Modeling the nasal vowel inventories predicted by phonetic biases and learning

Cross-linguistically, nasal contrasts are more common for low vowels than high vowels (Kingston 2007); for example, Amuzgo contrasts [a] and [ã] but has no nasal counterpart to [i] (Longacre 1966). Analogously, low vowels across languages are produced with a lower velum than high vowels, perhaps from lowering biomechanics, which researchers have hypothesized as causing nasal contrasts to be more frequent for low vowels (Henderson 1984; Whalen & Beddor 1989; Blevins & Garrett 1993; Barnes 2002).

However, the mechanisms linking exactly *how* low vowels' greater nasality would lead to more low nasal contrasts remain to be specified and evaluated. As a proof of concept, I demonstrate that, when assuming the often-discussed Mixture of Gaussians (MOG) model of category learning and sound change (e.g. Gubian et al. 2023), low vowels' greater nasality does *not* predict they are more likely to split into nasal/oral contrasts.

A MOG learner searches for the set of categories that maximizes the likelihood of its input data, which is a set of uncategorized tokens (Figure 1). Intuitively, the less overlap between vowel distributions, the more likely they'll be learned as separate categories (cf. Feldman 2013). Generations of speakers can be modeled with a parent MOG and a child MOG, where the child's learning input consists of the parent's productions: unlabeled, noisy samples from the parent's categories. Because of the noise in the child MOG learner's input, it might learn different categories from the parent's. Differences in parent and child categories can involve vowel categories splitting or merging (e.g. Gubian et al. 2023).

Nasal contrasts arise when vowels neighboring nasal consonants split into a nasal allophone category, followed by consonant deletion ({ba, ban} → {ba, bãn} → {ba,bã} , Figure 2) (cf. Hajek & Maeda 2000). If greater nasality contributes to more nasal contrasts, then adding low vowels' greater nasality to the learning data (Figure 3) should make MOG more likely to split them into oral and nasal categories.

However, Figure 3 demonstrates that even with greater nasality, oral/nasal splits for low vowels are *not* more likely given MOG. Speakers' intended low vowels (left) are shifted (center) toward greater nasality (right), qualitatively reflecting Henderson (1984)'s measurements of phonetic bias. Even when the low vowel distribution is biased to greater nasality, the amount of overlap between oral and nasal context vowels is the same for high {bi,bin} as low {ba, ban}. This result challenges the hypothesis connecting the typological frequency of low vowels' nasal contrasts, but generates further questions: empirically, is low vowels' nasality *difference* (ba vs ban) also greater? Could a revised model, jointly inferring category and context, misattribute consonant nasality more to already-more-nasal low vowels (cf. Ohala 1994; Beddor 2009)?

Broadly, this demonstration underscores that hypothesized relationships between phonetics and typology depend on assumptions about learning.

I will also discuss different representations of vowel nasalization (as in Beddor 2009) and how low vowels' greater nasality interacts with the more complex MOG-based model described in Gubian et al. (2023), with agent interaction, a lexicon, and additional layer of abstraction.

References [1]Kingston, J. (2007). The phonetics-phonology interface. *The Cambridge handbook of phonology*, 401-434. [2] Longacre, Robert E. 1966. On the Linguistic Affinities of Amuzgo. *International Journal of American Linguistics* 32. [3] Henderson, J. B. (1984). Velopharyngeal Function in Oral and Nasal Vowels: A Cross-Language Study. Dissertation, University of Connecticut. [4] Whalen, D. H., & Beddor, P. S. (1989). Connections between nasality and vowel duration and height: Elucidation of the Eastern Algonquian intrusive nasal. *Language.* [5] Blevins, J. & Garrett, A. (1993) The Evolution of Ponapeic Nasal Substitution. *Oceanic Linguistics.* [6] Barnes, J. (2002) Positional Neutralization: A Phonologization Approach to Typological Patterns. Dissertation, University of California Berkeley. [7] Gubian, M et al. (2023). Phonetic and phonological sound changes in an agent-based model. *Speech Communication.* [8] Feldman, N. H. et al. (2013). A role for the developing lexicon in phonetic category acquisition. *Psychological Review* [9] Hajek, J., & Maeda, S. (2000). Investigating universals of sound change: the effect of vowel height and duration. *Papers in Laboratory Phonology* [10] Ohala, J. J. (1994). Towards a universal, phonetically-based, theory of vowel harmony. *Third International Conference on Spoken Language Processing*. [11] Beddor, P. (2009) A Coarticulatory Path to Sound Change. *Language*.

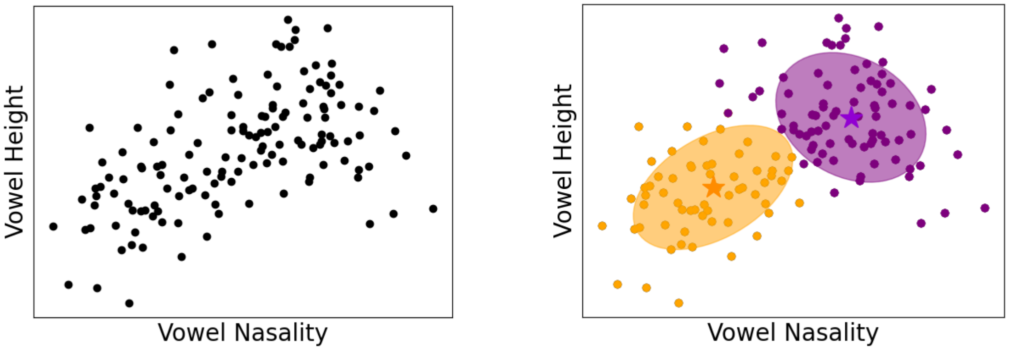

Figure 1. Example MOG uncategorized input (left) and categorized output (right). Categories are Gaussian distributions. Each point represents a vowel token defined by two dimensions, F1 and nasality. "Nasality" is abstracted here, but could be quantified by a perceptual scale (Whalen & Beddor 1989) or velar port measurements as in (Henderson 1984). The number of categories need not be prespecified, by using either a Dirichelet process (e.g. Feldman 2013) or model comparison (e.g. Gubian et al. 2023).

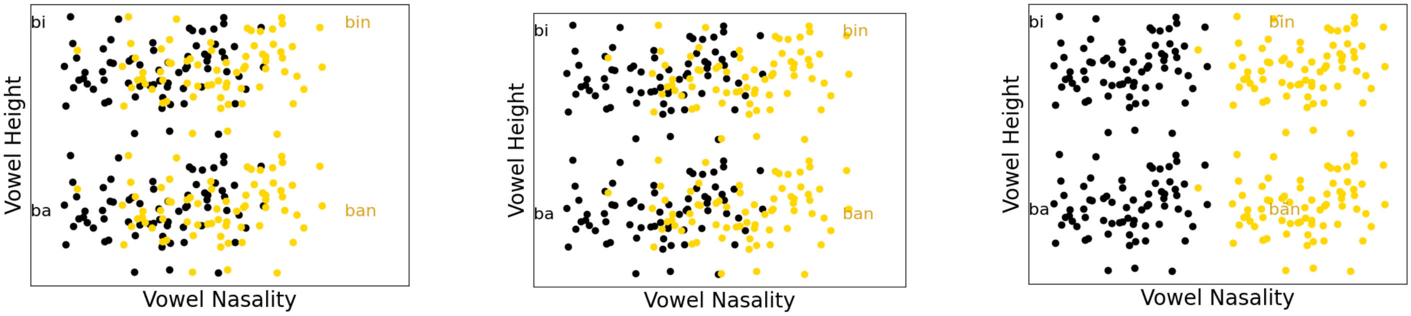

Figure 2. Example progression of nasal coarticulation (slightly more nasality in [ban] than [ba]) leading to separate nasal/oral allophone categories (e.g. ba vs bãn), with consonant deletion assumed to happen afterward.

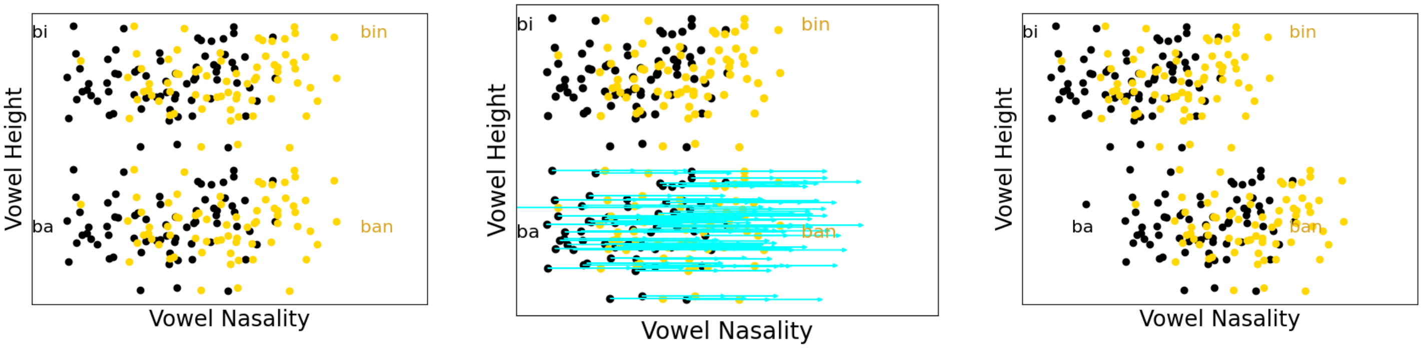

Figure 3. Illustration of low vowels' greater nasality does not change the predicted number of categories with a MOG learner.