Comparing Neighborhood Density and Phonotactic Probability: Evidence from Nasal Coarticulation

Colin Wilson (colin@cogsci.jhu.edu)
Johns Hopkins University

Rebecca Scarborough (rebecca.scarborough@colorado.edu)
University of Colorado, Boulder

Introduction

Phonotactic probability (PP) and **phonological neighborhood density** (ND) have been claimed to be relevant for a wide range of phenomena:

- acceptability judgments (Bailey & Hahn 2001)
- spoken word recognition (Vitevitch & Luce 1999)
- speech production errors (Vitevitch 1997) and latencies (Vitevitch 2002)
- word learning (Storkel 2001, Freedman & Barlow 2012)
- **hyper-/hypo-articulation** (Wright 2004) and **coarticulation**

Because there are many ways of quantifying PP and ND, and *because they are highly correlated in natural lexicons* (Vitevitch et al. 1999), it is challenging to disentangle their effects on a given aspect of performance (but see Luce & Large 2001, Pylkkanen et al., 2002, Storkel et al. 2006, 2011).

Production study 1 (Scarborough 2013)

English participants (N=10) produced $C^+VN(C)$ and $(C)NVC^+$ monosyllables within carrier sentences to listeners in a dictation task.

	higher ND ('hard')	lower ND ('easy')
VN	*band* (24)	*chomp* (24)
NV	*mast* (24)	*noise* (24)

Items were all of high Hoosier familiarity (Nusbaum et al. 1984) and balanced for lexical frequency, vowel, and nasal consonant across conditions.

In the experimental design, **neighborhood density** ND_{bin} was defined as the inverse of
R_{bin} = binarized $\log \frac{freq(w^*)}{\sum_{w_i \in \mathcal{N}(w^*)} freq(w_i)}$ where $\mathcal{N}(w^*)$ is single-edit neighborhood.

Degree of nasal coarticulation on the N-adjacent vowel was quantified by
A1-P0: amplitude of F1 - amplitude of low frequency nasal peak (Chen 1997)
NB. Greater vowel nasality damps A1 and increases P0, resulting in *lower* A1-P0.

Statistical reanalysis

Results of the production study were previously analyzed with separate repeated-measures ANOVAs, here replicated with a single mixed-effects linear regression:

`fixed` A1-P0 $\sim$ Set (VN,NV) * ND_{bin} + Vowel + Nasal
`random` + (1 + Set * ND_{bin} | speaker) + (1 | word)

with outliers removed (± 2.5 sd within participant × stimulus type), dependent variable centered, and binary predictors scaled to mean 0 and sd 0.5.

Significant effect of ND_{bin} ($\beta = -0.25$, SE = 0.08, $t = -3.33$) and of Set ($\beta = -0.27$, SE = 0.126, $t = -2.20$, no sig. interaction. Also significant effects of nasalized vowel (e.g., /eɪ/ $\beta = -0.60$, $t = -3.80$; /aʊ/ $\beta = -0.44$, $t = -2.47$) and nasal consonant (/ŋ/ $\beta = -0.46$, $t = -3.07$), which were not previously investigated but do not eliminate the effect of ND.

Does nasal coarticulation track density?

- Could phonotactic probability provide an alternative account of the coarticulation data in spite of item matching? (possibility suggested by Baese-Berk & Goldrick 2009)
- More generally, can species of lexical and sublexical factors be distinguished by their effects on phonetic realization? (see also Baese-Berk & Goldrick 2009, Gahl et al. 2012)

Variants of ND and PP

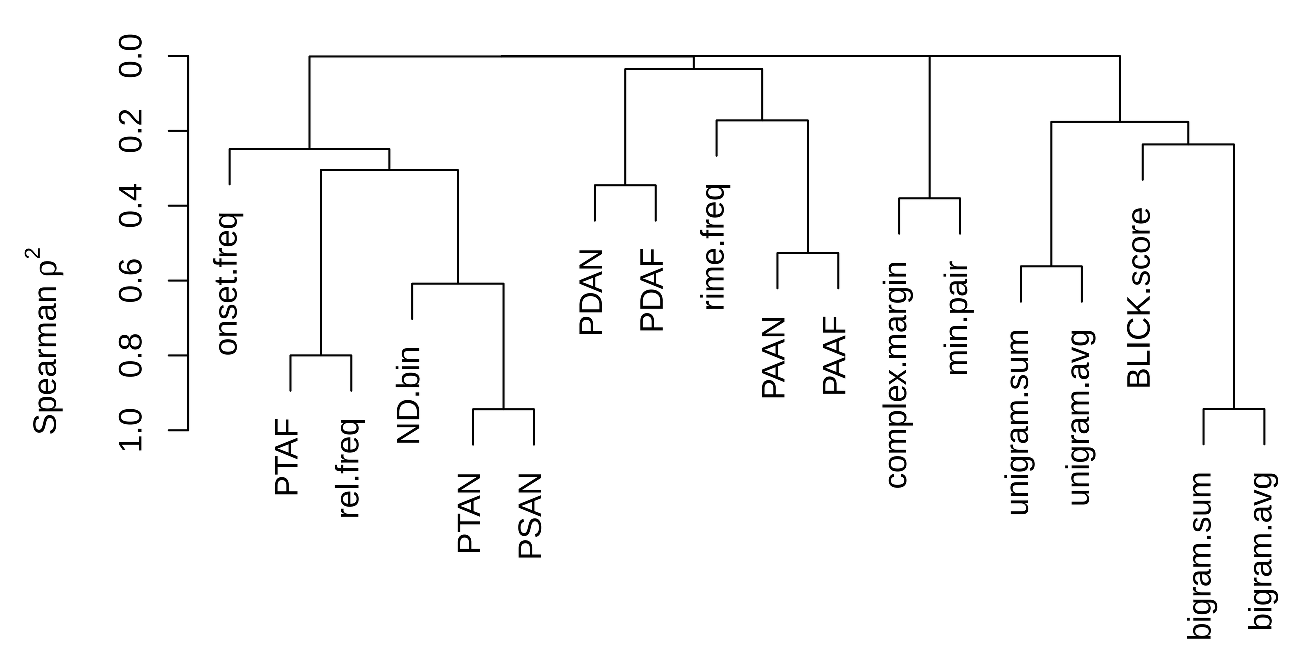
A large number of ND variants were calculated for the items of the production study from CLEARPOND (Marian et al., 2012; clearpond.northwestern.edu):

- **count** of all phonological neighbors (PTAN) as well as those differing from the target by only substitution (PSAN), deletion (PDAN), or addition (PAAN)
- **mean frequency** for each phonological neighbor type (PTAF, PSAF, PDAF, PAAF)

The PP variants were **maxent harmony scores** computed from BLICK (Hayes 2012), **Onset and Rime relative frequencies** across word types (Coleman & Pierrehumbert 1997) from the same CMU dictionary used to train BLICK (Weide, 1998; www.speech.cs.cmu/cgibin/cmudict), **positional n-gram sums and averages** (Jusczyk & Luce 1994), and **margin complexity** (NC^+ or C^+N).

Unsurprisingly many of the measures are *highly correlated*, making discrimination among them with this set of items statistically challenging:

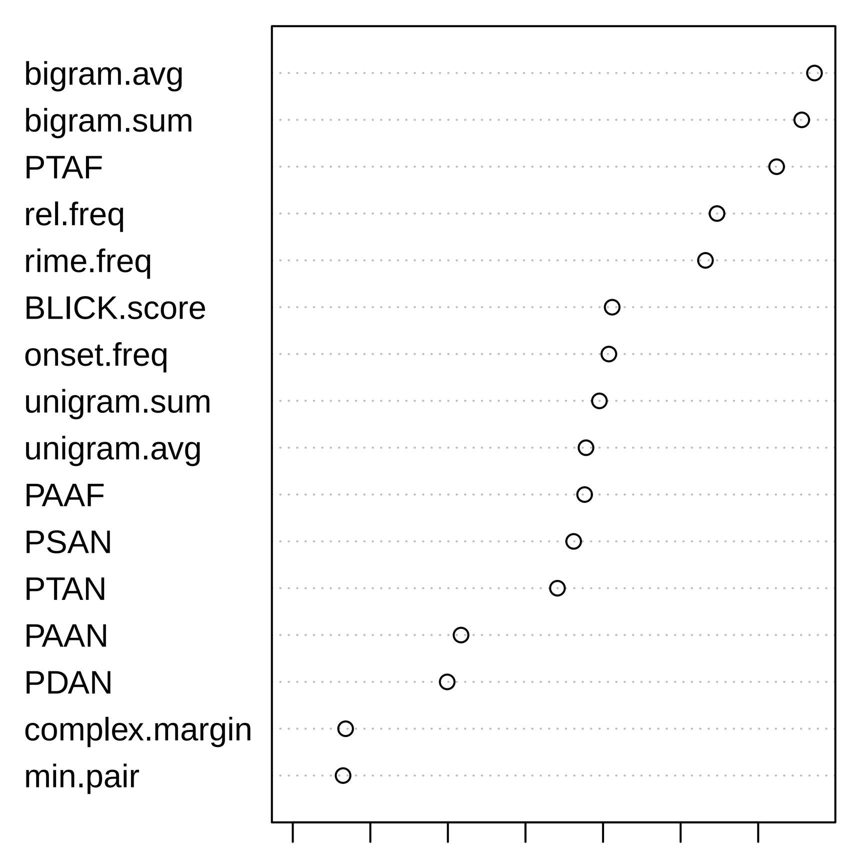
Predictor correlations (Scarborough 2013 items)



Random forest evaluation & model comparison

Random forest regression (Breiman 2001) used to identify the numerical variant of each predictor type with **maximal importance** (inspired by the method of Bürki et al. 2011)

Variable importance (Scarborough 2013)



Low correlation between the two best representatives of the lexical (PTAF) and sublexical (avg bigram probability) types: $r = 0.009$ n.s., and each survives a Likelihood Ratio Test for nested models ($ps < 0.05$): PTAF $\chi^2(1) = 5.51$, bigram.avg $\chi^2(1) = 5.16$

PTAF and bigram.avg together achieve a log-likelihood (-1056.13) similar to that for the original predictor ND_{bin} alone (-1056.578).

PP appears to supplement, but not eliminate, the influence of ND on nasal coarticulation in English. What about for other languages and other aspects of phonetic realization?

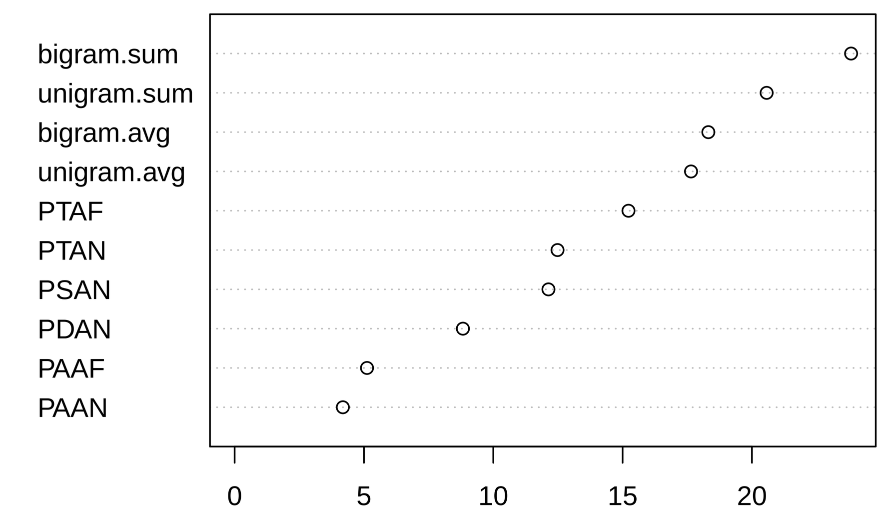
Production study 2 (Scarborough 2004)

French participants (N=8) produced words (mostly biysyllables) containing VN and NV sequences within carrier sentences to listeners in a dictation task.

	higher ND ('hard')	lower ND ('easy')
VN	*bedaine* (32)	*piscine* (32)
NV	*genou* (32)	*hypnose* (32)

Items were balanced for lexical frequency, vowel, and nasal consonant across conditions. (Additional items with high vowels omitted here due to measurement complexities.)

Variable importance (Scarborough 2004)

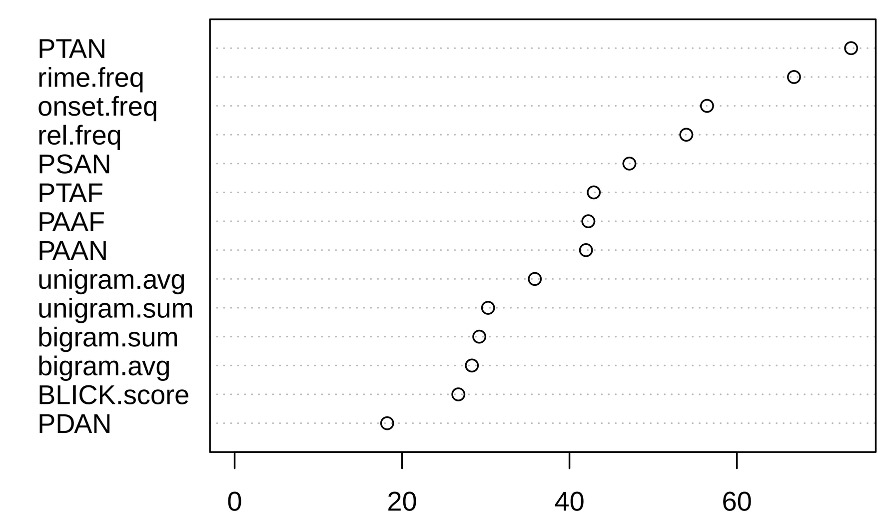


Contrary to the findings from English, the best CLEARPOND predictors in French are all *sublexical* (PP) factors — plausibly due to sparser neighborhoods overall for polysyllables.

Production study 3 (Baese-Berk & Goldrick 2009)

English participants (N=23) produced monosyllables beginning with voiceless stops. Original analysis focused on effect of voiced neighbor (*cod* – *god* vs. *cop* – **gop*) on VOT hyperarticulation, but random forest evaluation suggests there are much stronger PP and ND predictors. (Thanks to the authors for making this data set available to the research community!)

Variable importance (Baese–Berk & Goldrick 2009)



Discussion

- Comparison of PP and ND contributes to the general problem of distinguishing sublexical / structural vs. lexical / holistic accounts of linguistic sound patterns. (e.g., Albright & Hayes 2001, Bürki & Gaskell 2012, Sadat et al., 2014, Becker et al. (submitted))
- Lexical properties (ND) condition phonetic realization in at least some cases, acting alongside sublexical properties (PP) to determine coarticulation & hyperarticulation.
- High lexical correlation of PP and ND motivates the search for converging evidence across studies, and statistical tools for predictor selection and model comparison: methodologies common to many other fields (e.g., Guyon & Elisseef 2003, Myung & Pitt 2011).