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\(^6,7\) (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.

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 (\(N_{\text{MV}}, N_{\text{RC}}\)). The counts encode the prior probabilities of MVs and RCs (e.g., \(P(\text{RC}) = N_{\text{RC}} / N_{\text{RC}} + N_{\text{MV}}\)). 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 \(\times\) block (structure) \(\times\) ambiguity.

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 (\(N_{\text{MV}} = 44, 62; N_{\text{RC}} = 6.1, 1.1\) for [3,6], respectively; \(\rightarrow P(\text{RC}) = 0.1, 0.01\)). The inferred priors make sense: from natural language use, we would expect \(P(\text{RC}) = 0.11\).\(^8\)

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—imagined 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