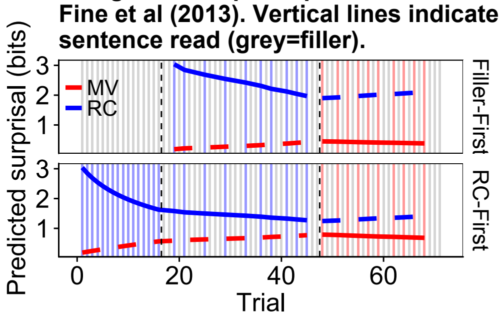
UNDERSTANDING CHANGES IN GARDEN-PATHS AS EXPECTATION ADAPTATION

Sentence processing seems to draw on implicit expectations about syntactic structures. Some theories hold that expectations are continuously *adapted* towards the syntactic statistics of the input[1,2], minimizing average surprisal.[3] A few studies have found evidence qualitatively compatible with adaptation to new syntactic distributions.[2−5] Principled *models* and their quantitative test against human data, however, have been lacking. We test a Bayesian belief-updating model against data from two garden-path reading experiments[3,6] (N=77, 415 subjects; 71, 142 items, respectively). The experiments reported conflicting results. We find that both datasets are, in fact, captured by simple belief-updating. The syntactic priors inferred from the reading data are similar across experiments, *and* approximate syntactic statistics of language corpora.

Data. Both studies[3,6] investigated the main verb (MV)/relative clause (RC) ambiguity, using the same block design (Fig 1), but different items and numbers of items. Subjects were randomly assigned to either the *RC-First* or *Filler-First* group. The RC-First group read only RCs in Block 1. The Filler-First group read only fillers. In Block 2, both groups read RCs and fillers. In Block 3, both groups read MVs. Half of the MV/RCs in each block contained the ambiguity (Latin-Squared). Block-based between-group (factorial) analyses found adaptation in [3] but not [6]. But these analyses do not take into account that [6] doubled the number of MV/RCs per block, changing the predicted expectation adaptation. We ask whether belief-updating explains both results.

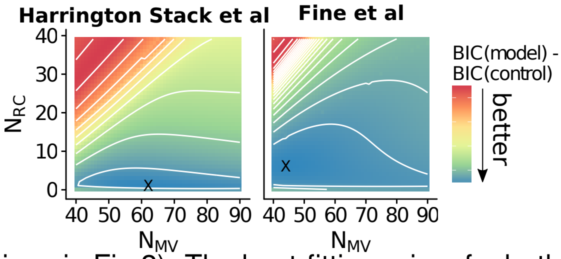
Design and surprisal predictions for Fine et al (2013). Vertical lines indicate sentence read (grey=filler).



Model prediction. The theory of expectation adaptation predicts that listeners incrementally adapt their expectations based on the frequency of MVs and RCs in the input.[3] We operationalize this as beta-binomial belief-updating.[4] This model has two DFs (inferred from the RT data): the prior MV and RC counts (N_{MV}, N_{RC}). The counts encode the prior probabilities of MVs and RCs (e.g., $P(RC) = N_{RC}/N_{RC} + N_{MV}$). The sum of the parameters captures how relevant listeners consider prior experience in the current situation. We then incrementally update expectations (and thus surprisal[7]) each time subjects read an RC/MV (Fig 1).

Analysis. We corrected RTs for word length and log trial order to remove the effects of adaptation to self-paced reading. We fit linear mixed models to both datasets, predicting RTs in the disambiguation region from surprisal, ambiguity, and their interactions. We compare the surprisal model to a control model predicting RTs from the design variables–group x block (structure) x ambiguity.

Fig2: Fits to data by prior MV, RC counts (X=best)



Results. For both[3,6], the surprisal model fits the data significantly better than the control, across a wide range of prior parameterizations (surprisal BIC $<$ control BIC; blue and green regions in Fig 2). The best-fitting priors for both[3,6] were similar, as expected if subjects on average hold similar prior experience, and thus beliefs ($N_{MV} = 44, 62$; $N_{RC} = 6.1, 1.1$ for [3,6], respectively; $\rightarrow P(RC) = 0.1, 0.01$). The inferred priors make sense: from natural language use, we would expect $\hat{P}(\text{RC}) = .011$.[8]

Conclusion. Bayesian belief-updating captures changes in RTs and garden-path effects, even for data reported not to show adaptation.[6] The fact that the priors—inferred from comprehension data alone—match corpus data supports experience-based theories.[9] Comprehenders seem to adapt their syntactic expectations to the statistics of recent input.

[1]Chang et al 06-*PsyRev*; [2]Wells et al 09-*CogPsy*; [3]Fine et al 13-*PlosOne*; [4]Myslin&Levy 16-*Cognition*; [5]Ryskin et al 16-*JEP*; [6]Harrington Stack et al 18-*Mem&Cog*; [7]Hale 01-*ACL*; [8]Roland et al 07-*JML*; [9]MacDonald 13-*Frontiers*