Speech models represent phonemes in an emergent, substance-informed feature space

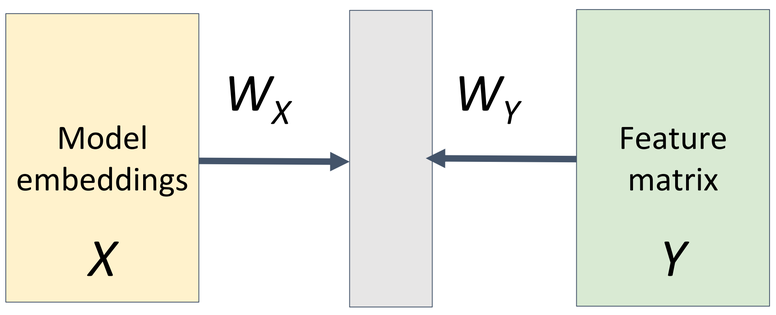
INTRODUCTION

To what degree do featural representations reference phonetic substance?

Substance-informed (Chomsky & Halle 1968)	**Substance-free** (Hale & Reiss 2000)
Phonemes contain information about their phonetic characteristics	Phonemes are represented distributionally, not related to their phonetic characteristics
/ŋ/, /g/, /m/ are phonetically similar	/ŋ/, /ʒ/, /v/ are distributed similarly

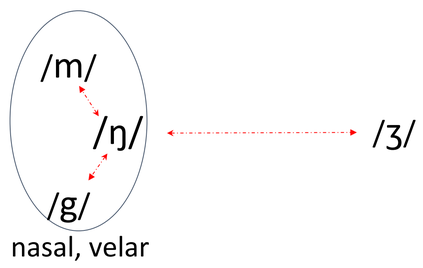
Which type of feature system **better corresponds to models' representations?**

APPROACH

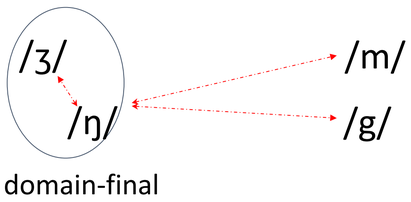


Align Speech Model embeddings of phonemes with different feature systems using Canonical Correlation Analysis (CCA):

- **Substance-informed feature system from Hayes (2009)** (17 dim.): → what do phonemes sound like?



- **Substance-free feature system** from Mayer (2020) (34 dim.): → how are phonemes distributed?



Data

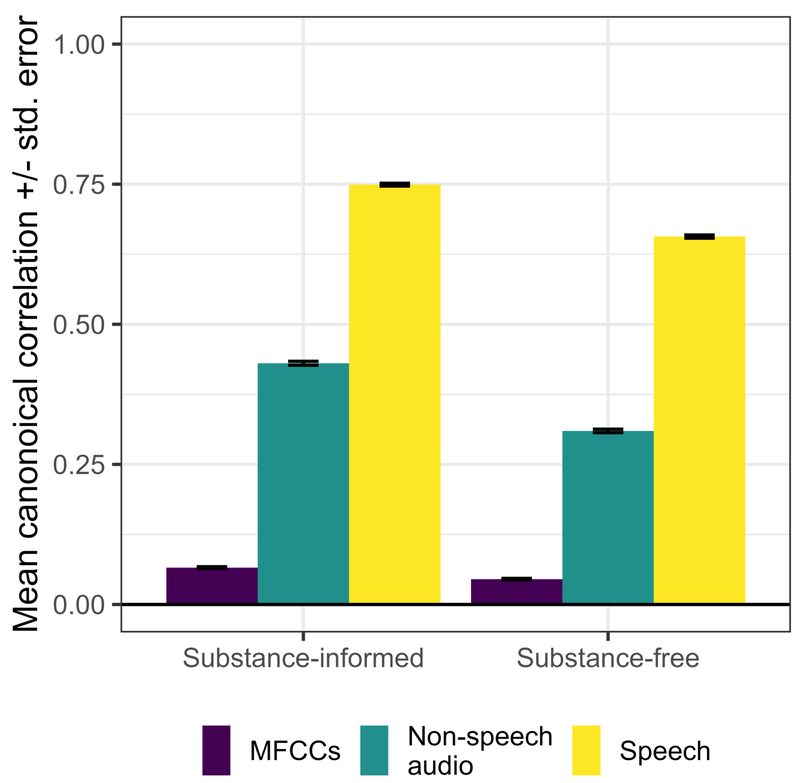
39 English phonemes, extracted from CV and VC sequences of English, synthesized by 10 TTS voices.

MODELS TESTED

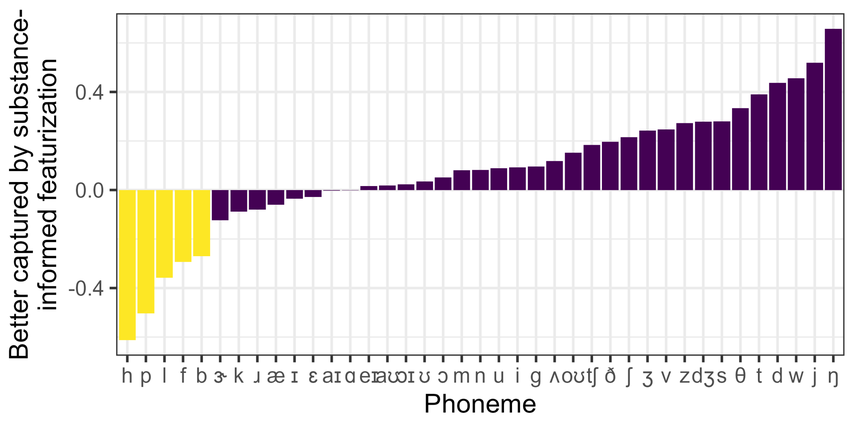
Hubert-Large (trained on English); Hubert-Large (trained on non-speech ambient sounds); Wav2Vec2-Large (not shown)

RESULTS

CCA model-feature alignment:



Second-order representational similarity:



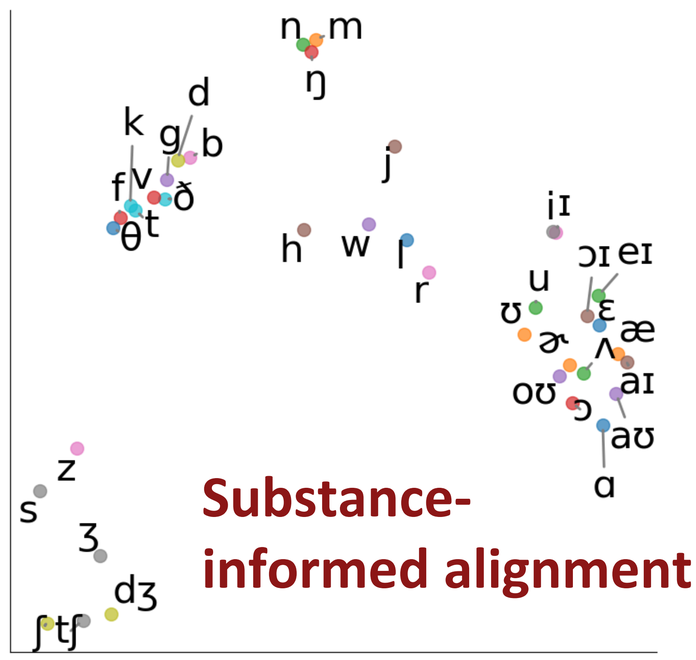
Highly correlated with preference for onset position in Mayer (2020)

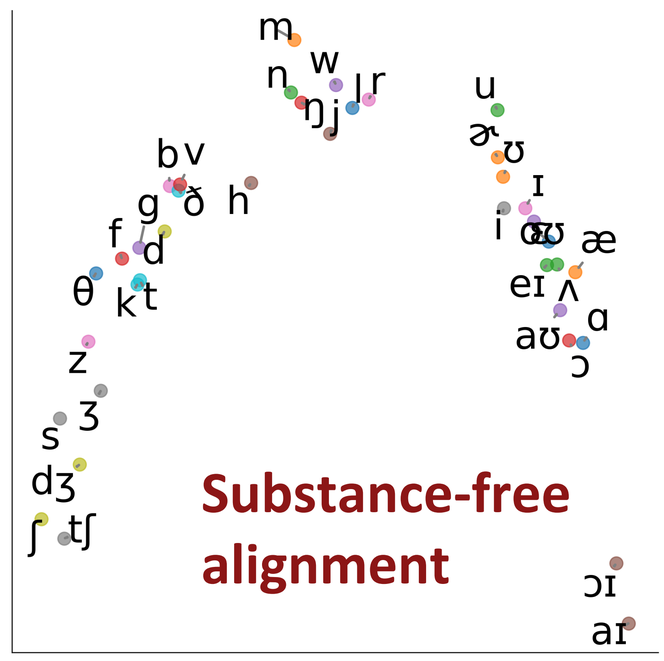
Figure 10 (Mayer 2020)

12th (for substance-informed features) and 14th (substance-free) layers shown.

ERROR ANALYSIS

Model embeddings struggle to capture the [ŋ] ~ [ʒ] relationship in the substance-free feature system, even with supervision through CCA.





TAKEAWAYS

Speech models exhibit **emergent, featurally-structured** phoneme representations

Speech model's phoneme embeddings are primarily **substantive**: they encode phonetic properties better, on average, than abstract distributional properties.

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