A Bayesian belief-updating model of syntactic expectation adaptation

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Work over the last 20 years has provided evidence that syntactic comprehension is affected by comprehenders' language experience: Structures that are more expected in their context are processed faster [1-2]. Comprehenders achieve this by integrating information from multiple cues [1,3]. Recent work further suggests that how these cues are combined into syntactic expectations can change due to *recent experience* [2,4-6]. However, there are so far no models of how comprehenders adapt to changes in the informativity of the cues that explain the observed ability to adapt syntactic expectations.

Here we develop a Bayesian belief-updating model which captures the qualitative behavioral effects found in a recent study on cue-combination and syntactic adaptation [6]. Via a Dirichlet-multinomial model, this model formalizes the following related claims: that comprehenders (a) track the co-occurrence of syntactic structures—here, sentence complement (SC) or direct object (DO) continuations, as in (1)—and cues providing information about the probability of those structures (here, the verbs and the complementizer *that*), and (b) use these *continuously updated* estimates to generate expectations about upcoming syntactic structures.

In a between-subjects, multi-visit self-paced reading experiment (pre-test session, three exposure sessions over 6 days, post-test session 2 days after last exposure session, cf.[5]), we previously investigated [6] whether comprehenders update their estimates of the probability of the syntactic structures in (1) conditioned on the verb used in the sentence and the presence of the complementizer *that*. The High Verb Reliability (HVR) group received evidence that SC-taking verbs *always* occur in sentences like (1b), while the Low Verb Reliability (LVR) group was exposed to a 50/50 mix of SC (1a) and DO (1b) continuations. For both groups, *that* occurred in 50% of all SC sentences, and was thus equally reliable across the two groups.

The basic behavioral result is that reading times changed from pre- to post-training depending on the statistics of the intervening experience, with LVR subjects relying more on the complementizer during post-training, owing to the verb having become a relatively *unreliable* cue to syntactic structure. The observed behavioral data is naturally predicted and quantitatively well-described by the model (r^2=.3; two free parameters) as a result of simply tracking and updating—via Bayesian inference, over the course of the experiment—the joint distribution over syntactic structures, verbs, and the presence or absence of the complementizer *that*.

The model is computationally very similar to previous modeling work on both adaptation [7] and cue combination [8-9] in perception. Moreover, the model extends these efforts by suggesting a link between adaptation and cue combination: by simply tracking the statistics of the linguistic environment, the model naturally predicts that the degree to which cues are relied upon should change according to those statistics. This model therefore provides a single computational framework for capturing two behavioral results previously treated as largely separate phenomena: syntactic adaptation and cue combination.

The framework employed here extends naturally to phonetic adaptation[10-11] and has previously been employed in vision, audition, and motor control[7-9], suggesting a potentially unifying framework for investigating adaptation and cue combination in human cognition.

(1) Dexter believed (that) his brother…
   a. …(DO) because they had known each other so long.
   b. …(SC) was a cold-blooded psychopath.

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