Appendix C: Non-significant predictors in the AX discrimination study

Non-significant segment-level predictors

Segmental frequency

Segmental frequency is simply the number of occurrences of a particular segment type in some representative corpus. Segmental frequency has been shown to influence the location of the boundary between phonemic categories in a discrimination task (Kataoka & Johnson, 2007). Crucially for this study, the difference in segmental frequency between two phonemes may also condition discrimination accuracy above and beyond the acoustic differences between those two phonemes (Bundgaard-Nielsen & Baker, 2014; Bundgaard-Nielsen, Baker, Kroos, Harvey, & Best, 2015).

Further, segmental frequency has been shown to influence the probability of a segment being misperceived in English, as well as the quality of the segment that listeners incorrectly perceive when making a perceptual error. Using naturalistic misperception data in English, Tang (2015, Ch. 4) found that (a) more frequent segments are more likely to be misperceived, and (b) when a segment is misperceived, listeners are more likely to report hearing a relatively frequent segment.

In our case, segment frequency is calculated over each stop consonant type regardless of the vowel that follows it and its position in a syllable (onset or coda).

Non-significant word-level predictors

Neighborhood density and neighborhood frequency

The Phonological Neighbors of a given word *w* are usually defined as words which differ from *w* only by the deletion, addition, or substitution of one phoneme. The phonological Neighborhood Density of a word *w* is simply defined as the number of neighbors *w* has. It has been demonstrated that frequency-weighted lexical neighborhood density (the number of neighbors of a given word, weighted by their token frequencies) can affect the phonemic categorization of a stimulus much like the lexical status of a stimulus can (Ganong, 1980; Newman, Sawusch, & Luce, 1997, 2005).

More generally, Neighborhood Density and Average Neighborhood Frequency (the average of the log token frequencies of an item's neighbours) can have an inhibitory effect on spoken/visual word recognition, such that words with high neighborhood density and/or high average neighborhood frequency are more difficult to recognize (Grainger & Segui, 1990; Luce, 1986; Luce & Pisoni, 1998). Furthermore, when a word is recognized incorrectly, the neighborhood density of the perceived word is typically similar to the neighborhood density of the intended word (Vitevitch, 2002). Consequently, even if a stimulus in our study were incorrectly perceived, its neighborhood density could still bias the participants' responses.

In order to keep our results directly comparable to a large body of past work in speech perception, we focused on just neighborhood density and average neighborhood frequency—two common measures of neighborhood structure—as potential neighborhood-related predictors of stimulus confusability. For general discussion, as well as other techniques for calculating neighborhood density and related measures, see Bailey and Hahn (2001); Gahl and Strand (2016); Luce (1986); Vitevitch and Luce (2016); Yao (2011); Yarkoni, Balota, and Yap (2008).

Bigram frequency

Bigram Frequency refers to the frequency of occurrence of each two-phoneme sequence (bigram) in some corpus. In the context of our study, the bigram frequency of a stimulus can be interpreted as the number of times a given stop consonant is preceded/followed by a given vowel in our written corpus. Our Bigram Frequency predictor characterized the difference in bigram frequency between the two stimuli presented on a given trial.

Bigram frequency is known to play a role in non-word acceptability tasks (Albright, 2009) as well as in the recognition of both real words and non-words (Rice & Robinson, 1975; Vitevitch & Luce, 1999). In terms of our stimuli, bigram frequency can be interpreted as an approximate estimate of overall word-likeness.

Given that our stimuli consisted of monosyllables, the bigram frequency of a given stimulus is likely to correlate with an estimate of syllable frequency. It is well-known that syllable frequency influences word recognition, with an inhibitory effect: Words with high-frequency initial syllables are recognized more slowly than words with low-frequency initial syllables. This effect can be understood in a cohort model of lexical activation: a high-frequency initial syllable should activate a larger number of competing lexical candidates, thus slowing word recognition. This effect is found in both visual (Barber, Vergara, & Carreiras, 2004; Carreiras, Alvarez, & de Vega, 1993) and spoken word recognition (González-Alvarez & Palomar-García, 2016).

References

Albright, A. (2009). Feature-based generalisation as a source of gradient acceptability. *Phonology*, *26*(01), 9–41.

Bailey, T. M., & Hahn, U. (2001). Determinants of wordlikeness: Phonotactics or lexical neighborhoods? *Journal of Memory and Language*, *44*(4), 568–591. doi: 10.1006/jmla.2000.2756

Barber, H., Vergara, M., & Carreiras, M. (2004). Syllable-frequency effects in visual word recognition: evidence from ERPs. *Neuroreport*, *15*(3), 545–548. doi: 00001756-200403010-00032

Bundgaard-Nielsen, R. L., & Baker, B. J. (2014). Frequency in the input affects perception of phonological contrasts for native speakers. In J. Hay & E. Parnell (Eds.), *Proceedings of the 15th Australasian International Speech Science and Technology Conference* (pp. 205–208). Christchurch, New Zealand: Australasian Speech Science and Technology Association.

Bundgaard-Nielsen, R. L., Baker, B. J., Kroos, C. H., Harvey, M., & Best, C. T. (2015). Discrimination of multiple coronal stop contrasts in Wubuy (Australia): A natural referent consonant account. *PLOS ONE*, *10*(12), 1–30. doi: 10.1371/journal.pone.0142054

Carreiras, M., Alvarez, C. J., & de Vega, M. (1993). Syllable frequency and visual word recognition in Spanish. *Journal of Memory and Language*, *32*(6), 766–780. doi: 10.1006/jmla.1993.1038

Gahl, S., & Strand, J. F. (2016). Many neighborhoods: Phonological and perceptual neighborhood density in lexical production and perception. *Journal of Memory and Language*, *89*, 162–178. doi: 10.1016/j.jml.2015.12.006

Ganong, W. F. (1980). Phonetic categorization in auditory word perception. *Journal of Experimental Psychology: Human Perception and Performance*, *6*(1), 110–125. doi: 10.1037/0096-1523.6.1.110

González-Alvarez, J., & Palomar-García, M.-A. (2016). Syllable frequency and spoken word recognition: An inhibitory effect. *Psychological Reports*, *119*(1), 263–275. doi: 10.1177/0033294116654449

Grainger, J., & Segui, J. (1990). Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies. *Perception & Psychophysics*, *47*(2), 191–198. doi: 10.3758/BF03205983

Kataoka, R., & Johnson, K. (2007). Frequency effects in cross-linguistic stop place perception: A case of /t/ - /k/ in Japanese and English. In *UC Berkeley Phonology Lab annual report* (pp. 273–301). Department of Linguistics, UC Berkeley. (Available online at http://linguistics.berkeley.edu/phonlab/documents/2007/Kataoka_Johnson.pdf)

Luce, P. A. (1986). *Neighborhoods of words in the mental lexicon* (Unpublished doctoral dissertation). Department of Psychology, Indiana University, Bloomington, Indiana.

Luce, P. A., & Pisoni, D. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing*, *19*(1), 1–36. doi: 10.1097/00003446-199802000-00001

Newman, R. S., Sawusch, J. R., & Luce, P. A. (1997). Lexical neighborhood effects in phonetic processing. *Journal of Experimental Psychology-Human Perception and Performance*, *23*(3), 873–889. doi: 10.1037/0096-1523.23.3.873

Newman, R. S., Sawusch, J. R., & Luce, P. A. (2005). Do postonset segments define a lexical neighborhood? *Memory & Cognition*, *33*(6), 941–960. doi: 10.3758/bf03193204

Rice, G. A., & Robinson, D. O. (1975). The role of bigram frequency in the perception of words and nonwords. *Memory & Cognition*, *3*(5), 513–518. doi: 10.3758/BF03197523

Tang, K. (2015). *Naturalistic speech misperception* (Unpublished doctoral dissertation). University College London.

Vitevitch, M. (2002). Naturalistic and experimental analyses of word frequency and neighborhood density effects in slips of the ear. *Language and speech*, *45*(4), 407-434. doi: 10.1177/00238309020450040501

Vitevitch, M., & Luce, P. A. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language*, *40*(3), 374–408. doi: 10.1006/jmla.1998.2618

Vitevitch, M., & Luce, P. A. (2016). Phonological neighborhood effects in spoken word perception and production. *Annual Review of Linguistics*, *2*, 75–94. doi: 0.1146/annurev-linguistics-030514-124832

Yao, Y. (2011). *The effects of phonological neighborhoods on pronunciation variation in conversational speech* (Unpublished doctoral dissertation). University of California, Berkeley.

Yarkoni, T., Balota, D., & Yap, M. (2008). Moving beyond Coltheart's N: A new measure of orthographic similarity. *Psychonomic Bulletin & Review*, *15*(5), 971–979. doi: 10.3758/pbr.15.5.971