

Context: It's early on Saturday morning. A and B are talking about their son.

A: Why is Phil up already?

B: Perhaps he forgot that his ballet class is canceled today.

In Simons et al. 2017, the CC of a clause-embedding predicate projects if it is entailed by the Current Question of the utterance (where the Current Question is the question that is congruent with the utterance).<sup>8</sup> In (4), the Current Question of B's utterance might be the set of propositions {Phil forgot that his ballet class is canceled today, Phil is aware that his ballet class is canceled today}. If so, the Current Question entails that Phil's ballet class is canceled today, and the CC may therefore project under Simons et al.'s 2017 analysis.

**(I) The relation between prior beliefs and lexical meaning in modulating projection.** Neither of these analyses predicts the effect of prior beliefs on projection, for the same reasons as the analyses discussed in the previous section: Neither analysis makes predictions about the projection of the majority of the 20 predicates, namely those whose CCs are not entailed, and prior beliefs do not play a role in either analysis.

**(II) The relation between at-issueness and lexical meaning in modulating projection.** Projection is sensitive to at-issueness in Abrusán 2011, 2016 and Simons et al. 2017. Specifically, both analyses predict that content that is at-issue with respect to the question addressed by the utterance does not project, and

<sup>8</sup>The Current Question is defined in Simons et al. 2017, 194 as follows: “The Current Question for an utterance is a privileged subset of the focal alternative set of the uttered sentence (given a structural analysis of that sentence, including focus marking)” which meets the conditions that “i) the proposition expressed is a member of the Current Question and ii) the Current Question has at least one additional member.”

that content that is not-at-issue with respect to said question may project. As such, both analyses correctly predict that entailed CCs that are not-at-issue are more projective than entailed CCs that are at-issue. What neither analysis can predict, however, is that at-issueness may modulate projection not only for entailed CCs but also for nonentailed ones.

In sum, the analyses in Abrusán 2011, 2016 and Simons et al. 2017 predict that entailed CCs may project and that their projection is sensitive to at-issueness. These analyses do not, however, predict the effect of prior beliefs on projection, that nonentailed CCs may also project, and that their projection may also be sensitive to at-issueness.

### 4.3 Schlenker 2021

On the analysis proposed in Schlenker 2021, the CC of a sentence  $S$  like (5a) that is uttered in a context  $c$  is presupposed if the CC is presupposed by the sentence  $S'$  under the entailment-canceling operator, that is (5b), in the local context  $c'$ . For the CC to be presupposed in (5b), two conditions must be met: i)  $S'$  contextually entails the CC relative to  $c'$ ; and ii) If we consider a generic agent who believes the propositions in  $c'$  and who has now learned about the truth of  $S'$ , then the probability that this generic agent already believed the CC is above a contextual threshold  $\alpha$  (§6.2). More colloquially, condition ii) requires that the generic agent “typically antecedently believes” the CC (p.6) upon interpreting  $S'$  in  $c'$ . Applied to (5), Schlenker’s 2021 analysis predicts that the CC of *know* in (5) is presupposed if i) (5b) contextually entails that Julian dances salsa, and ii) if a generic agent would typically antecedently believe that Julian dances salsa upon interpreting (5b) in the minimal contexts we provided to our participants. (For Schlenker 2021, the local context under negation  $c'$  is identical to  $c$ .)

- (5)    a. Cole doesn’t know that Julian dances salsa.
- b. Cole knows that Julian dances salsa.

Condition i) is met under the assumption that the CC of (5b) is an entailment. Schlenker 2021 also assumes the condition ii) is met: “in many cases, one’s knowledge of facts will precede one’s knowledge of [Cole’s] beliefs about them... believing that [Julian dances salsa] is often an epistemic precondition for believing that” Cole knows that Julian dances salsa (p.6). One might, however, challenge this assumption on the basis of the corpus study presented in Spenader 2002, which showed that the CCs of the majority of the utterances of sentences with factive verbs (namely 81 of 109) had to be accommodated (i.e., were not contextually entailed). In other words, utterance of sentences with the factive predicates investigated by Spenader (2002) were “generally used to communicate information the speaker thought was hearer-new” (p.99); *know* was one of the predicates considered in Spenader 2002. This result might suggest that one cannot assume that a generic agent typically antecedently believes the CC of *know*.

Let’s assume that it is an open, empirical question which predicates are such that the probability of a generic agent antecedently believing the CC is above the contextual threshold  $\alpha$  (and, of course, what that threshold might be). Schlenker 2021 appears to assume that there are two classes of predicates: those where the probability is above the contextual threshold (which includes *know*, *announce*, and *inform*), and those where it is not (which includes *demonstrate* and *establish*; see p.12 and appendix I). Thus, one advantage of Schlenker’s 2021 analysis over the analyses reviewed above is that it is able to predict the projection of the CCs of nonfactive predicates (modulo the open questions about condition ii)). The analysis correctly predicts that the CCs of *know*, *inform*, and *announce* are more projective than the CCs of *demonstrate* and *establish*, by virtue of the CCs of the former being possibly presupposed, in contrast to the CCs of the latter.

**(I) The relation between prior beliefs and lexical meaning in modulating projection.** Although the analysis in Schlenker 2021 may be able to predict projection for the CCs of nonfactive predicates, it is not

clear that it is able to predict the observed by-predicate projection variation because the analysis – even though it does not divide predicates into factive and nonfactive ones – nevertheless suggests a binary, categorical distinction between predicates, such that the CCs of predicates with probabilities above the threshold may be presupposed (depending on the context), and those below the threshold are not. As such, the analysis does not appear to predict the projection variation between the CCs that are analyzed as presupposed (e.g., that the CC of *be annoyed* is more projective than that of *reveal*). Furthermore, as discussed in Degen and Tonhauser 2022, the CCs of nonfactive predicates like *establish* and *demonstrate* are projective when compared to nonprojective main clause content. Schlenker's 2021 analysis does not make predictions for these CCs. In Exp. 1, the mean certainty rating of the CC of *announce*, whose CC is assumed to possibly be presupposed, is .45, and that of *demonstrate*, whose CC is not assumed to be presupposed, is .38 (both means are aggregated across entailment-canceling operators). It is not clear that this particular difference in mean certainty rating motivates analyzing the CC of *announce* as presupposed in contrast to that of *demonstrate*.

Schlenker's 2021 analysis may be able to not only predict projection for some nonfactive predicates but also that projection is sensitive to interpreters' prior beliefs. For instance, the CC of (6) might be presupposed if i) (6) contextually entails that Julian dances salsa (which may very well be the case in a context in which Julian is Cuban, and Cole is a reliable source of information about Julian), and ii) if a generic agent typically believes that Julian dances salsa prior to interpreting (6).

- (6) Cole informed Sam that Julian dances salsa.

If, on the other hand, (6) is uttered in a context in which the CC is not contextually entailed (e.g., if Julian is German or Cole is an unreliable source), the CC might not be presupposed in (6). Thus, if condition i) allows for prior beliefs to be considered in determining contextual entailment, Schlenker's 2021 analysis might be able to predict that projection is sensitive to interpreters' prior beliefs.

**(II) The relation between at-issueness and lexical meaning in modulating projection.** It is not clear how at-issueness in the form of sensitivity to the QUD would modulate projection in the analysis proposed in Schlenker 2021. It is conceivable, however, to enrich the analysis, for instance, by incorporating Abrusán's 2011 constraint that entailments that would otherwise be backgrounded (and therefore presupposed) are not backgrounded if they are at-issue with respect to the QUD addressed by the utterance.

In sum, Schlenker's 2021 analysis may be able to predict that the CCs of some nonfactive predicates project and it may also be able to predict that projection is sensitive to prior beliefs. The analysis does not, however, predict that the CCs of many predicates which he takes to be nonpresupposed are projective when compared to main clause content and that, for many predicates, the CCs are more projective when they are more not-at-issue.

#### 4.4 Qing et al. 2016 and Warstadt 2022

The projection analyses in Qing et al. 2016 and Warstadt 2022 were formulated in the Rational Speech Act (RSA) framework (for an introduction see Degen 2023). These analyses were developed for the pre-state content of *stop* (e.g., that *Sam stopped smoking* implies that Sam smoked) and for the genus content of species predication (e.g., that *Tom has a green card* implies that Tom is not a US citizen), respectively.<sup>9</sup> As such, neither analysis captures the variable contributions of the lexical meanings of the clause-embedding predicates to projection inferences. We can nevertheless consider how these analyses capture the relation between (I) prior beliefs and lexical meaning, and (II) at-issueness and lexical meaning. We use the analysis in Qing et al. 2016 but the same considerations apply to that in Warstadt 2022.

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<sup>9</sup>For other projection analyses formulated in the RSA framework see Stevens et al. 2017 and Pan and Degen 2023.

Qing et al.’s 2016 analysis follows the basic RSA model in assuming a literal listener who forms the basis of the reasoning process, a speaker who reasons about the literal listener in choosing their utterances, and a pragmatic listener who infers the speaker’s most likely intended meaning. In Qing et al.’s 2016 analysis, the literal listener observes an utterance (e.g., *Sam didn’t stop smoking*) and interprets its literal meaning. There are four possible world states against which utterances are interpreted; these differ in whether Sam smoked in the past, and in whether Sam smokes now. The literal meaning of the positive utterance *Sam stopped smoking* is compatible only with the world state in which Sam smoked in the past and does not smoke now, which means that the literal meaning of the negative variant is compatible with the other three world states. This means that the projection inference, which is the inference to the world state in which Sam smoked in the past and does not smoke now, is not coded in the lexical meaning of *stop* and not achieved by the literal listener.

The literal listener in Qing et al.’s 2016 analysis does not simply return a distribution over the world states in which the utterance is literally true, but it rather returns a distribution over answers to the possible QUDs. In RSA, QUDs are modeled as partitions of the set of world states (e.g., Kao et al. 2014). For instance, the QUD of whether Sam smokes now partitions the set of world states into the set of two world states in which he does not smoke now, and the set of two in which he smokes now. What is not at-issue with respect to this QUD is whether Sam smoked in the past. Thus, when the literal listener interprets the utterance *Sam didn’t stop smoking* relative to the QUD of whether Sam smokes now and in a world state in which Sam did not smoke in the past but smokes now, the literal listener returns a distribution in which the positive answer to the QUD has a very high probability (approaching 1) and the negative answer has a very low one (approaching 0).

A modification to the basic RSA model introduced in Qing et al. 2016 is that interpretation, including that by the literal listener, is relative to a common ground, which consists of the power set of the four possible world states minus the empty set. For the literal listener, this means that they consider only those world states that are compatible with the literal meaning of the utterance and that, additionally, are compatible with the speaker’s common ground.

The speaker in Qing et al.’s 2016 analysis wants to convey a particular world state given a common ground. The speaker evaluates all possible utterance alternatives with respect to how likely the literal listener is to infer the world state that the speaker wants to communicate, given the common ground. For instance, if the common ground is the set of world states (that is, nothing is known yet) and the speaker wants to communicate the world state in which Sam smoked in the past and does not smoke anymore, the utterance *Sam stopped smoking* has much more utility than the utterance *Sam didn’t stop smoking*, because the literal listener is more likely to infer the intended world state with the former than with the latter.

The pragmatic listener, finally, observes an utterance, and reasons about the world state and the common ground intended by the speaker. As shown in Qing et al. 2016, the projection inference is sensitive to the QUD: When the pragmatic listener observes *Sam didn’t stop smoking* and the QUD is whether Sam smokes now, the most likely world state is the state in which Sam smoked in the past and does not smoke anymore (the projection inference), whereas it is the state that Sam didn’t smoke in the past or now, if the QUD is whether Sam smoked in the past.

**(I) The relation between prior beliefs and lexical meaning in modulating projection.** Qing et al. 2016 assume a uniform prior over world states, which means that Sam is just as likely to have smoked in the past as he is to not have smoked in the past. Warstadt 2022 also assumes a uniform prior for the literal listener, but a non-uniform one for the pragmatic listener. Specifically, the prior over world states for the pragmatic listener is sensitive to the common ground: If, for instance, the common ground already entails that Sam smoked in the past (to use an example from Qing et al. 2016), then the two world states in which Sam smoked in the past would have a higher prior probability than the world states in which he did not

smoke in the past (even possibly a zero probability). These examples illustrate that prior beliefs can be straightforwardly integrated into RSA models, by modifying the distributions over world states (see also, e.g., Goodman and Stuhlmüller 2013; Degen 2023).

**(II) The relation between at-issueness and lexical meaning in modulating projection.** Both Qing et al. 2016 and Warstadt 2022 show that the investigated projection inferences are QUD-sensitive: Content is more likely to project when it is not at-issue with respect to the QUD than when it is at-issue with respect to the QUD. These examples illustrate that analyses of projection formulated within the RSA framework can, in principle, integrate the effect of the QUD, and therefore of at-issueness. What remains an open question is how such analyses can capture the by-predicate variation observed in the effect of at-issueness in projection in our experiments.

In sum, the RSA analyses in Qing et al. 2016 and Warstadt 2022 are able to predict projection inferences without assuming that the projective content is lexically specified as presupposed. These analyses also show that the effects of prior beliefs and at-issueness can be captured in analyses formulated within the RSA framework. An exciting task for future research is to develop an analysis of the projection of the CCs of clause-embedding predicates in the RSA framework that is able to predict the observed by-predicate projection variation and the observed by-predicate variation in the effect of at-issueness on projection.

#### 4.5 Summary

A predictive analysis of projection inferences must be able to predict that there is by-predicate projection variation, that prior beliefs modulate projection across clause-embedding predicates, and that there is by-predicate variation in the effect of at-issueness on projection. As illustrated in this section, there is no analysis on the market that can capture all of these observations. One of the largest obstacles to developing such an analysis is that lexical meaning modulates projection in more fine-grained ways than previously assumed and that the CCs of nonfactive predicates may also project. The lack of a principled account of how lexical meaning modulates projection also means that there is not yet a satisfactory analysis of the by-predicate variation observed in how at-issueness modulates projection. We hypothesize that (yet to be identified) components of lexical meaning constrain whether the projection of the CC is modulated by the QUD. For instance, an analysis according to which the lexical meaning of *pretend* entails that the speaker is committed to the falsity of the CC may predict that this content does not project even when it is not at-issue. Which components of lexical meaning play a role in modulating projection inferences and its interaction with at-issueness is an important question for future research.

### 5 Conclusions

This paper investigated how projection inferences are modulated by prior beliefs, at-issueness, and lexical meaning and possible interactions between these factors. The results of Exps. 1 and 2 showed that (I) the effect of prior beliefs on projection persists across the meanings of clause-embedding predicates, (II) the effect of at-issueness on projection varies by predicate, (III.a) prior beliefs and at-issueness do not interact in modulating projection, and (III.b) there is no effect of prior beliefs on at-issueness. Developing an analysis that is able to predict these results is a pressing task for future research.

## Data accessibility statement

The experiments, data, and R code for generating the figures and analyses reported on in this paper are available at . **CREATE LINK TO ANONYMIZED REPO** . Exps. 1 and 2 were preregistered at **ANONYMIZED POINTER**

## Ethics and consent

The experiments were declared exempt from review by the IRB of [university redacted for review]. Informed consent was obtained from the participants.

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## Supplements

### A Target and control items

**Target items** This list shows the 20 clauses of the target items with their lower and higher probability facts, respectively:

1. Mary is pregnant. Facts: Mary is a middle school student / Mary is taking a prenatal yoga class
2. Josie went on vacation to France. Facts: Josie doesn't have a passport / Josie loves France
3. Emma studied on Saturday morning. Facts: Emma is in first grade / Emma is in law school
4. Olivia sleeps until noon. Facts: Olivia has two small children / Olivia works the third shift
5. Sophia got a tattoo. Facts: Sophia is a high end fashion model / Sophia is a hipster
6. Mia drank 2 cocktails last night. Facts: Mia is a nun / Mia is a college student
7. Isabella ate a steak on Sunday. Facts: Isabella is a vegetarian / Isabella is from Argentina
8. Emily bought a car yesterday. Facts: Emily never has any money / Emily has been saving for a year
9. Grace visited her sister. Facts: Grace hates her sister / Grace loves her sister
10. Zoe calculated the tip. Facts: Zoe is 5 years old / Zoe is a math major
11. Danny ate the last cupcake. Facts: Danny is a diabetic / Danny loves cake
12. Frank got a cat. Facts: Frank is allergic to cats / Frank has always wanted a pet
13. Jackson ran 10 miles. Facts: Jackson is obese / Jackson is training for a marathon
14. Jayden rented a car. Facts: Jayden doesn't have a driver's license / Jayden's car is in the shop
15. Tony had a drink last night. Facts: Tony has been sober for 20 years / Tony really likes to party with his friends
16. Josh learned to ride a bike yesterday. Facts: Josh is a 75-year old man / Josh is a 5-year old boy
17. Owen shoveled snow last winter. Facts: Owen lives in New Orleans / Owen lives in Chicago
18. Julian dances salsa. Facts: Julian is German / Julian is Cuban
19. Jon walks to work. Facts: Jon lives 10 miles away from work / Jon lives 2 blocks away from work
20. Charley speaks Spanish. Facts: Charley lives in Korea / Charley lives in Mexico

In the target items of the projection and at-issueness blocks, eventive predicates, like *discover* and *hear*, were realized in the past tense and stative predicates, like *know* and *be annoyed*, were realized in the present tense. The direct object of *inform* was realized by the proper name *Sam*. Each clause-embedding predicate was paired with a unique subject proper name. The speaker of the target items was realized by a randomly sampled unique proper name.

**Control and filler items** The not-at-issueness and projection blocks included 6 control trials each. The full set of control items is given in (7). The content of these items was expected to be at-issue and not to project: For example, (7f) the speaker is asking about the main clause content, that is, whether Samantha has a new hat, and the speaker is not committed to the main clause content, that Samantha has a new hat. The same 6 main clauses were also used to form 6 filler trials in the prior block. These filler items were not used to assess participants' attention.

- (7) a. Do these muffins have blueberries in them? Fact: Muffins are sold at the bakery.  
b. Does this pizza have mushrooms on it? Fact: Pizza is sold at the pizzeria.

- c. Was Jack playing outside with the kids? Fact: Many children like ice cream.
- d. Does Ann dance ballet? Fact: Ballet is a type of dance.
- e. Were Carl's kids in the garage? Fact: Garages are used to store cars and other things.
- f. Does Samantha have a new hat? Fact: Hats are worn on the head.

## B Data exclusion

**Exp. 1.** We excluded the data from 16 participants who did not self-identify as native speakers of American English. We also excluded the data from one participant who always clicked on the same point of the scale across the target trials, as well as the data from 78 participants whose response means on the 6 not-at-issueness and projection control items were more than 2 sd above the group means.

**Exp. 2.** We excluded the data from 27 participants who did not self-identify as native speakers of American English. We also excluded the data from 5 participants who always clicked on the same point of the scale across the target trials, as well as the data from 60 participants whose response means on the 6 not-at-issueness and projection control items were more than 2 sd above the group means.

## C Manipulation of prior beliefs in Exp. 1

Fig. A1 shows the mean prior probability ratings of the 20 contents by fact from Exp. 1. As shown, contents presented with the higher probability fact received higher prior probability ratings than contents presented with the lower probability fact. This result is confirmed by a mixed-effects linear regression model that predicts prior probability slider ratings from dummy-coded fact type (reference level: ‘lower probability’) and random by-content and by-participant intercepts and slopes for fact type. The content’s mean prior probability was rated as higher when it was presented with its higher probability fact than when it was presented with its lower probability fact ( $\beta = 0.51$ ,  $SE = 0.03$ ,  $t = 17.41$ ,  $p < .0001$ ). This result suggests that the manipulation of the prior probability of the 20 contents was successful.

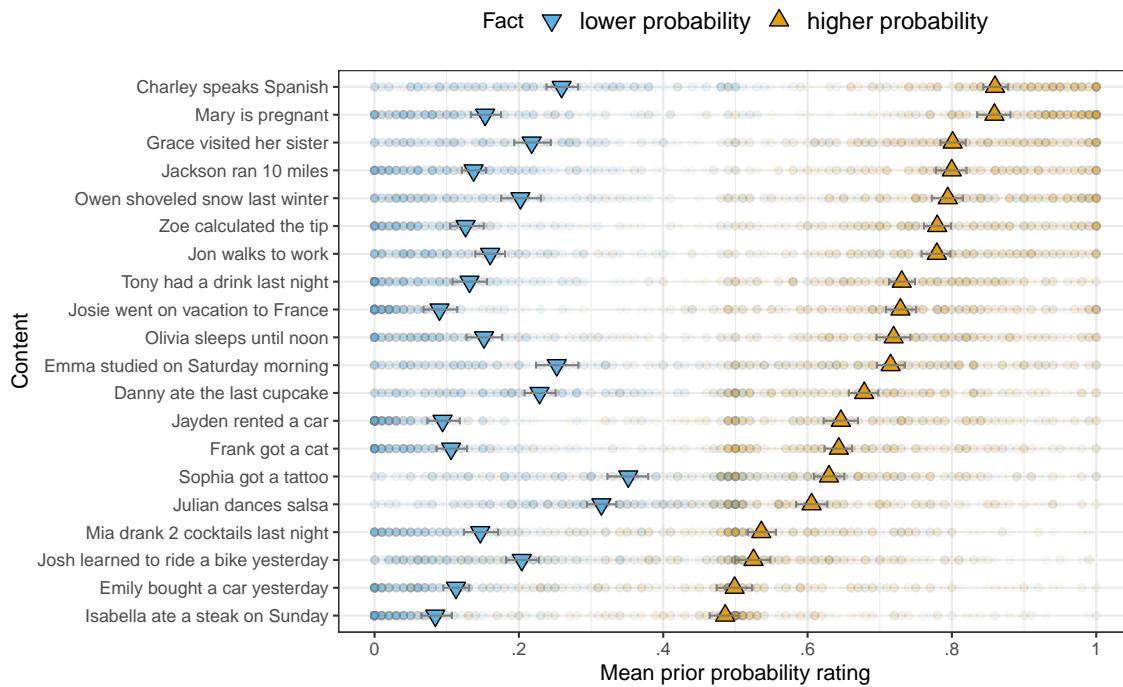
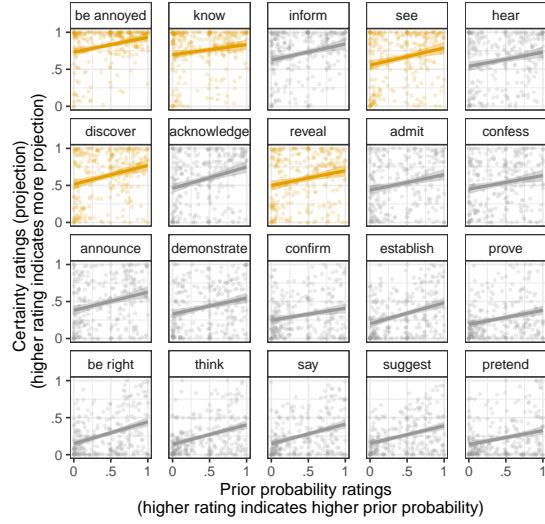


Figure A1: Mean prior probability rating by content and fact in Exp. 1. Error bars indicate 95% bootstrapped confidence intervals. Transparent dots indicate individual participant ratings.

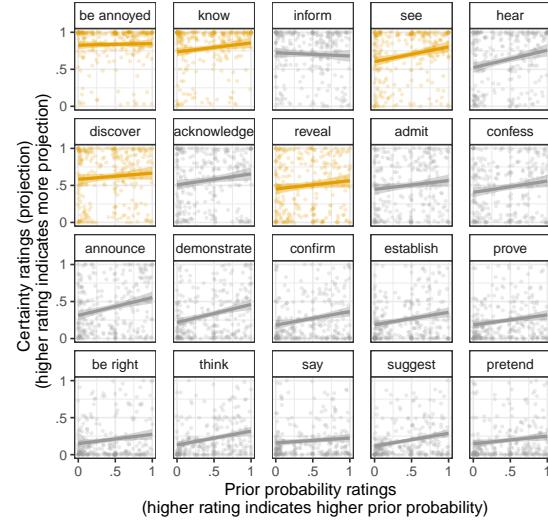
## D Exp. 1: Results by block order

The figures in this section present the results of Exp. 1 by block order, with the results for the two blocks side-by-side.

### D.1 Exp. 1: Certainty against prior probability ratings, by block order



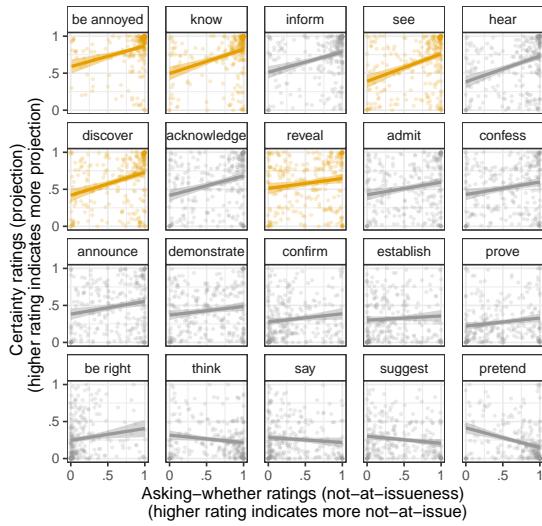
(a) Proj/ai dataset.



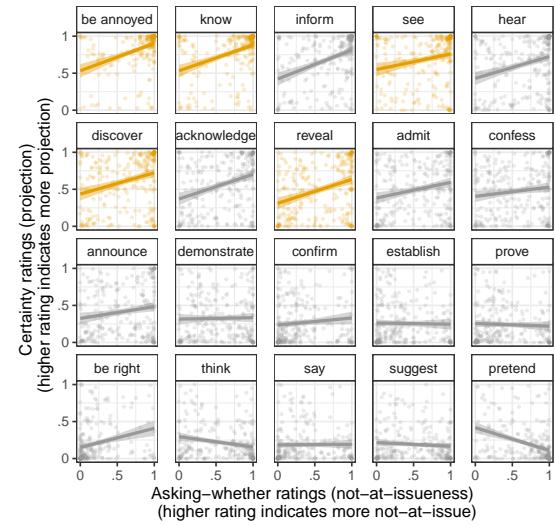
(b) Ai/proj dataset.

Figure A2: Participants' certainty ratings (measuring projection) against prior probability ratings in Exp. 2: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

## D.2 Exp. 1: Certainty against asking-whether ratings, by block order



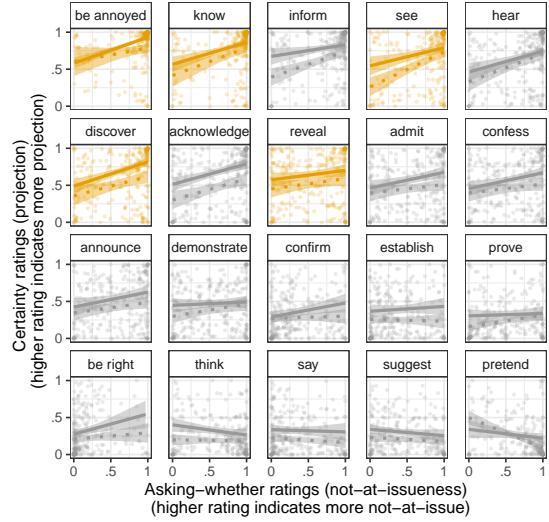
(a) Proj/ai dataset.



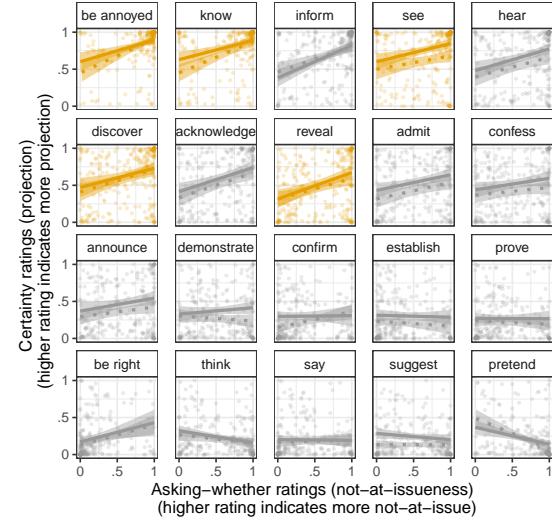
(b) Ai/proj dataset.

Figure A3: Participants' certainty ratings (measuring projection) against asking-whether ratings (measuring projection) in Exp. 1: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

### D.3 Exp. 1: Certainty against asking-whether ratings by prior probability, by block order



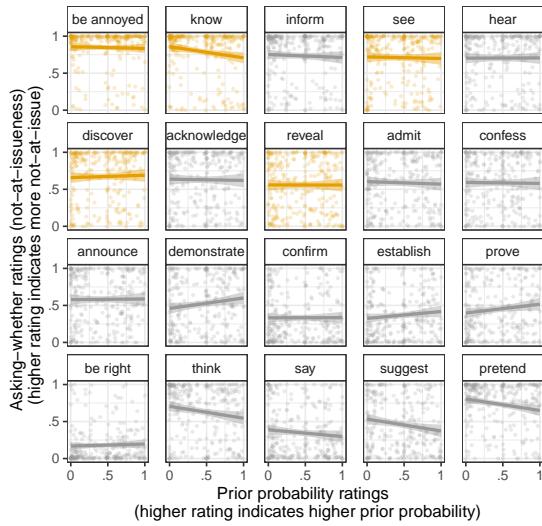
(a) Proj/ai dataset.



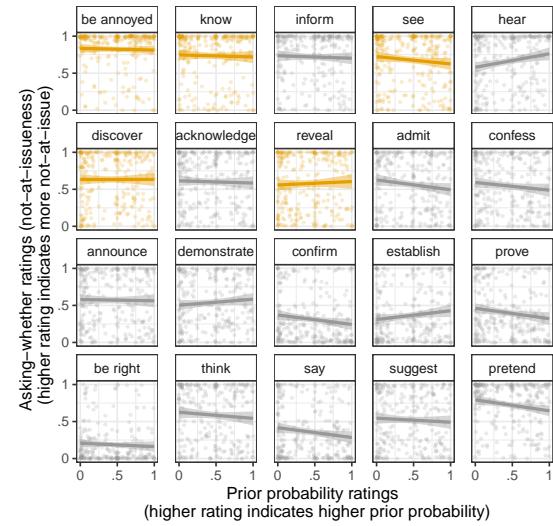
(b) Ai/proj dataset.

Figure A4: Participants' certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by high (solid line: —) and low prior probability fact (dotted line: ···) in Exp. 1: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

#### D.4 Exp. 1: Asking-whether against prior probability ratings, by block order



(a) Proj/ai dataset.



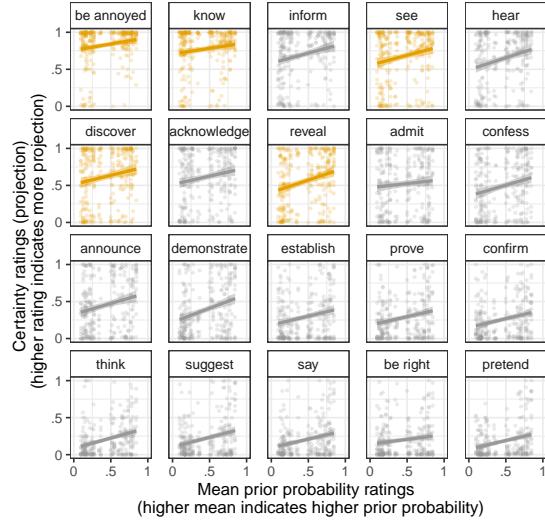
(b) Ai/proj dataset.

Figure A5: Participants' asking-whether ratings (measuring at-issuelessness) against prior probability ratings in Exp. 1: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

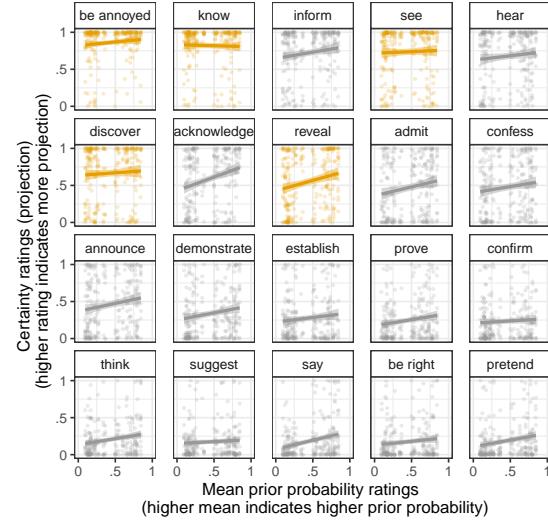
## E Exp. 2: Results by block order

The figures in this section present the results of Exp. 2 by block order, with the results for the two blocks side-by-side.

### E.1 Exp. 2: Certainty against mean prior probability ratings, by block order



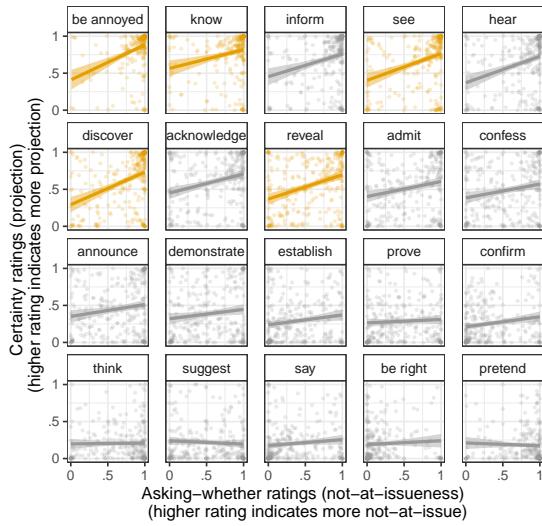
(a) Proj/ai dataset.



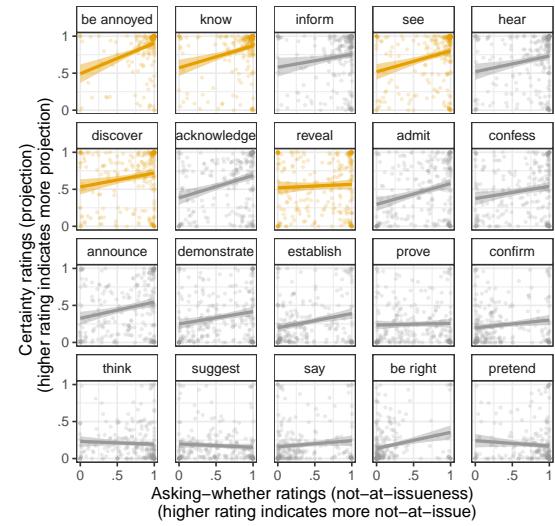
(b) Ai/proj dataset.

Figure A6: Participants' certainty ratings (measuring projection) against mean prior probability ratings in Exp. 2: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

## E.2 Exp. 2: Certainty against asking-whether ratings, by block order



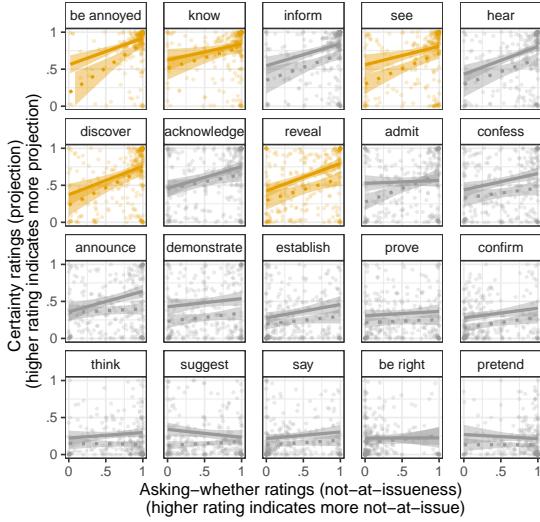
(a) Proj/ai dataset.



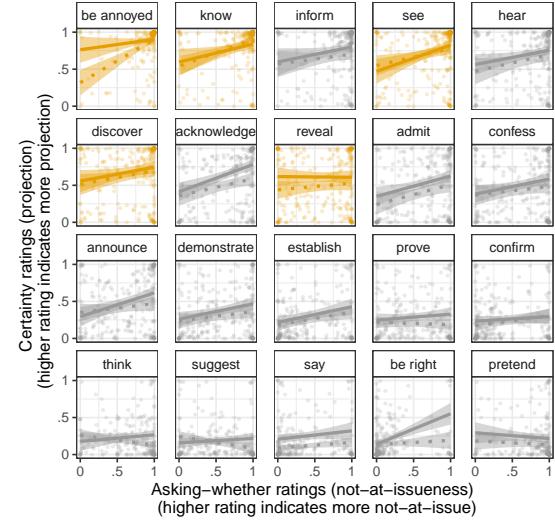
(b) Ai/proj dataset.

Figure A7: Participants' certainty ratings (measuring projection) against asking-whether ratings (measuring projection) in Exp. 2: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

### E.3 Exp. 2: Certainty against asking-whether ratings by prior probability, by block order



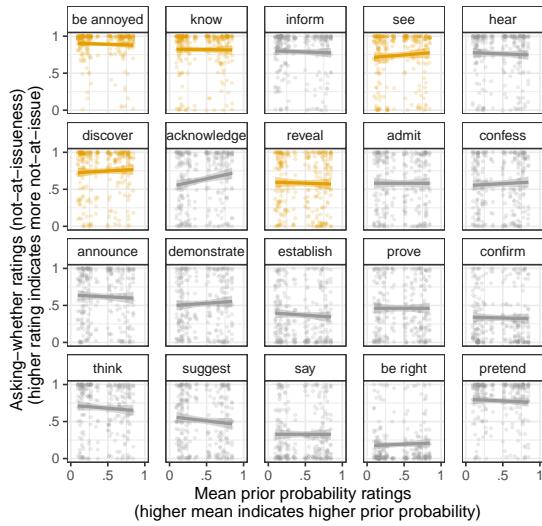
(a) Proj/ai dataset.



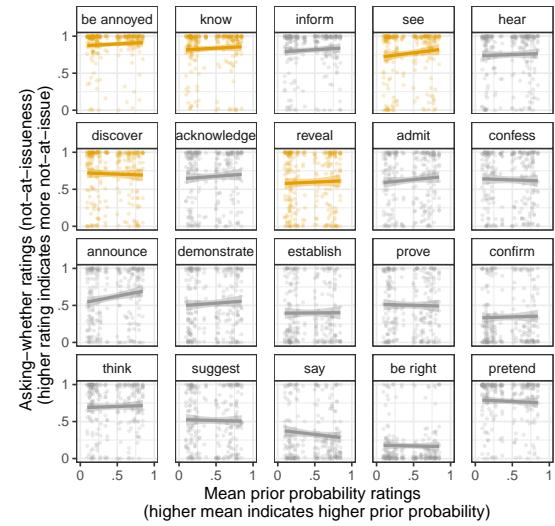
(b) Ai/proj dataset.

Figure A8: Participants' certainty ratings (measuring projection) against asking-whether ratings (measuring at-issueness) by high (solid line: —) and low prior probability fact (dotted line: ···) in Exp. 1: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

#### E.4 Exp. 2: Asking-whether against prior probability ratings, by block order



(a) Proj/ai dataset.



(b) Ai/proj dataset.

Figure A9: Participants' asking-whether ratings (measuring at-issueness) against mean prior probability ratings in Exp. 2: (a) Proj/ai dataset, (b) Ai/proj dataset. Linear smoothers with 95% confidence intervals overlaid. Predicates are ordered by projection mean, with purportedly factive predicates in orange.

## F Cross-experiment comparisons of ratings

### F.1 Prior belief ratings

Fig. A10 compares the mean by-content/fact prior probability ratings from Exp. 1 and the two experiments in Degen and Tonhauser 2021 (referred to as DT1 and DT2). For each content/fact combination, there was a mean of 252 ratings in Exp. 1, a mean of 143 ratings in DT1, and a mean of 38 ratings in DT2.

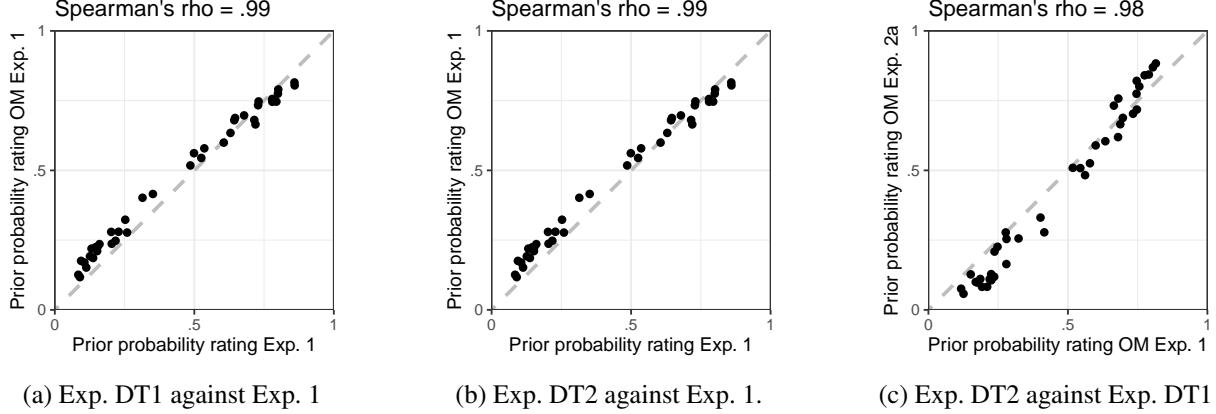


Figure A10: Comparisons of 40 mean by-content/fact prior belief ratings in Exp. 1 and the two experiments in Degen and Tonhauser 2021 (abbreviated DT1 and DT2), with Spearman rank correlations in the title. Error bars indicate 95% bootstrapped confidence intervals.

### F.2 Certain-that ratings (projection)

Fig. A11 compares the certainty ratings from Exps. 1 and 2. For each predicate, there were 505 ratings in Exp. 1 and 500 ratings in Exp. 2. For each predicate/content combination, there was a mean of 25 ratings in both Exps. 1 and 2. For each predicate/content/fact combination, there was a mean of 13 ratings in both Exps. 1 and 2.

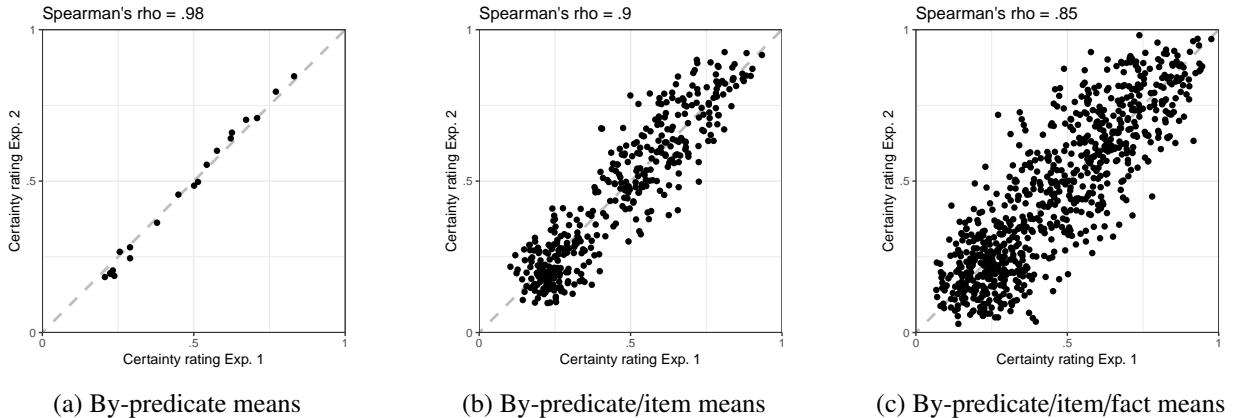


Figure A11: Comparisons of (a) 20 mean by-predicate, (b) 400 by-predicate/item certainty ratings, and (c) 800 by-predicate/item/fact ratings from Exps. 1 and 2, with Spearman rank correlations in the title. Error bars indicate 95% bootstrapped confidence intervals.

### F.3 Asking-whether ratings (at-issueness)

Fig. A12 compares the certainty ratings from Exps. 1 and 2. For each predicate, there were 505 ratings in Exp. 1 and 500 ratings in Exp. 2. For each predicate/content combination, there was a mean of 25 ratings in both Exps. 1 and 2. For each predicate/content/fact combination, there was a mean of 13 ratings in both Exps. 1 and 2.

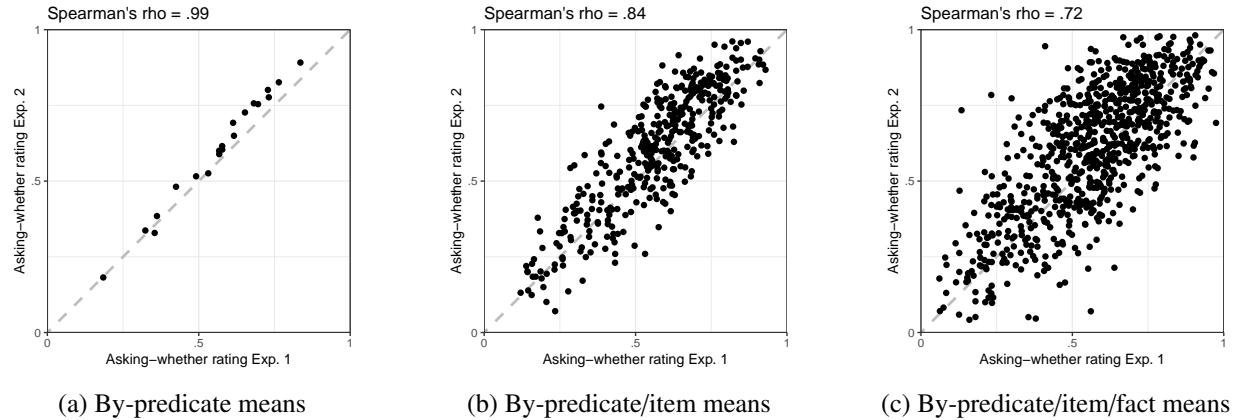


Figure A12: Comparisons of (a) 20 mean by-predicate, (b) 400 by-predicate/item certainty ratings, and (c) 800 by-predicate/item asking-whether ratings from Exps. 1 and 2, with Spearman rank correlations in the title. Error bars indicate 95% bootstrapped confidence intervals.