MODELING THE PERCEPTION OF VOWEL NASALIZATION

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Bayesian Perception

Perception Models:

- Bayesian models that employ step-conditioned distributions for two categories of vowels -- phonologically nasalized vowels and oral vowels.
- Bayes' Theorem

$$P(A\,\big|\,B) = \frac{P(B\,|\,A) \times P(A)}{P(B)}$$

$$P(Category_i\,\big|\,Acoustics) = \frac{P(Acoustics\,|\,Category_i) \times P(Category_i)}{\sum_{i=1}^{n} P(Category_i) \times P(Acoustics\,|\,Category_i)}$$

Acoustic models:

- Acoustic models were trained for two vowel categories: oral (V-oral) and nasalized (V-nasalized).
- Mel-frequency cepstral coefficients (MFCCs) were used to represent acoustic information (Davis and Mermelstein, 1980).
- Likelihood distributions were generated for each category.
- The models were tested with the same nonce words as presented to actual listeners.

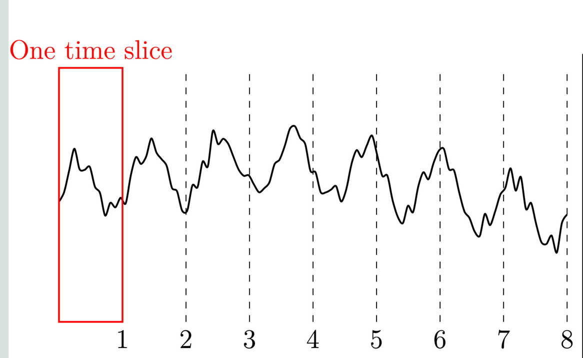


Fig. 1 Dividing a vowel into eight discrete time slices and measuring 12 MFCCs from each time slice

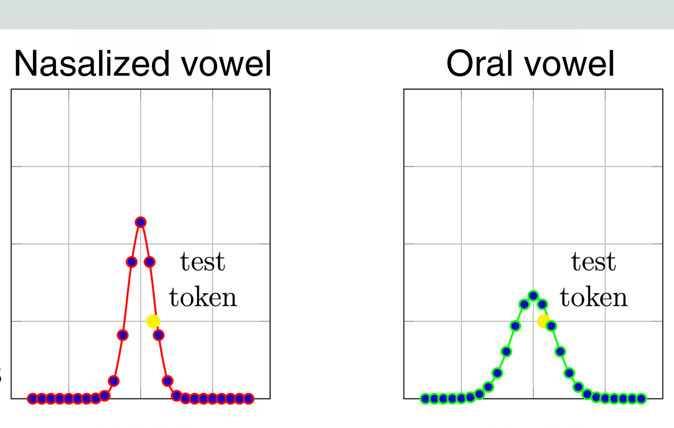


Fig. 2 Simulated probability distributions for two vowel categories at each time point for a single MFCC value

Introduction

Some debates around speech perception:

- Whether listeners access stored exemplars with fine-grained phonetic details (Pierrehumbert et al., 2002; Pierrehumbert, 2001, 2016). or are attuned to subtle variations such as different levels of coarticulation (Fowler, 1981, 1984).
- Whether listeners perceive speech through underspecified URs or SRs (Marslen-Wilson 1980, 1984, 1991; Ohala and Ohala, 1995; Kotzor et al. 2022).
- What is the mechanism of speech perception (Liberman et al. 1967; McClelland and Elman, 1986; Cutler and Norris 1979; McClelland and Elman 1986; Norris and McQueen 2008 etc.).

Questions

Do listeners rely on ...

- Incremental inference updates or immediate acoustics?
- Nuanced temporal information or abstract categories?
- Underspecified representations?

Take-aways

1. **Categorical, underspecified representations are sufficient to account for the patterns in listeners' perception of vowel nasalization.**
2. **Listeners engage in Bayesian inference where their decisions are continuously updated based on previous information.**

Methodology

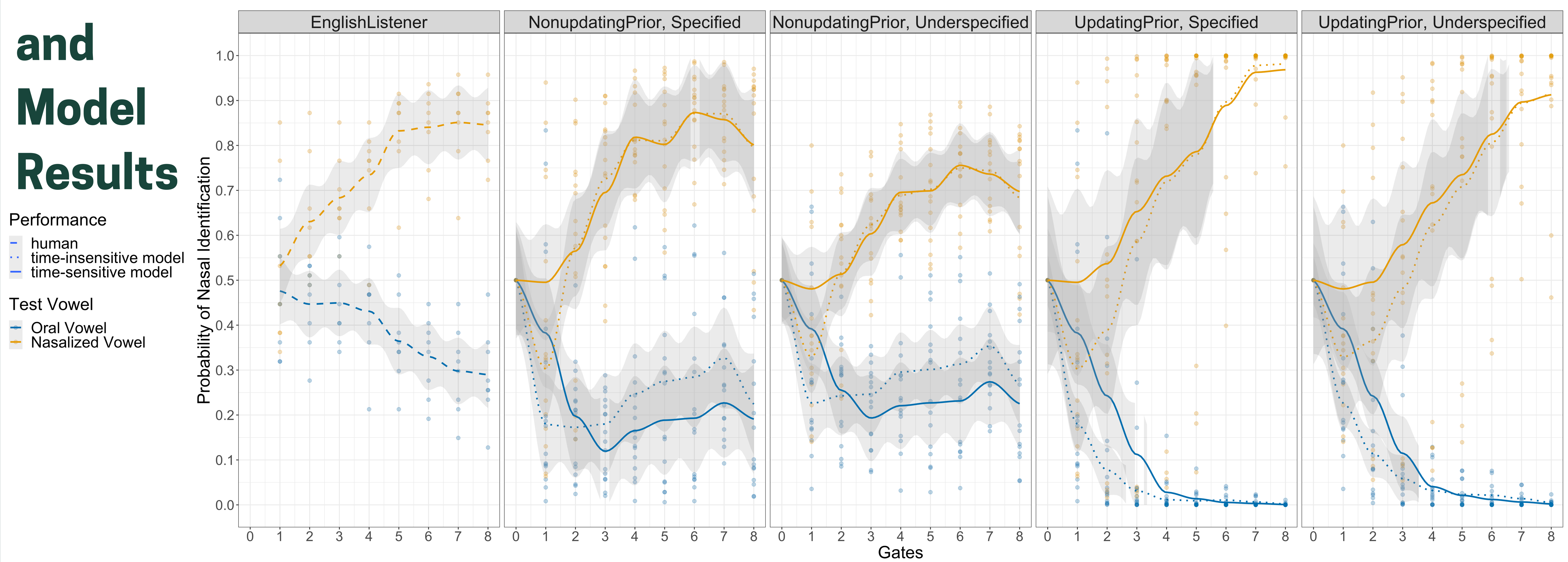
- Participants: 43 native American English speakers.
- Production Task:
  - Wordlist of CVC (oral) and CVN (nasalized) words + fillers.
  - Multiple repetitions of each word.
  - Data used to train acoustic models.
- Perception Task:
  - Forced-choice segment identification task on end-truncated CVC and CVN nonce words.
  - Audio stimuli presented in 8 gated time steps (gates).

Listener and Model Results

Fig. 3a Percentage of nasal responses from 43 English speakers

Fig. 3b-c Bayesian Perception Model with Nonupdating Prior

Fig. 3d-e Bayesian Perception Model with Updating Prior



Listener and Model:
(comparing 3a and 3b-e)

- Listeners could differentiate between V-oral and V-nasalized from the outset.
- Listener accuracy is monotonically increasing.
- Some models perform better than listeners.

Time Sensitivity:
(comparing linetypes)

- **Yes:** Each vowel category is represented with eight time-normalized multidimensional distributions.
- **No:** One distribution across the entire vowel.

Time-insensitive models perform well.
→ Listeners do not need fine temporal details for perceptual accuracy.

Underspecification:
(comparing 3b and 3c; 3d and 3e)

- **Yes:** V-oral was trained with general data from all words (CVC+CVN), V-nasalized was trained with CVN words only.
- **No:** V-oral and V-nasalized were trained with context-specific data from CVC and CVN words respectively.

Models using underspecified representations match the performance from specified acoustic models.
→ Listeners do not need fully specified representations.

Updating Inference:
(comparing 3b-c and 3d-e)

- **Yes:** The posterior at each time step/gate becomes the prior for the next time step/gate.
- **No:** Unchanging, equiprobable priors.

Models with dynamically updating priors, better reflected the monotonic increasing trend in the actual listener behavior than the non-updating ones.
→ Listeners' decisions are continuously influenced by an evolving prior that incorporates newly accumulated probabilistic information .

What's Next?

- Modeling perception in languages with different vowel nasalization patterns: nasal vowels (e.g. Hindi); phonetic nasalization (e.g. Peninsular Spanish).
- Quantitatively compare model performance.
- Evaluating the assumptions and predictions of perception theories.

Selected References

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