Evaluation of a Bayesian belief-updating model for the time course of linguistic adaptation

Dave Kleinschmidt & T. Florian Jaeger (University of Rochester)
dkleinschmidt@bcs.rochester.edu

Speech perception; Phonetic adaptation; Computational modeling; Mechanical Turk; English

Language understanding requires inference over noisy input. There is broad agreement that comprehenders make use of a variety of acoustic, syntactic, and discourse cues. Comprehenders also seem to rapidly adapt to situation- or speaker-specific changes in these statistical regularities [1-5]. These findings are compatible with experience-based accounts of language processing, which hold that individual experience affects language processing. What is missing, however, is a *theory* of such adaptation, an account that makes predictions about when and in what form adaptation should be observed. One theoretical framework with the potential to provide a unified account of the flexibility of language comprehension across linguistic levels is belief-updating, quantified as Bayesian inference. Bayesian belief-updating models have successfully been employed to model syntactic adaptation [6] as well as phonetic adaptation [7-9]. Here, we test the quantitative predictions of our Bayesian belief-updating model of phonetic adaptation, which we have previously evaluated *post hoc* against Dutch [8]. We used simulations over this model to derive predictions for English, which were then evaluated against human perception data, including several previously untested adaptation conditions.

Vroomen et al. [5] induced phonetic adaptation using AV /aba/ and /ada/ stimuli, where videos of a speaker producing either /aba/ or /ada/ were dubbed with synthetic audio which was either an unambiguous rendition of the video category, or was ambiguous. Unambiguous AV adaptors exhibited selective adaptation, where fewer (audio-only) test stimuli were categorized as /b/ after /b/-exposure, while ambiguous adaptors exhibited recalibration--more /b/ responses at test. Interestingly, selective adaptation strengthened with further exposure, while recalibration peaked after about 30 repetitions and then declined.

Experiment 1 replicates [5] on English, using a novel web-based approach (audio quality assessed in an initial calibration phase; only participants with sufficient category sensitivity finish). All effects of ambiguity found by [5] are present (logistic mixed-effects regression, $p<0.05$), and as in [8] the belief-updating model fits well ($r^2=0.67$).

Experiment 2: Our model predicts that selective adaptation and recalibration are not, as previously claimed, distinct, but arise from listeners matching their expectations to the statistics of recent experience. That is, selective adaptation and recalibration are two points on a continuum, and intermediate adaptors should produce intermediate effects. Examining such an intermediate adaptor that is not fully ambiguous (auditory stimulus classified with 86% consistency), the adaptation effect is indeed intermediate between those in Experiment 1 (logistic mixed-effects regression, $p<0.05$ for both main effects and one interaction). Furthermore, the model fits from Experiment 1 provide as good a fit for Experiment 2 ($r^2=0.66$) as for Experiment 1.

Experiment 3 tests our model's prediction that exposure to a high-variance distribution of ambiguous adaptors, would produce longer-lasting recalibration than the standard design using repetitions of exactly the same adaptor with no variability. Indeed, at the end of such high-variance exposure, recalibration was stronger compared to the original, low-variance condition (paired Wilcoxon V(42)=627, $p=0.028$).

Together, these results strongly support a unified Bayesian belief-updating model of selective adaptation and recalibration. Crucially, this framework is broadly applicable to linguistic prediction and inference, and in fact makes predictions about syntactic adaptation that are consistent with recent experiments [1,3].

[1] T. A. Farmer, A. B. Fine, and T. F. Jaeger, 2011, *CogSci11 Proceedings*.
[2] J. B. Wells, M. H. Christiansen, D. S. Race, D. J. Acheson, and M. C. MacDonald, 2009, *Cognitive Psychology*
[3] D. Grodner and J. C. Sedivy, 2011, *The Processing and Acquisition of Reference*, MIT Press,
[4] A. G. Samuel and T. Kraljic, 2009, *Attention, Perception, & Psychophysics*
[5] J. Vroomen, S. van Linden, B. de Gelder, and P. Bertelson, 2007, *Neuropsychologia*
[6] A. B. Fine, T. Qian, T. F. Jaeger, and R. A. Jacobs, 2010, *ACL CMCL Proceedings*
[7] M. A. Clayards, M. K. Tanenhaus, R. N. Aslin, and R. A. Jacobs, 2008, *Cognition*
[8] D. F. Kleinschmidt, T. F. Jaeger, 2011, *ACL CMCL Proceedings*
[9] M. Sonderegger and A. Yu, 2010, *CogSci10 Proceedings*