

Wait for it: Predicted Error vs. Prediction Error in Language Processing

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Introduction

The free-energy principle [1, 2], provides a parsimonious account of cortical activity as an expectation-maximization process in a hierarchical model. In this framework, prediction is pre-activation; however, pre-activation is not necessarily restricted to simple Hebbian association, but is rather an integrative, partially pooled stochastic computation across multiple timescales, including an infinite past (a prior in the Bayesian framework or long-term memory in neurocognitive terms).

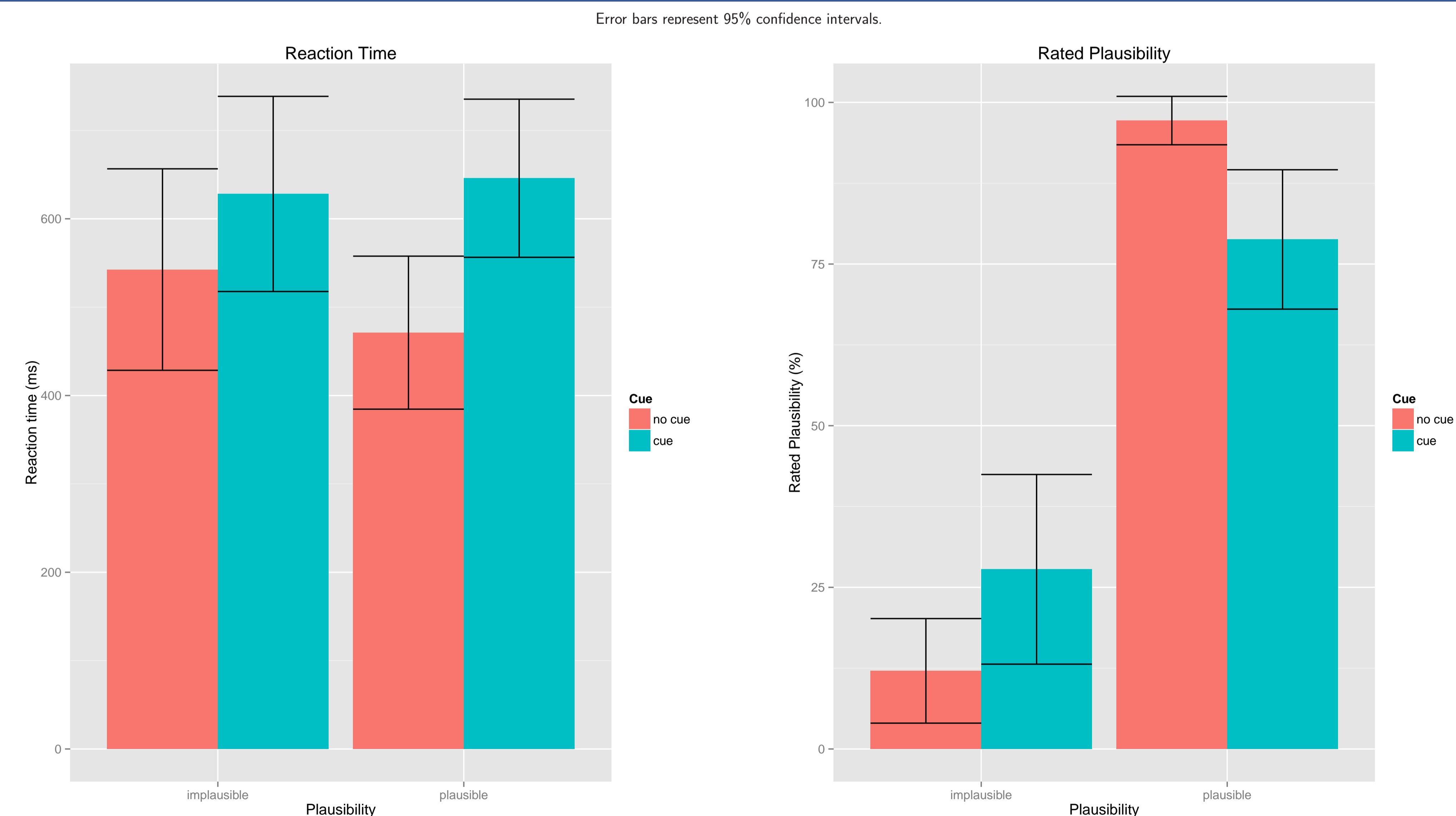
What to expect when you're expecting

Recent attempts to quantitatively model the N400 through information theoretic measures (e.g. surprisal, entropy, [3]) capture a large part of this variation through conditional frequency distributions, but naive corpus measures fail to capture the effect of explicit markers of information content such as “surprisingly” or “importantly”, whose conditional frequency is uniformly low.

Design

cue	plausibility	example
no cue	plausible	The kind doctor gave his patient a red lollipop.
no cue	implausible	The kind doctor gave his patient a red fork.
cue	plausible	The strange doctor gave his patient a red lollipop.
cue	implausible	The strange doctor gave his patient a red fork.

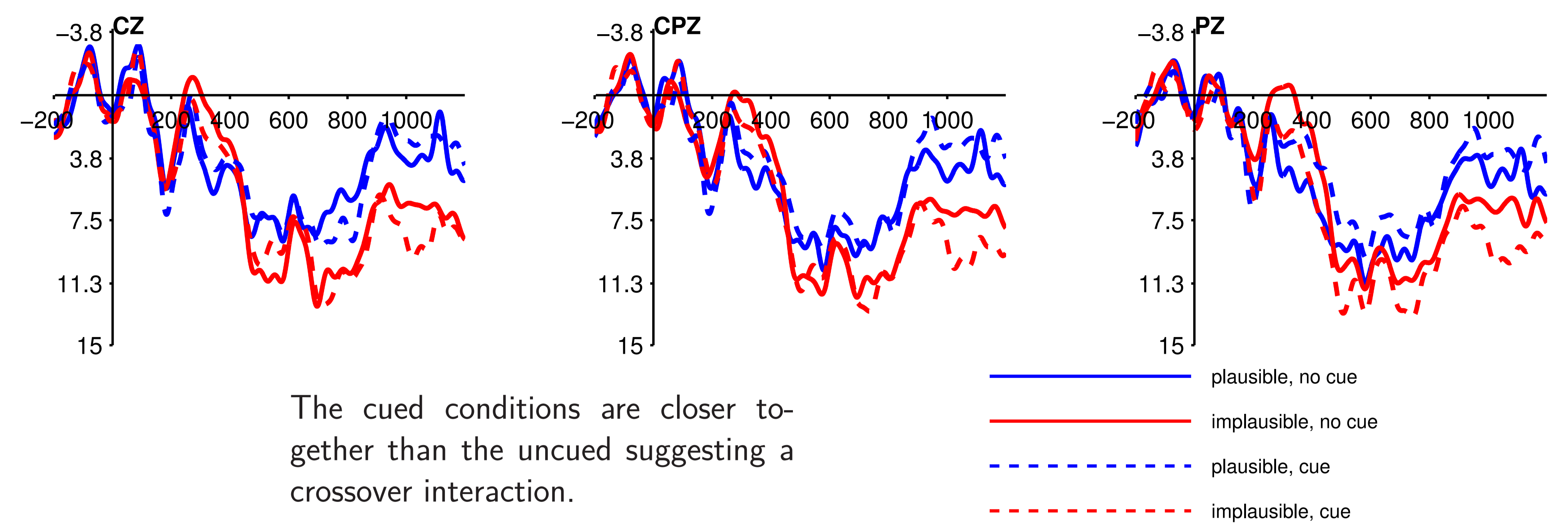
Behavioral Results



Cueing and plausibility have additive (main) effects upon reaction time. Cueing leads to more complex expectations and longer reaction times.

There is a crossover interaction for cueing and plausibility. Coherent cueing leads to an increase in plausibility, but incoherent cueing decreases plausibility.

ERP Results



Analysis

Single-trial mean amplitude in the N400 time window was analyzed with mixed-effects models [4].

Linear mixed model fit by maximum likelihood

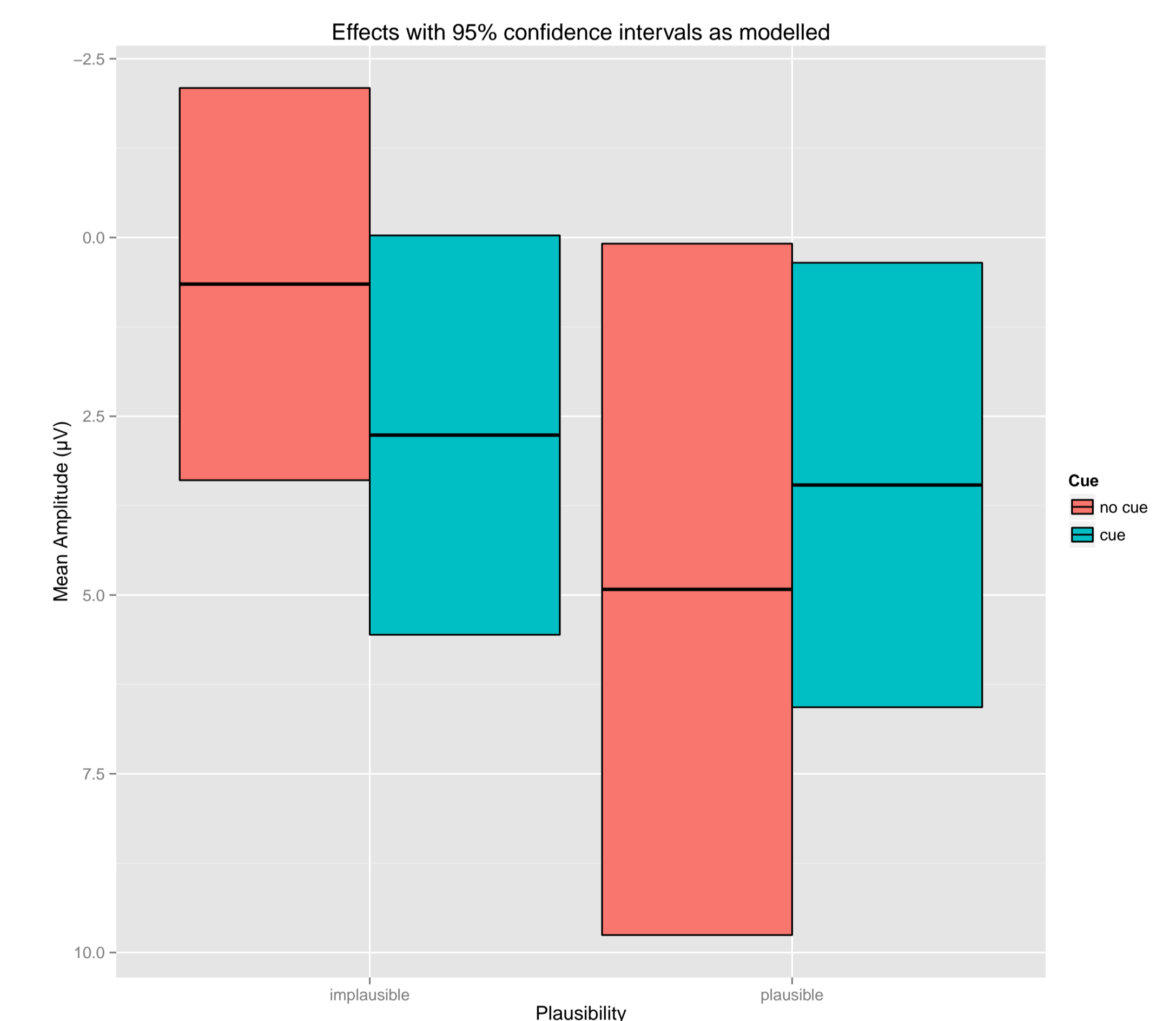
AIC	BIC	logLik	deviance
27117	27204	-13545	27089

Scaled residuals:

Min	1Q	Median	3Q	Max
-4.36	-0.61	0	0.62	3.94

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	2.9	1.2	2.5
plausibility	-1.2	0.87	-1.4
cue	0.16	0.99	0.16
plausibility:cue	0.89	0.17	5.2



The crossover interaction dominates the well-established main effect for plausibility in this small sample ($n=13$).

Conclusion

Naive stochastic measures (e.g. co-occurrences or transition probability) capture only part of the the information-theoretic surprisal that the N400 indexes. Information content — whether expressed through syntax [5], semantics [6] or pragmatics [7] — may ultimately rely on frequencies, but they are not the surface frequencies of simple co-occurrences and local transition probabilities.

Prediction arises from a hierarchical, generative model that pools both distributional information and information about expected distributions. A predicted error can reduce the prediction error because prediction overrides and overcomes frequency.

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Literature

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 [7] M. J. Pickering, M. J. Traxler, et al. (2000). *Journal of Memory and Language*.