Reduction versus Analogical Pressures on Structured Variability in Production: A Case of R-Schwa Reversal in American English

by

Nadia L. Clement

A thesis accepted and approved in partial fulfillment of the

requirements for the degree of

Master of Arts

in Linguistics

Thesis Committee:

Melissa A. Redford, Chair

Vsevolod Kapatsinski, Member

University of Oregon

Spring 2026

© 2026 Nadia L. Clement

This work is openly licensed via CC BY 4.0



Thesis Abstract

Nadia L. Clement

Master of Arts in Linguistics

Title: Reduction versus Analogical Pressures on Structured Variability in Production: A Case of R-Schwa Reversal in American English

Reduction-based accounts of phonological change predict that more frequent words drive change, while analogical accounts predict that less frequent words change first. These two mechanisms are often discussed separately, but there exist patterns of variation for which either could plausibly apply — making them ideal test cases for understanding how competing motivations interact.

This study investigates one such case: variation in the pronunciation of word-initial, unstressed /pɹə/ in West Coast Standard American English, where [pɹə] → [pɚ] (e.g., *production* → *perduction*, *predict* → *perdict*). We elicited productions of 12 /pɹə/-initial words and 12 matched /pɚ/-initial control words — matched for syllable count, stress pattern, and corpus frequency — from 25 adults in read speech under a read speech prosodic focus manipulation (focused vs. unfocused) and in spontaneous speech. Acoustic analysis focused on two measures of rhoticity: F3-F2 distance and center of gravity (COG), extracted at 10 equidistant points across the word-initial sonorant interval.

Results showed that the vowel quality of more frequent /pɹə/ words was more similar to /pɚ/ words $p < .05$, Cohen's $F^2 = .002$, $\chi^2 = 4.620$), and that the /pɚ/-like quality was attenuated under prosodic ($p < .001$, Cohen's $F^2 = 0.0005$, $\chi^2 = 15.343$). The interaction between frequency and word type was replicated in spontaneous speech ($p < .01$, Cohen's $F^2 = 0.007$, $\chi^2 = 13.431$). COG did not show significant effects of frequency or focus. These findings support a reduction-based account of this variation: frequent words are the first to develop variant pronunciations. The attenuation of the variant under prosodic focus indicates that the change remains in a stage of variation rather than becoming fully phonologized.

Acknowledgements

I would like to express utmost gratitude to my thesis advisor, Professor Melissa A. Redford, for her support, guidance, and expertise over the course of my graduate degree and, specifically, in bringing this thesis to completion. These years working with Professor Redford have been incredibly fulfilling and rewarding, and it has been an honor to collaborate with someone who is so passionate and dedicated to this research. Thank you for always holding me to a high standard and supporting me through my academic journey.

I would also like to thank Professor Vsevolod Kapatsinski for his thoughtful contributions and feedback throughout this project, from the initial formulation stage to the final manuscript, and Professor Don Daniels for his advice during the initial development of the research question for this thesis.

I acknowledge the use of Claude 4.6 Sonnet (https://claude.ai/) to improve the clarity and grammatical structure of parts of this manuscript. All suggestions from Claude were reviewed before inclusion to ensure accuracy. I therefore take full responsibility for the final contents of this publication.

Table of Contents

1. Introduction……6
   1.1. Lexical frequency effects on sound change……7
      1.1.1. Reduction-based change……7
      1.1.2. Pattern-based/analogical change……9
   1.2. Case Study: word-initial, unstressed /pɹə/ and /pɚ/……10
      1.2.1. Reduction-based pathway from /pɹə/ to /pɚ/……12
      1.2.2. Analogical pathway from /pɹə/ to /pɚ/……13
   1.3. Current Study……14
2. Methods……16
   2.1. Participants……16
   2.2. Elicitation Materials……16
   2.3. Procedure……17
   2.4. Acoustic Measures……19
   2.5. Analyses……20
3. Results……21
   3.1. Read Speech……21
   3.2. Spontaneous Speech……25
4. Discussion……26
   4.1. Levels in the Production Model……27
   4.2. Familiarity versus Frequency……29
   4.3. Limitations and Future Directions……30
5. Conclusion……32

Appendix I: Following Vowel and Consonant Distributions……34

Appendix II: Background Information Form……36

References……37

1. Introduction

Lexical frequency plays a well-documented role in phonological change (Hooper 1976, Bybee 2002, 2006, 2010, Pierrehumbert 2002, Dinkin 2008, Gahl 2008). However, different theories present competing predictions, whereby high frequency words can plausibly serve as both the **target** and the **source** of sound change. In reduction-based accounts of sound change, high frequency words are the words that undergo a sound change first. In analogical accounts, high-frequency words provide the template upon which low frequency words may be modeled (Bybee & Brewer, 1980). These two accounts are often discussed separately and assumed to affect different classes of words. However, there *are* classes of words that display patterns of variation that could be explained by either reduction or analogy. Investigating one such case could illuminate the mechanisms by which these two motivations compete, and which will win out in a competing scenario.

Reduction-based accounts of language change explain that more frequent words drive change because they are used more often: their frequent use optimizes the neuromotor routines used in their production, hence the reduction of participating articulatory gestures (Hooper 1976, Bybee 2006, 2007). Frequent words also tend to be more predictable (Turnbull 2023, Blevins 2005, Hall et al 2018, Shaw & Kawahara 2018) and are more likely to occur out of prosodic focus (Silbert & de Jong 2008, Turnbull et al 2015, Calhoun 2010, Burdin & Clopper 2015), allowing for further reduction. On the other hand, analogical accounts predict that less frequent words drive change (Bybee 1985, Hock 2017, Fertig 2015, Lahiri 2013, Phillips 1984), as they are less entrenched and thus have a less consistent/rigid pronunciation (Goldinger 1998, Munson 2001). They are therefore thought to be more susceptible to pressures from lexicon-level factors like type frequency and neighborhood effects (Rosemeyer 2015, Bybee 1985). Hooper (1976) and Phillips (2006) have both asserted that sound changes motivated by phonetic processes (e.g. assimilation or reduction) will affect frequent words first, where sound changes motivated by reanalysis of phonotactic constraints or lexicon-level patterns will affect infrequent words first (Phillips 2006). But, given that both factors are always at play (Kapatsinski 2021), which effect will win out? This is the research question that we address in the present study.

1.1. Lexical frequency effects on sound change

Two theoretical mechanisms drive the relationship between lexical frequency and sound change: phonetic reduction and lexical analogy. Each makes competing predictions on whether frequent or infrequent words will lead change, the role of prosodic focus, and the locus of change within the production system.

1.1.1. Reduction-based change

Phonetic reduction—the phenomenon of sounds or syllables becoming shorter, losing identifying phonetic qualities, displaying increased coarticulation with surrounding segments, or being completely deleted—is a universal feature of spoken language (Fourakis 1991, Aylett & Turk, 2006, Bell, Brenier, Gregory, Girand, & Jurafsky, 2009; Bybee, 2001; Fowler & Housum, 1987; Gahl, 2008, 2009; Gahl & Garnsey, 2004; Hunnicutt, 1985; Jurafsky, 2003; Quené, 2008; Tily et al., 2009). The ubiquity of reduction across languages reflects a drive toward articulatory ease: speakers tend to streamline neuromotor routines by minimizing articulatory effort where doing so does not compromise intelligibility (or even sometimes where it does) (Lindblom 1990). However, this streamlining is not random. Rather, languages differ in which reduction processes are permissible based on their specific phonological grammars, balancing the pressures of articulatory ease against the need for perceptual distinctiveness. An example, common to many languages, is vowel reduction to a neutral vowel (such as schwa) in unstressed syllables (Burzio 2007). Other patterns of reduction include extreme reduction of a vowel to the point that the vowel disappears completely, which can lead to a sonorant consonant taking on the role of syllable nucleus, as will be posited for reduction in this case (Russell Webb and Bradley 2009; Kijak 2009). It is well-documented across many languages that certain sonorant consonants can act as syllable nuclei. Sonorants are by far the most common type of consonant to be syllabified, because of their "vowel-like acoustic structure" (Ridouane 2008, p. 322). The precise consonants that are permitted to act as syllable nuclei depend on the particular language, and in Standard American English, these include nasals and liquids.

It has been well established that reduction occurs more often in high-frequency words and phrases than rare ones (Jurafsky et al 2001, Lin et al 2014, Pluymaekers et al 2005, Burdin & Clopper 2015, Bybee 2006,

Czaplicki 2013, Kijak 2009). Frequency effects on reduction arise from two interconnected mechanisms: accessibility and predictability. High-frequency words are more accessible, meaning they are retrieved faster and with less cognitive effort. This accessibility reflects the fact that frequent words are more predictable in context, and predictability licenses reduction: because listeners do not require as much acoustic information to successfully identify expected words, speakers face less communicative pressure to maintain full phonetic distinctiveness (Burdin & Clopper 2015). They are thus freer to minimize articulatory effort, favoring changes that reduce the distance traveled by the articulators, the number of articulators involved, or the complexity of articulatory movements (Kirchner 2001, Lindblom 1990, Bybee 2002). Furthermore, predictability also correlates with reduced prosodic prominence: predictable words are less likely to receive focal stress. Since unfocused words in a prosodic contour are more likely to undergo reduction (Turnbull et al. 2015), high-frequency words are disproportionately subjected to these converging articulatory pressures. Critically, reduction of this kind is an online, output-level process: it operates during production, and change is achieved as enough reduced exemplars are stored, thus shifting the underlying representation (Pierrehumbert 2001).

We test this reduction-based account in the present study by manipulating prosodic focus in moderately frequent words with variable initial syllable productions (see 1.2). Because focus suppresses output-level reduction, it functions as a window onto the stored form; what surfaces under focus is a closer approximation of what is represented, to the extent that hyperarticulation under focus reflects a reach toward the stored target rather than a separate enhancement process (Lindblom 1990), an assumption consistent with evidence that focused productions restore contrast rather than simply amplify it (Seyfarth et al 2016, Wedel et al 2018). If the canonical form remains stored as the underlying representation, prosodic focus should attenuate the variability that appears under reduction. If, on the other hand, phonologization is complete and the variable form has itself become the stored representation, then focus will not diminish the chance of a variant production, because the stored form has changed.

1.1.2. Pattern-based/analogical change

Analogical sound change occurs when words exhibiting infrequent phonological patterns conform to the more frequent patterns in a language, where frequency here refers to *type frequency* (the number of lexical items displaying a given pattern) rather than token frequency (the rate at which individual words occur in use). A classic example is the unrounding of Middle English /ö(:)/, where rare (low token frequency) words containing this vowel adopted the more common (high type frequency) unrounded pronunciation (Ogura 2012). Unlike the reduction processes discussed above, analogical change spreads in the opposite direction: from words with low token frequency to those with high token frequency.

The mechanism underlying this reverse token frequency effect relates to differences in lexical entrenchment and representation. Words with low token frequency are less entrenched in memory and therefore more dependent on lexicon-level generalizations and neighborhood effects for their production (Bybee 1985; Clark & Trousdale 2008). Because speakers access these words less automatically, they rely more heavily on phonological patterns extracted from similar words in the lexicon. As Kiparsky (2003) notes, lexical diffusion of this type represents "the analogical generalization of lexical phonological rules" (p. 314). Words with high token frequency, by contrast, are stored more robustly and resist such generalization precisely because they are accessed holistically rather than through productive phonological patterns.

A key trigger for analogical sound change is perceptual ambiguity. When speakers cannot reliably identify phonetic categories on the basis of acoustic cues during perception, they may rely on similar words from the lexicon to inform their own production. This ambiguity is particularly likely to arise with features that have elongated acoustic cues—features whose effects spread to nearby segments or even neighboring syllables. Because these features extend their influence across multiple segments, listeners may misperceive the locus of the feature, placing it in a non-historical position (Russell Webb & Bradley 2009). Rhoticity has been widely noted as one such feature, where the lowered third formant (which characterizes rhoticity in English and many other languages) spreads into surrounding sounds and syllables (Czaplicki 2013, Tunley 1999, Kelly & Local 1986, West 1999). Evidence for perceptual ambiguity triggering analogical

change comes from multiple studies: Phillips (1984) documented glide deletion in Southern American English spreading from infrequent to frequent words, while Hay et al. (2015) found that New Zealand English vowel changes originated in low-frequency items. The elongated nature of rhoticity—the tendency for "r-like" acoustic cues to spread across adjacent segments—will be especially relevant to the phenomenon under investigation here. Unlike the output-level process described above, analogical change operates at a higher level of the production process, acting directly on the stored form, as the stored form of the affected word shifts toward the more type-frequent pattern. This means that prosodic focus, which suppresses output-level processes but cannot undo a change that has already taken place at the level of representation established through misperception and analogy to similar-sound words, should have no effect on words that have undergone analogical change.

1.2. Case Study: word-initial, unstressed /pɹə/ and /pɚ/

The study investigates the variation in the pronunciation of word-initial, unstressed /prə/ in West Coast Standard American English: the apparent reversal of the unstressed mid-central vowel and /ɹ/ in word-initial syllables beginning with /p/, such that [pɹə] → [pɚ] as in the following words: production → **per**duction; predict → **per**dict; protect → **per**tect. In this study, canonically /pɹə/-initial words will be compared to canonically /pɚ/-initial "control" words in order to determine their similarity under various conditions.

To investigate the possibilities of both reduction-based change and analogical change, it is necessary to look at a set of words with the following attributes: (a) the target syllable may be variably pronounced and matched with words that are canonically pronounced in the way we might expect for the variant/innovative production; (b) target syllable is unstressed, because reduction must be able to take place; (c) the set is sufficiently large to obtain meaningfully diverse individual token frequency statistics; (d) the variant pronunciation is more phonetically reduced than the canonical pronunciation, such that a prediction on directionality of change can be formulated from a reduction-based framework; and (e) the target syllable in canonical form has a lower type frequency than the variant form, such that a prediction on directionality of change can be formulated from an analogical framework.

One such set of words are those with unstressed word-initial /prə/. The observed variable pronunciation here is [pɚ]. Although this variant in pronunciation has not been reported or documented in detail but does show up in corpora such as MALD (Tucker 2019), where some tokens of the words included in this study have been listed as beginning with [pɚ] rather than the more typical [pɹə]. This variable pronunciation satisfies criteria (a), (b), and (c), as English contains many multisyllabic words of varying frequency beginning with canonical unstressed initial /pɚ/ (e.g. *performance, percentage, perplex*). Additionally, /pɚ/ satisfies (d) in that it is more phonetically reduced than /prə/, as it includes only two segments, and has (e) higher type frequency than /prə/ (Rosson 2014, Tucker 2019).

A general observation of rhotic-vowel metathesis has been noted in works such as Czaplicki (2013) and Alexander (1983). Both describe a pattern of bi-directional rhotic-vowel metathesis in word-initial onset clusters from Old English to present, where multiple variants may have been present at one time (e.g. *bryd* and *byrd* for "bird" in Middle English). However, both also focus (mainly) on single-syllable words and do not specifically look at schwas or reduction as a possible motivation for the changes. Here, we examine syllables prone to further reduction in multisyllabic words: those containing an unstressed schwa. Similar observations of rhotic-vowel metathesis have been made in French (Lyche 1995, Fougeron & Steriade 1997, Faust & Scheer 2025), Spanish (Russell Webb & Bradley 2009), and Croatian (Hofmann & Müller 2018). Russell Webb and Bradley (2009) investigated the opposing directionality of rhotic-vowel metathesis in Spanish and French dialectal varieties, with the rhotic moving leftward in Spanish and rightward in French. They mention that French /Re/ → /eR/ metathesis could be "an instance of vowel elision and syllabic /ɹ/" (Russell Webb and Bradley 2009, p. 5), which will be the mechanism of reduction described here. The cross-linguistic attestation of rhotic-vowel metathesis, and in particular the French pattern where /Re/ → /eR/ has been analyzed as vowel elision followed by syllabic reassignment of /ɹ/, provides independent typological support for the reduction-based pathway proposed here for English /pɹə/ → /pɚ/.

English words that are /pɹə/-initial and multi-syllabic are candidate words for the analogical pathway described above because they occupy a frequency range that makes them susceptible to both pathways of change. They are neither frequent enough for reduction to be strongly expected on the basis of frequency effects alone, nor infrequent enough for analogical pressure to be the obvious explanation. Critically, the same directionality of change (from /pɹə/ to /pɚ/) is predicted by both accounts: /pɚ/ is (d) more phonetically reduced than /pɹə/ and (e) has higher type frequency in the lexicon (Rosson 2014, Tucker 2019). This shared directionality prediction is what makes this set of words an ideal testing ground: we can hold the expected direction of change constant and use the frequency pattern of the words that change, along with the role of prosodic focus, to determine which mechanism of change is at work.

Because both criteria (d) and (e) above are fulfilled, from either a reduction-based framework or analogical framework we are expecting a variation from [prə] to [pɚ], as unstressed [pɚ] is both more reduced and more common in the lexicon. From the reduction-based framework, the variation arises because of phonetic reduction. In the analogical framework, the variation arises because of lexicon-level frequency effects.

1.2.1. Reduction-based pathway from /pɹə/ to /pɚ/

In a reduction-based account of /pɹə/ shifting to /pɚ/, the mechanism involves changes to the articulatory targets of /ɹ/. The rhotic approximant /ɹ/ in English involves a sequence of constrictions realized over time: a coronal constriction (tongue tip or blade approaching the alveolar or postalveolar region), followed by pharyngeal constriction (tongue root retraction), followed by the vocalic gesture of the adjacent vowel (Gick & Wilson 2006, Delattre & Freeman 1968, Espy-Wilson et al. 2000). In onset position, all three gestures are realized robustly and in sequence. However, the articulatory demands of maintaining two simultaneous constrictions create an opportunity for reduction. Because the pharyngeal and vocalic gestures can be executed simultaneously without conflict, they are susceptible to temporal overlap and eventual coalescence. The coronal constriction, by contrast, cannot overlap with the pharyngeal and vocalic gestures in the same way. Therefore, under reductive pressures, the pharyngeal and vocalic gestures merge, and the

coronal gesture is dropped. The coronal is not lost because it is more effortful, but because it cannot be folded into the coalesced pharyngeal-vocalic gesture that replaces the full /ɹ/ sequence. The result is a rhotacized schwa: in English, the loss of coronal constriction on /ɹ/ yields /ɚ/, as the preserved pharyngeal quality merges with the following vowel gesture into a single rhotacized nucleus.

1.2.2. Analogical pathway from /pɹə/ to /pɚ/

In the analogical account, the pathway of change is not articulatorily based, but rather, based on analysis of word-form patterns. As discussed above, analogical accounts of sound change posit that words with low token frequency are likely to "succumb to analogical pressure from the rest of the lexicon" – namely, toward patterns with high type frequency (Kapatsinski 2021, p. 2). In the MALD Corpus (Tucker et al. 2019), unstressed /pɚ/ syllables (coded as "P E R0" in the corpus) occur a total of 1628 times, compared to 790 occurrences of unstressed /pɹə/ (coded as "P R AH0), indicating a higher type frequency of /pɚ/. If we include the other lax variations /pɹɛ-/ and /pɹɪ-/ (coded as "P R EH0" and "P R IH0" respectively), this brings the /pɹV/ total to 1042, which is still lower than the /pɚ/ type frequency. This indicates that /pɹə/ words would more likely change to /pɚ/ than the other way around, if a change in pronunciation is driven by analogy.

Morphology is the domain that is perhaps the most affected by analogical processes (Anttila 1989, Hock 2017, Fertig 2013). However, when morphological analogy interacts with a phonological change, it is possible that pressures of these two types of change may interact in unexpected ways. Words beginning with unstressed /pɹə/ are an interesting case because they are, despite their historical structure, very often not identifiable by speakers as separate morphemes. *Pro-* and *pre-,* when used as prefixes on free morphemes/full words, are almost never pronounced with a schwa (e.g. *pro-choice, pre-teen, preconceived, prepackage, pro-bono, presuppose*). Therefore, it is precisely the words where the morphological structure has been obscured (*production, provide, preposterous, predicted, provincial*) that should be susceptible to variation in pronunciation. In this way, morphological opacity may create a particularly favorable environment for analogical change, removing a structural anchor that would otherwise reinforce the

canonical /pɹə/ pronunciation and leaving the word more exposed to lexical pressure from the more common /pɚ/ pattern.

1.3. Current Study

This study aims to determine which pattern of change will occur when both reduction and analogy could motivate a particular sound change. The study will pursue this aim using the /pɹə/ → /pɚ/ sound change described above as the case study. To adjudicate between a reduction-based and analogical change account, we select a set of canonical /pɹə/-initial words and compare their pronunciation to a set of canonical /pɚ/-initial words. Phonological factors are controlled; token frequency (henceforth referred to as *frequency*) and prosodic focus are manipulated. Importantly, the initial /pɚ/ syllable on the control words were always either non-prefixal (e.g. *personified*, *particular*) or attached to bound or ambiguous stems (e.g. *performance, perplex, pervasive*) and thus constituted a non-compositional prefix. There is precedent to treat non-prefixal syllables that share a phonological form with a prefix as similar enough to opaque prefixes that they may be analyzed together (Smith et al 2012). Oh & Redford (2012) also found that phonological processes (i.e., faux-gemination) are only contravened by morphology in situations of highly productive, transparent derivational morphology (Oh & Redford 2012).

Recall that, under the reduction hypothesis, more frequent /pɹə/-initial words are predicted to lead the /pɹə/ → /pɚ/ sound change, as their articulatory routines are optimized through repeated production and their reduced forms most rehearsed (Pierrehumbert 2001). In this study, this means that high-frequency /pɹə/-initial words are more likely to be pronounced like the control words /pɚ/-initial words than their low-frequency counterparts. But, because reduction is an output-level process, the underlying representation may remain /pɹə/ for all words that have not yet undergone the change. Prosodic focus should therefore attenuate the /pɚ/-like quality of all /pɹə/-initial words. If, however, phonologization is complete for higher-frequency words — that is, if /pɚ/ has itself become the stored form — then prosodic focus will not restore the /pɹə/ quality for those words.

In direct contrast to the reduction hypothesis, less frequent /pɹə/-initial words are predicted to lead the change under the analogy hypothesis. This is because low-frequency word representations are less robustly

specified and therefore more susceptible to lexical pressure from the more type-frequent /pɚ/ pattern and so more likely than their high-frequency counterparts to be pronounced like /pɚ/-initial words. Also, prosodic focus should have no effect on pronunciation: whether under focus or not, low-frequency /pɹə/-initial words should (on average) retain their /pɚ/-like quality.

To test these predictions, we elicited productions of 12 /pɹə/-initial target words and 12 matched /pɚ/-initial control words in read speech under prosodic focus manipulation (focused vs. unfocused). Each target word was matched to a control word on syllable count, stress pattern, and corpus frequency. Frequency was treated as a binary predictor (high vs. low) based on a median split of frequencies from the Corpus of Contemporary American English (COCA) database (Davies, 2008-). As an internal replication and to further test the frequency effect under more naturalistic conditions, we additionally elicited target words in a spontaneous speech task where orthographic information was decoupled from pronunciation. With this task, we aim to investigate whether any frequency-by-word-type interaction observed in read speech is also present in spontaneous speech. None of the words selected for this study are of the hyper-frequent variety that are often discussed in terms of frequent words leading sound change, and even the most frequent words of these classes have abstract meanings, without easily picturable properties (e.g. *provide, predict, performance*). As such, the spontaneous elicitation methods used in this study will need to use methods designed for these types of words.

Two acoustic measures of rhoticity were extracted from the acoustic recordings to assess pronunciation: the distance between F3 and F2 (F3-F2), which directly indexes the degree of rhoticity (Lindau 1978, Boyce & Espy-Wilson 1997, Hagiwara 1995, Harper et al 2020), and center of gravity (COG), which provides a complementary spectral measure (Feth et al. 2006)—the lower F3 in /pɚ/ syllables should lower COG compared to /pɹə/ syllables. Formant measures and COG were extracted at 10 equidistant points across the word-initial sonorant interval. Acoustic duration, amplitude, and f0 were additionally extracted to verify that the prosodic manipulation was successful, as focused productions are expected to be longer, louder, and show a more dramatic prosodic contour than unfocused ones.

2. Methods

All study procedures were approved by the University of Oregon Institutional Review Board. All participants gave informed consent.

2.1. Participants

43 undergraduate students from the University of Oregon Psychology & Linguistics Subject Pool were recruited into this study and compensated with course credit. All participants completed the study. The data presented here were elicited from 25 undergraduate students (7M;18F) aged 18-22, all self-identified as speaking a West Coast US dialect as their native language. The sample of 25 participants was arrived at due to the following exclusions: simultaneous bilingualism (1 Spanish-English, 1 Cantonese-English); self-reported speech language therapy in childhood (*N*=7), excluded because rhotic pronunciation is prevalent in speech language delays (Preston & Koenig 2012, McAllister et al 2025); dyslexia (*N*=1), excluded because the experimental design relies on written prompts of words with syllables that differ only in the ordering of letters “e” and “r” in many cases; and self-report of a dialect of American English other than the West Coast variety (Southern variety [*N*=3] and Midwestern variety [*N*=5]).

2.2. Elicitation Materials

The stimuli in this study included 24 multisyllabic target words with unstressed *pre-* or *per-* as initial syllables selected from the Corpus of Contemporary American English (COCA) database (Davies, 2008-). Each of 12 *pre*-initial words was matched to a *per*-initial word for syllable number, stress pattern, and frequency in COCA (as nearly as possible). Frequency in COCA was coded as a binary high or low value based on a median split. In all target words, the second syllable began with an obstruent consonant, to ensure that [pɚ.] was not re-analyzed as [pə.ɹ] and to facilitate acoustic segmentation. The identity of this consonant, as well as the following vowel, were added as random effects during analysis. These distributions can be found in Appendix I.

Table 1: Target /pɹə/ and /pɚ/ words

Syllables	Frequency	/pre/ word	/pre/ Freq COCA	Log /pre/ Freq COCA	/per/ Word	/per/ Freq COCA	Log /per/ Freq COCA
2	High	prescribed	13792	4.13962725	perhaps	191436	5.28202361
2	High	provide	351941	5.54646986	persuade	17229	4.23626007
2	Low	presides	5554	3.74460588	purport	2970	3.47275645
2	Low	profuse	271	2.43296929	perplex	2213	3.34498141
3	High	predicted	61151	4.78640356	percentage	47208	4.6740156
3	High	presented	111731	5.04817369	performance	127318	5.10488981
3	High	procedures	59288	4.7729668	perspective	53611	4.72925391
3	Low	propulsive	244	2.38738983	percussive	318	2.50242712
3	Low	provincial	5523	3.74217504	pervasive	5679	3.75427187
3	Low	professes	3579	3.5537617	purveyors	1424	3.15350999
4	Low	proprietors	2377	3.37602918	personified	1480	3.17026172
4	Low	preposterous	2049	3.31154196	particular (high)	124071	5.09367028

2.3. Procedure

Participants completed a consent form and a background information form (see Appendix II). They then completed: (1) a training task that was also used to elicit familiarity ratings; (2) the core read speech task; (3) the spontaneous speech task. Each of these tasks is described in turn next.

Training and familiarity ratings. In order to obtain fluent read speech, we familiarized participants with the word list. With this task, we also obtained familiarity ratings to ascertain the validity of the frequency manipulation. The tasks also enabled the prompts used in the spontaneous elicitation task (see §3.3.3). Each target word was presented to the participant on printed cards with the target word and a definition beneath it. These cards were shuffled and presented in random order. Participants were asked to read the word and definition aloud and then place the card on a familiarity scale from 1-4 (see Figure 2). This scale is based on the established method of obtaining familiarity judgements based on participants' subjective scoring of target words on a printed scale (Tanaka-Ishi & Terada 2011). If participants were unfamiliar with the word, or did not know how to pronounce it, they were asked to do the best they could and were given no pronunciation clues from the researcher. Familiarity scores were recorded. Participants

were then given 2 minutes to study the definitions on the cards, with the instruction that they would be asked to remember the words associated with each definition later on in the experiment.



Figure 1: Example definition card as presented to participants.

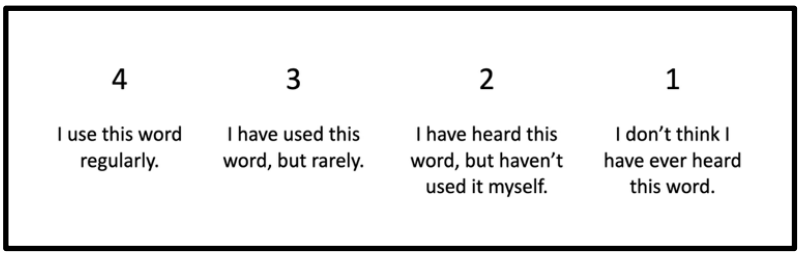


Figure 2: Printed familiarity judgement scale.

Read speech task. In this task, participants produced the target words in sentences under prosodic focus or not. Two sentences were created for each target word. Sentences were matched for target word position and total length in syllables; focus marking was manipulated using an implied contrastive focus structure: [statement with bolded word], not [statement that contradicts first statement], for example: "I looked at the clouds and **predicted** that it would snow, I didn't just guess" versus "I looked at the clouds and predicted that it would **snow**, not that it would rain." As in these examples, the in-focus words were bolded for participants. Bold and italic text have been shown to be effective at eliciting prosodic prominence (Berger et al 2018). Slides were also arranged with a line break at the prosodic boundary, denoted with a comma or em-dash, in order to emphasize the contrastive focus (see Table 2 and Figure 3 below).

Table 2: Prosodic Focus Manipulation Sentence Examples

Word	*Word Type*	*Prosodic Condition*	*Sentence (stimulus)*
perplex	/pɚ/	unfocused	Her behavior was **intended** to perplex – it wasn't accidental.
Perplex	/pɚ/	focused	Her behavior was intended to **perplex,** not to offend anyone.
Prescribed	/pɹə/	unfocused	The **pharmacist** told her it needed to be prescribed, not the doctor.
Prescribed	/pɹə/	focused	The pharmacist told her it needed to be **prescribed,** not just refilled.

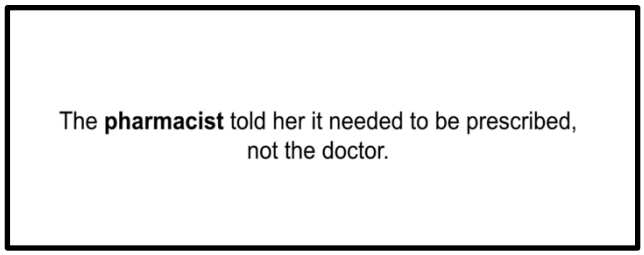


Figure 3: Prosodic Manipulation Example

Participants followed a self-paced slide deck that began with instructions read aloud by the researcher. The instructions asked participants to read the slides at their own pace, repeating each slide 3 times before moving on, and to verbally emphasize the word in boldface type. The researcher demonstrated this with a practice sentence, and then the participant was asked to practice with a set of 5 training sentences. Then the participants were instructed to begin the main task. The 64 target sentences, including 32 with target words under prosodic focus and 32 with target words out of prosodic focus, were presented in random order. Participant audio was recorded using a Zoom H-series portable audio recorder clipped to the collar of the participant's shirt (approximately 6-8 inches from mouth).

Spontaneous speech task. Finally, participants were shown a slide deck including only the definitions from the training and familiarity rating task (see §3.2.3). The order was randomized for each participant. Participants were asked to remember the word associated with the definition on each slide and use it aloud in a sentence. If they could not remember the word, they moved on to the next slide. Participants' speech was digitally audio was recorded for later analyses using the same recording methods as above.

2.4. Acoustic Measures

Audio files were segmented using Praat (Boersma 2001). The original text grid for each file was created using a json file created by Google Cloud's speech to text API (Google 2024) automatic transcription function. This text grid contained a tier with the transcribed phrases/sentences from Google Cloud, along with two hand-segmented tiers: a word-level tier and a sonorant-level tier. The sonorant tier was used for all analyses in this study. Its intervals contained only the sonorant part (/ɚ/ or /ɹə/) of the target syllable (the word-initial /pɚ/ or /pɹə/). The interval boundaries were placed at, respectively, the start of voicing of the sonorant and the start of the following consonant.

Acoustic duration, amplitude, and f0 were automatically extracted from this interval to verify that the prosodic manipulation worked. Center of Gravity (COG) was extracted at 10 equidistant points along the interval using a Praat script by DiCanio (2013). Next, automatically-tracked formants from Praat were manually inspected and corrected by modifying the number of formants tracked and the max formant frequency. Default extraction parameters were: 4 formants, maximum formant value 3700 Hz, and dynamic range of 35. This was manually adjusted for each token in order to align formant tracking with the visible formant trajectory as viewed by the researcher. After being manually corrected, formant values were extracted at 10 equidistant points across the sonorant interval. The difference between F3 and F2 at each point in the sonorant was then calculated.

2.5. Analyses

In some cases, speakers devoiced the sonorant portion of the weak initial syllable, or the vowel was completely elided. These tokens could not be included in the analysis. After removing these tokens, 1670 /pɚ/ and 1814 /pɹə/ syllables were utilized for analyses on intensity, duration, and COG analyses. Of these, 178 /pɚ/ and 193 /pɹə/ syllables were acquired in the definition recall section, with the remaining syllables being produced in the prosodic manipulation section. Syllables with un-trackable formants were excluded from the formant data, resulting in a lower number of available syllables used for these analyses (1568 /pɚ/ [155 in definition recall) and 1685 /pɹə/ [169 in definition recall].)

Study predictions were tested on these data using linear mixed-effects regression models built in R (Rstudio team, 2021) using the lme4 package (Bates et al., 2015). F3-F2 and center of gravity were each used as the dependent variable in their respective models. Subjective familiarity and syllable number were included as control variables. Participant, initial consonant of the following syllable, and vowel of the following syllable were included as random effects. All models included random intercepts for the initial consonant and vowel of the following syllable, and included random slopes and intercepts for participant, with prosodic condition and frequency as the slope predictors (except in spontaneous speech, where prosodic condition was not controlled). Frequency (low or high), word type (canonical /pɹə/ or /pɚ/), and manipulation condition (either prosodic focus condition or elicitation condition) were included as fixed

effects. Frequency was treated as a categorical predictor (high vs. low) in all models, reflecting the fact that the binary contrast was built into the stimulus design from the outset via median split rather than sampled continuously across the frequency range. All three- and two-way interactions between fixed effects were also included. Non-significant variables and interaction terms were removed from models, and those models were then compared to the original models using log likelihood tests in the "Stats" R package (R Core Team 2023). χ^2 values for significant effects were obtained by comparing the best model to a model not containing the significant effect. A term was only included in the final model if the χ^2 value from this log likelihood test was significant. Cohen's F^2 values were calculated manually using marginal R^2 values obtained using the Multi-Model Inference package in R (Bartón 2024), which quantify the variance attributable to the fixed effects only.

3. Results

Results are presented as follows. First, we establish that the prosodic manipulation in the core read speech task worked as expected. Then, we confirm that the acoustic measures of rhoticity reliably distinguished canonical /pɚ/-initial words from canonical /pɹə/-initial words, confirming their appropriateness for subsequent analyses. After these checks, we report results from the core read speech task to test study predictions by investigating the effects of prosodic focus, word frequency, and their interaction with word type on the COG and F3-F2 measures. Finally, we present results from the spontaneous speech task, which provides a complementary test of the frequency effect under more naturalistic production conditions.

3.1. Read Speech

Analyses on duration, amplitude, and f0 indicated that the prosodic manipulation was successful. Sonorant portions of target syllables produced in-focus were longer ($p < 0.001$, Cohen's $F^2 = 0.015$, $\chi^2 = 22.609$) and louder ($p < 0.001$, Cohen's $F^2 = 0.010$, $\chi^2 = 13.42$). Focused productions were, on average, produced with a lower f0 ($p = 0.653$) than those produced out-of-focus, but this difference was not significant. A lower f0 under prosodic focus, although not significant in p-value, is expected given that the syllables analyzed are immediately pre-stress, resulting in an increased lowering of f0 before the stress-

induced rise in f0 that is characteristic of the dramatic prosodic contour under contrastive focus (Braun & Tagliapietra 2009, Roessig et al 2022).

Results also confirm that the two acoustic measures (F3-F2 and COG) distinguish canonical /pɚ/ words and canonical /pɹə/ words in the expected directions. Canonical /pɹə/ words had a greater difference between F3 and F2 on average ($p < .001$, Cohen's $F^2 = 0.020$, $\chi^2 = 77.078$) and a higher COG than /pɚ/ words on average ($p < .05$, Cohen's $F^2 = 0.005$, $\chi^2 = 8.048$). As discussed above, both of these results are in line with expected acoustic characteristics of these syllable types, as lower COG and closer distance between F3 and F2 both indicate a more sustained rhotic pronunciation across the syllable (more like a syllabic /ɹ/). These results confirm that these measures were appropriate for this analysis.

Moving on to the primary analyses, recall that the prediction from the reduction hypothesis is that more frequent /pɹə/-intial words would be produced with the /pɚ/-like quality associated true /pɚ/-initial words (i.e., lower F3-F2 and lower COG), and that this /pɚ/-like quality would be attenuated under prosodic focus. By contrast, the analogical change predictions were that low-frequency /pɹə/-intial words would be produced with more /pɚ/-like quality than high-frequency words, and that this effect would be impervious to the prosodic focus manipulation. Full model results, reported in Tables 3 and 4, are more consistent with the reduction hypothesis than with the analogical change hypothesis.

Table 3: Mixed Effects Model Results for F3-F2 in Read Speech
F3-F2 by Frequency, Familiarity, Prosodic Condition, Word Type, Prosodic Condition*Word Type and Frequency*Word Type

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	407.762	36.019	38.968	11.321	6.89e-14 ***
Frequency (high)	-2.027	15.501	30.183	-0.131	0.89685
Familiarity	8.677	2.969	8549.373	2.923	0.00347 **
Prosodic Condition (focused)	-19.470	13.918	14.725	-1.399	0.18256
Word Type (/pɹə/)	69.211	11.254	240.653	6.150	3.21e-09 ***
Syllable Number	11.492	3.786	2855.032	3.035	0.00243 **
Prosodic Condition * Word Type	25.247	6.450	18817.904	3.914	9.11e-05 ***
Frequency * Word Type	-23.124	10.745	980.273	-2.152	0.03164 *

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Table 4: Mixed Effects Model Results for COG in Read Speech
COG by Frequency, Familiarity, Prosodic Condition, Word Type, Prosodic Condition*Word Type and Frequency*Word Type

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	5970.70	81.71	85.72	73.069	<2e-16 ***
Frequency (high)	60.71	42.61	103.80	1.425	0.1572
Familiarity	-12.13	16.38	611.97	-0.741	0.4591
Prosodic Condition (focused)	-47.91	31.34	51.24	-1.529	0.1325
Word Type (/pɹə/)	95.67	38.93	88.53	2.457	0.0159 *
Syllable Number	-19.71	17.61	111.35	-1.119	0.2654
Prosodic Condition * Word Type	-24.12	38.32	2445.07	-0.629	0.5291
Frequency * Word Type	-19.76	46.16	146.55	-0.428	0.6692

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

As shown in Table 4, the interaction between frequency and word type was significant for F3-F2 ($p < .05$, Cohen's $F^2 = .002$, $\chi^2 = 4.620$): more frequent /pɹə/-initial words were produced with smaller F3-F2 distances (that is, more /pɚ/-like) than less frequent /pɹə/-initial words. The main effect of frequency alone was not significant ($p = .897$), indicating that the frequency effect was specific to the /pɹə/ word type rather than a general across-the-board reduction effect. No significant frequency × word type interaction was observed for COG ($p = .669$), suggesting that this measure was less sensitive to the effect at the current sample size. Familiarity was a significant predictor of F3-F2 ($p < .01$, Cohen's $F^2 = .004$, $\chi^2 = 8.423$), reflecting expected individual differences in word knowledge independent of corpus frequency – a point which we return to in the Discussion. Together, the F3-F2 results suggests that it is the more frequent /pɹə/-initial words that are leading the change.

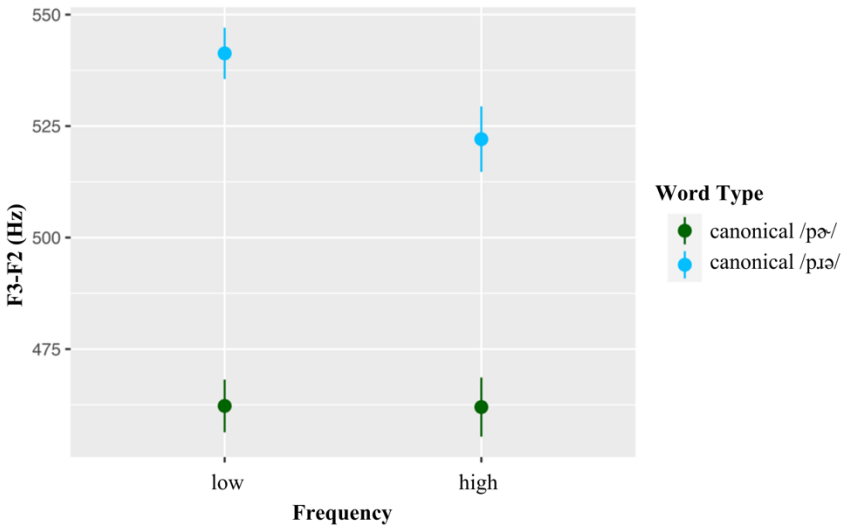


Figure 4: F3-F2 by Frequency and Word Type in Read Speech

The interaction between prosodic condition and word type was significant for F3-F2 ($p < .001$, Cohen's $F^2 = 0.0005$, $\chi^2 = 15.343$): /pɹə/-initial words produced out of prosodic focus were more /pɚ/-like than those produced under focus. This attenuation of the variant under prosodic focus is the critical signature of an output-level, reduction-based process: if the change were representational (as the analogical hypothesis predicts), hyperarticulation under focus would not be expected to reduce it. No significant prosodic condition × word type interaction was observed for COG ($p = 0.529$).

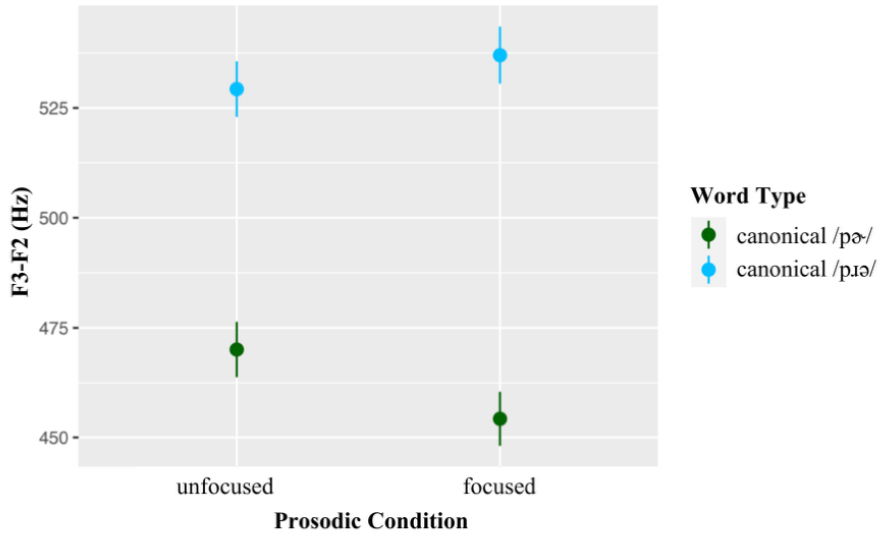


Figure 5: F3-F2 by Prosodic Condition and Word Type in Read Speech

Taken together, the F3-F2 results are consistent with the reduction-based hypothesis on both counts: more frequent /pɹə/-initial words lead the change, and the change is more likely to occur outside of prosodic focus. COG did not replicate these patterns, which will be further discussed below.

3.2. Spontaneous Speech

The spontaneous speech task (definition recall) served as an internal replication of the frequency effect observed in read speech, removing orthographic cues to word type and, with these, the ability to manipulate prosodic focus. The full model results, reported in Tables 5 and 6, are consistent with the findings from the read speech task: low-frequency /pɹə/-initial words are more more /pɚ/-like than their high-frequency counterparts.

Table 5: Mixed Effects Model Results for F3-F2 in Spontaneous Speech
F3-F2 by Frequency, Familiarity, Word Type, and Frequency*Word Type

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	315.461	61.689	49.839	5.114	5.05e-06 ***
Frequency (high)	2.652	40.740	25.516	0.065	0.94860
Familiarity	9.080	9.824	955.360	0.924	0.35558
Word Type (/pɹə/)	108.118	22.157	39.403	4.880	1.79e-05 ***
Syllable Number	28.942	9.940	225.208	2.912	0.00396 **
Frequency * Word Type	-80.808	26.282	121.074	-3.075	0.00260 **

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Table 6: Mixed Effects Model Results for COG in Spontaneous Speech
COG by Frequency, Familiarity, Word Type, and Frequency*Word Type

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	5932.75	158.75	156.63	37.371	<2e-16 ***
Frequency (high)	25.80	86.07	133.89	0.300	0.765
Familiarity	-35.79	39.66	279.28	-0.902	0.368
Word Type (/pɹə/)	42.32	70.94	165.70	0.597	0.552
Syllable Number	22.92	37.62	303.04	0.609	0.543
Frequency * Word Type	24.47	101.25	172.07	0.242	0.809

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

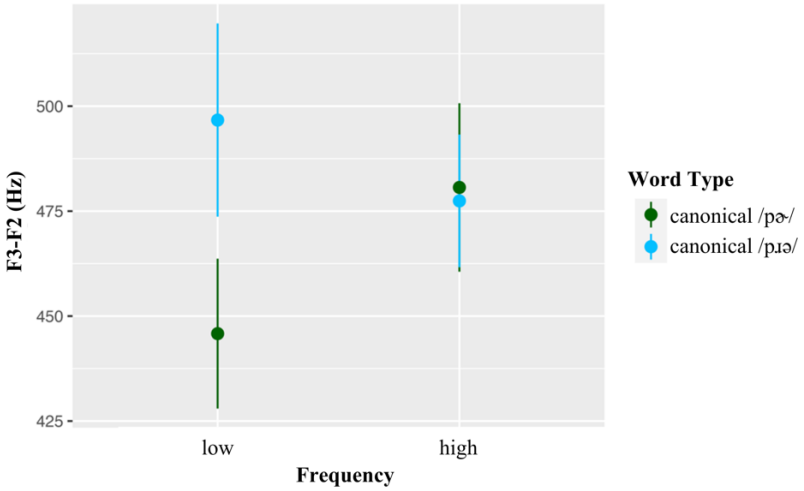


Figure 6: F3-F2 by Frequency and Word Type in Spontaneous Speech

As reported in Table 5 and displayed in Figure 6, the interaction between frequency and word type was replicated in spontaneous speech for F3-F2 ($p < .01$, Cohen's $F^2 = 0.007$, $\chi^2 = 13.431$): more frequent /pɹə/-initial words were produced with smaller F3-F2 distances than less frequent /pɹə/-initial words. As in read speech, the main effect of frequency on F3-F2 was not significant, ($p = .949$), again indicating that the frequency effect was specific to the /pɹə/ word type. No significant main effect of frequency or frequency × word type interaction was observed for COG (frequency: $p = .765$, frequency × word type: $p = .809$).

The replication of the frequency × word type interaction in spontaneous speech strengthens the case for the reduction-based hypothesis: the pattern is not an artifact of the read speech task or the prosodic focus manipulation but reflects a more general property of how these words are stored and produced.

4. Discussion

This study set out to determine which mechanism of sound change (phonetic reduction or lexical analogy) drives the observed variation between /pɹə/ and /pɚ/ in word-initial, unstressed syllables in West Coast Standard American English. The reduction-based hypothesis predicts that more frequent /pɹə/-initial words will lead the change. Token frequency drives this in two ways: at the output level, high-frequency words benefit from more optimized articulatory routines (Lindblom 1990; Kirchner 2001); at the representational level, repeated production and perception cause stored forms to drift incrementally toward

reduction (Pierrehumbert 2001; Bybee 2001). If the variation is simply a result of output-level reduction, where the underlying representation has not shifted, prosodic focus should attenuate the /pɚ/-like quality of high-frequency words by suppressing output-level reduction. If the underlying representation has indeed shifted, we would not expect attenuation of reduction under focus. The analogical hypothesis predicted the opposite frequency pattern: less frequent /pɹə/ words would lead the change, as their representations are less robustly specified and more susceptible to lexical pressure from the more type-frequent /pɚ/ pattern. Because analogical change operates at the level of representation, prosodic focus should have no effect — the change has already taken place above the output level.

The results support the reduction-based hypothesis on both counts. First, more frequent /pɹə/-initial words were produced with smaller F3-F2 distances — that is, more /pɚ/-like — than less frequent /pɹə/-initial words, in both read speech and spontaneous speech. This frequency × word type interaction is precisely what the reduction hypothesis predicts: high-frequency words lead the change. Second, /pɹə/-initial words were pronounced as more /pɚ/-like when not under prosodic focus. When brought under focal stress, the output-level reduction process is suppressed, allowing the stored /pɹə/ form to surface more fully. The analogical hypothesis predicts no such focus effect; its absence would have pointed to a representational change already complete. Instead, the change remains in progress, as we only see output-level reduction effects.

Both results rest primarily on the F3-F2 measure, as COG showed no significant frequency × word type interaction in either task and no significant prosodic condition × word type interaction, a pattern of null results we address below. Note, however, that because COG integrates energy across a broader frequency range, it is more susceptible to noise and less directly tied to the spectral property (lowered F3 relative to F2) that defines the segmental distinction relevant here (Jongman 2024, Shadle 2023). F3-F2 is therefore treated as the primary measure for the interpretations that follow.

4.1. Levels in the Production Model

The differing processes at play in a reduction-based change versus an analogical change imply that the two types of change are initiated at different levels of the production system — a distinction established in

the theoretical framework of this paper (§1.1.1–1.1.2) and formalized in Pierrehumbert's (2002) exemplar dynamics model. In this model, each word's stored representation consists of a collection of detailed phonetic memories accumulated through repeated production and perception. High-frequency words accumulate more reduced exemplars over time, because articulatory ease exerts a persistent weakening pressure on each production. This pressure is output-level: it operates on the selected exemplar during production, and the stored distribution shifts once reduced exemplars become sufficiently numerous and entrenched. The frequency effects observed in the present study are consistent with this account, but because we do see attenuation of reduction under focus, we can infer that the exemplar clouds for /pɹə/ forms have not entirely shifted toward a /pɚ/-like production.

Analogical change, by contrast, operates at the level of representation directly. As established in §1.1.2, the stored form of the affected word shifts toward the more type-frequent pattern (Phillips 1984). This is a change that prosodic focus cannot undo, because it has taken place prior to the output level. The present results, in which focus attenuated /pɚ/-like quality, are therefore consistent with reduction and inconsistent with analogy, drawing on exactly the output/representation distinction the model predicts.

These findings are also relevant to a broader debate about whether phonetically gradual and lexically gradual change can co-occur. Labov argued that phonetically conditioned change sweeps uniformly through the lexicon, while lexical diffusion is restricted to abrupt, categorical changes (Labov 1981, 1994). Bybee (2002), however, argues that a phonetically motivated reduction can spread through the lexicon by affecting highly frequent words first, producing gradience at both levels simultaneously. The present results align with Bybee's account: the /pɹə/ → /pɚ/ shift is phonetically gradient, as evidenced by gradient F3-F2 values, and simultaneously lexically gradient, proceeding further in higher-frequency words. That this gradient pattern is attenuated under prosodic focus confirms that it originates in output-level reduction rather than categorical reanalysis, which is precisely the mechanism Bybee (2002) describes.

This framing also allows a return to the role of morphological opacity introduced in §1.1.4. In the Pierrehumbert (2002) model, articulatory weakening is a persistent pressure that accumulates across productions. Morphological opacity — the condition whereby a prefix like *pre-* or *pro-* is no longer parsed

as a separable morpheme — licenses prosodic reduction of the prefix syllable, which in turn licenses articulatory weakening of the onset cluster. By contrast, transparent morphology imposes a structural constraint that reinforces the canonical form: speakers who parse *pre-* as a productive prefix have access to a phonological representation that resists weakening, consistent with the findings of Oh & Redford (2012) on fake geminates. This suggests a diachronic trajectory in which morphological opacity increases the opportunity for output-level reduction to take hold.

4.2. Familiarity versus Frequency

In this study, individual subjective familiarity judgements were obtained after pilot data collection indicated that many participants were completely unfamiliar with many of the target words in the stimuli. In the analyses presented here, familiarity was used as a control variable, but familiarity could also be treated as a main effect. As familiarity was not balanced from the outset during stimulus creation in the way that frequency was, the analysis of familiarity as a main effect was not practical in this study: it was included as a covariate in all models to control for individual variation in word knowledge but was not analyzed as a predictor. Regardless, the question is raised: is frequency or familiarity more informative where sound change is concerned, frequency or familiarity?

Gernsbacher (1984) suggested that subjective familiarity may be more useful than lexical frequency in predicting lexical processing speeds. Nusbaum et al (1984) examined subjective familiarity to account for individual speakers' different "experienced frequency," rather than a universal frequency measure. If, as our data suggested, individual familiarity for an item can vary greatly between speakers, it would be reasonable to hypothesize that individual familiarity plays a larger role than lexical frequency. This would be especially true for reduction-based sound changes, as the proposed mechanism for reduction-based change involves repetition of the articulatory routines associated with target words. This process, then, is highly individual, and relies not on a global measure of frequency from all language experiences, but particularly a familiarity in *producing* target words. Hence, the familiarity scale used in this study, where subjective familiarity ratings of 1 and 2 indicate that a speaker has never produced the word themselves, where ratings of 3 and 4 indicate that a speaker has produced the word (see §2.1.4). Analogical change, on

the other hand, may rely less on whether a speaker has produced a form, and more on the overall frequency with which they experience the form in any modality – particularly if analogy is largely a perceptually-motivated process, as discussed in §1.1.2.

In the present data, subjective familiarity ratings and corpus frequency were not strongly correlated across the word set (r = 0. 440). Familiarity ratings showed substantial ceiling effects, which may account for the weak correlation. Alternatively, the weak correlation could suggest that, although the two measures are tracking a similar construct (cumulative experience with a word), individual production history introduces meaningful variation that a global frequency measure cannot capture. For a reduction-based account specifically, if the mechanism driving change is the optimization of articulatory routines through repeated production, then individual familiarity is theoretically the more precise predictor, as it more directly indexes the speaker's own history of producing the target form. The correlation between the two measures in the present data and previous studies (Tanaka-Ishii & Terada 2011, Gernsbacher 1984, Gordon 1985, Large & Pisoni 1998) indicates that corpus frequency is a reasonable proxy, but future work should treat familiarity as a primary variable rather than a control, and design stimuli that allow their independent reduction effects to be directly assessed.

4.3. Limitations and Future Directions

Several limitations of the present study warrant acknowledgment, alongside suggested directions for future research.

A first limitation concerns the operationalization of frequency as a binary variable. While the high/low frequency contrast was built into the stimulus design from the outset and is appropriate for testing our predictions, it does not capture the gradient nature of frequency effects that both the reduction hypothesis and the Pierrehumbert (2001) exemplar model predict. Future work should treat frequency as a continuous predictor, which would allow for a more precise characterization of the relationship between token frequency and degree of reduction across the full frequency range of /pɹə/-initial words.

A second limitation is the absence of morphological opacity as a tested variable. The Introduction established morphological opacity as theoretically relevant, as it more readily allows for articulatory

weakening, but our analyses did not directly examine effects of morphological opacity. The stimuli all contain non-compositional prefixes, meaning opacity was held constant rather than varied. Future work should include words spanning a range of morphological transparency, which would allow a direct test of whether opacity is indeed a prerequisite for reduction-based change, as the diachronic trajectory proposed in §4.1 implies.

A third limitation, discussed in §4.2, is the confound between familiarity and frequency in the present stimulus set. Because the two measures were not orthogonalized during stimulus design, their independent contributions to reduction cannot be fully disentangled. Future work should design stimuli that independently vary familiarity and corpus frequency, allowing a direct test of which measure is the stronger predictor of /pɚ/-like production — a question with direct theoretical implications for whether reduction is driven by global distributional patterns or by individual articulatory history.

A fourth limitation concerns effect size. The effects observed in the present study, while statistically significant, were small: all Cohen's F^2 values were under 0.01, aside from the diagnostic measure that canonical /pɪə/ words had a greater difference between F3 and F2 on average than canonical /pɚ/ words. This likely reflects a combination of factors: the change may be at an early stage, such that the /pɚ/-like variant has not yet accumulated sufficient momentum to produce large differences across frequency or focus conditions; the frequency range of the stimulus set may be too narrow to capture the full extent of the gradient effect; and read speech more generally constrains the degree of reduction speakers produce, compressing the range of variation relative to what might be observed in fully spontaneous speech. Despite this, the current study succeeds in directly contributing to discussions on the differential role of frequency on sound change and, in fact, is the first to attempt to test between competing accounts of frequency on change.

A fifth limitation concerns the absence of prosodic information for spontaneous speech productions. The spontaneous speech data in this study suggest that high-frequency words may already exhibit a merged /pɚ/-like representation — consistent with the possibility of change in progress — but this interpretation rests on the assumption that prosodic conditions are equivalent across high- and low-frequency items.

Because prosodic factors were not controlled or measured in the spontaneous productions, it is possible that differences in prosodic context, rather than lexical frequency per se, are driving the apparent pattern. The absence of prosodic controls for spontaneous speech therefore limits the strength of any inference about change in progress from that data source, and it may also partly explain why a significant three-way interaction among frequency, focus condition, and speech style did not emerge. This limitation will be remedied in a follow up study that examines the acoustic signatures of prosodic focus in the spontaneous speech data. It is likely that there are too few tokens in the current study to fully resolve the issue, but this exploratory work could signal a path forward for more rigorous study of the interaction between reduction and prosodic condition in spontaneous speech.

Finally, the question of whether the /pɹə/ → /pɚ/ variation represents a sound change in progress or a stable pattern of phonetic variability remains open. The present study is better positioned to identify reduction than to identify change. The evidence for reduction is clear, but distinguishing ongoing change from stable synchronic variability requires diachronic evidence that the present design does not provide. While the spontaneous speech results are suggestive, this inference cannot be made with confidence given the absence of prosodic information from the spontaneous speech condition noted above. The read speech paradigm, necessary for experimental control of focus and segmental context, introduces its own constraint: by limiting the degree of reduction speakers produce, it compresses the range of variation and may obscure the frequency effects and speech-style interactions that would most clearly signal change in progress. Future work will extend prosodic analysis to spontaneous speech, but an apparent-time study comparing productions across age groups would be necessary to more directly evaluate whether this variability constitutes a sound change in progress.

5. Conclusion

This study set out to illuminate the outcome when two mechanisms of sound change (phonetic reduction and lexical analogy) make competing predictions about variation in the pronunciation of the same phonological sequence. The case of /pɹə/ → /pɚ/ in West Coast Standard American English was selected because both reduction and analogical processes predict the same directionality of change, which enables a

testing ground to test the competing predictions that the different mechanisms make regarding pronunciation as a function of frequency and prosodic focus. Across both diagnostics, the results converged on the reduction hypothesis: more frequent /pɹə/-initial words led the change, and prosodic focus attenuated /pə/-like quality.

The current study findings suggest that when phonetic reduction and lexical analogy compete, at least under the conditions instantiated here, reduction prevails. The conditions are worth specifying because they are absolutely not universal. The case of /pre/-initial words was identified as especially interesting for study because it involves a set of words that are morphologically opaque, of middling frequency, and subject to a reduction pathway that is attested cross-linguistically. It is possible that analogy would win out under different conditions, where the target syllable type has a higher type frequency advantage, where words are frequent enough to have robustly specified representations that resist reduction, or where morphological transparency reinforces the canonical form and blocks reduction. The present findings therefore do not establish reduction as universally dominant, but they do establish that output-level articulatory pressures can override lexicon-level analogical pressures when morphological opacity removes the structural brake on reduction. Determining the precise boundary conditions under which each mechanism prevails is an important question for future research, and one that the theoretical framework and methodological approach developed here are well positioned to address.

Appendix I: Following Vowel and Consonant Distributions

Table A1: Following Vowel in Formant Analysis (token counts)

	Read speech		*Spontaneous speech*	
Following Vowel	**Canonical [pɚ]**	**Canonical [pɹə]**	**Canonical [pɚ]**	**Canonical [pɹə]**
a	120	109	18	11
aɪ	0	540	0	59
aʊ	0	0	0	10
eɪ	417	0	40	0
ɛ	416	274	54	18
i	0	127	0	11
ɪ	84	225	4	47
oʊ	0	0	0	8
ɔ	239	0	19	0
u	0	120	0	8
ʌ	137	121	20	6

Table A2: Following Vowel in COG Analysis (token counts)

	Read speech		*Spontaneous speech*	
Following Vowel	**Canonical [pɚ]**	**Canonical [pɹə]**	**Canonical [pɚ]**	**Canonical [pɹə]**
a	123	125	20	16
aɪ	0	572	0	66
aʊ	0	0	0	2
eɪ	434	0	45	0
ɛ	441	294	59	19
i	0	139	0	13
ɪ	90	231	4	54
oʊ	0	0	0	8
ɔ	264	0	25	0
u	0	127	0	9
ʌ	140	133	25	6

Table A3: Following Consonant in Formant Analysis (token counts)

	Read speech		*Spontaneous speech*	
Following Consonant	**Canonical [pɚ]**	**Canonical [pɹə]**	**Canonical [pɚ]**	**Canonical [pɹə]**
d	0	119	0	28
f	120	261	12	10
k	137	0	20	0
n	0	0	0	1
p	257	363	21	41
s	536	261	76	35
t	84	0	4	2
v	279	245	22	33
z	0	267	0	19

Table A4: Following Consonant in COG Analysis (token counts)

	Read speech		*Spontaneous speech*	
Following Consonant	**Canonical [pɚ]**	**Canonical [pɹə]**	**Canonical [pɚ]**	**Canonical [pɹə]**
d	0	123	0	31
f	135	276	15	12
k	140	0	25	0
n	0	0	0	2
p	277	397	28	50
s	560	284	82	41
t	90	0	4	2
v	290	252	24	36
z	0	289	0	19

Appendix II: Background Information Form

Please check mark your responses or leave blank if you are not interested in reporting this information.

Gender:

□ Woman □ Man □ Non-binary

Birth year: _____

First language *(English, Spanish..)*: _____

Second language & proficiency: _____

Additional language(s) & proficiency: _____

How long have you lived in Oregon? _____

Where did you grow up? _____

Where else have you lived and for how long? _____

How would you characterize your English dialect (e.g., New England, West Coast US, Southern US, African American, Chicano American)?

_____

What type of environment did you grow up in? (circle one)

URBAN SUBURBAN RURAL

What is the highest level of education that your mother received? If you did not grow up with your mother, what is the highest level of education that your primary caregiver received?

_____

How would you identify the socioeconomic status you grew up in? (circle one)

LOWER LOWER MIDDLE MIDDLE UPPER MIDDLE UPPER

Have you ever received speech-language therapy (circle one) ? YES NO

If YES, when and for how long? _____

If YES, what aspect of your speech-language was targeted in therapy (be as specific as possible in your response)?

_____

References

Anttila, R. (1989). *Historical and comparative linguistics*. John Benjamins Publishing Company.

Berger, S., Nieburh, O., & Fischer, K. (2018) Eliciting extra prominence in read-speech tasks: The effects of different text-highlighting methods on acoustic cues to perceived prominence. *9th International Conference on Speech Prosody 2018.* doi: 10.21437/SpeechProsody.2018-15

Blevins, J. (2005). The role of phonological predictability in sound change: Privileged reduction in Oceanic reduplicated substrings. *Oceanic Linguistics, 44,* 455-464.

Bonilla, J. C. M. (2003). The Formation of Syllabic Consonants and Their Distribution in Southern British English. *Atlantis*, *25*(2), 97–112. http://www.jstor.org/stable/41055118

Brand, S., & Ernestus, M. (2018). Reduction of word-final obstruent-liquid-schwa clusters in Parisian French. *Corpus Linguistics and Linguistic Theory, 17*, 249–285.

Braun, B., & Tagliapietra, L. (2009). The role of contrastive intonation contours in the retrieval of contextual alternatives. *Language and Cognitive Processes*, *25*(7–9), 1024–1043. https://doi.org/10.1080/01690960903036836

Brink, J., Wright, R., & Pisoni, D. B. (1998) Eliciting Speech Reduction in the Laboratory: Assessment of a New Experimental Method. *Research on Spoken Language Processing Progress Report No*, *22*.

Burdin, R. S., & Clopper, C. G. (2015). Phonetic Reduction, Vowel Duration, and Prosodic Structure, *18th International Congress of Phonetic Sciences.*

Bürki, A., Ernestus, M., Gendrot, C., Fougeron, C., & Frauenfelder, U. (2011). What affects the presence versus absence of schwa and its duration: A corpus analysis of French connected speech. *Journal of the Acoustical Society of America, 130*(6), 3980–3991.

Bürki, A., Spinelli, E., & Gaskell, G. (2012). A written word is worth a thousand spoken words: The influence of spelling on spoken-word production. *Journal of Memory and Language, 67*(4).

Bybee, J. (1994). Productivity, Regularity and Fusion: How language use affects the lexicon. *Trubetzkoy's Orphan: Proceedings Of The Montréal Roundtable On "Morphonology: Contemporary Responses."*

Bybee, J. (2002). Word frequency and context of use in the lexical diffusion of phonetically conditioned sound change. *Language Variation and Change*, *14*(3), 261–290.

Bybee, J. (2006). FROM USAGE TO GRAMMAR: THE MIND'S RESPONSE TO REPETITION. *Language, 84*(4), 711-733. doi: 10.1353/lan.2006.0186

Bybee, J. (2007). *Frequency of Use and the Organization of Language*. Oxford Academic. https://doi.org/10.1093/acprof:oso/9780195301571.001.0001

Bybee, J. (2010). *Language, Usage and Cognition.* Cambridge University Press.

Calhoun, S. (2010). How does informativeness affect prosodic prominence? *Language and Cognitive Processes*, *25*(7–9), 1099–1140. https://doi.org/10.1080/01690965.2010.491682

Colantoni, L., & Steele, J. (2005). Liquid asymmetries in French and Spanish. *Toronto Working Papers in Linguistics, 24.*

Connine, C. M., Mullennix, J., Shernoff, E., & Yelen, J. (1990). Word familiarity and frequency in visual and auditory word recognition.*Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(6), 1084–1096. https://doi-org.uoregon.idm.oclc.org/10.1037/0278-7393.16.6.1084

Davies, M. (2008-). *The Corpus of Contemporary American English (COCA)*. Available online at https://www.english-corpora.org/coca/.

Delattre, P. & Freeman, D. C. (1968). A dialect study of American r's by x-ray motion picture. *Linguistics*, 6(44), 29–68.

Dinkin, A. J. (2008). The Real Effect of Word Frequency on Phonetic Variation. *University of Pennsylvania Working Papers in Linguistics: Proceedings of the 31st Annual Penn Linguistics Colloquium 14*(1).

Espy-Wilson, C. Y., Boyce, S. E., Jackson, M., Narayanan, S., & Alwan, A. (2000). Acoustic modeling of American English /ɹ/. *Journal of the Acoustical Society of America, 108*(1), 343-56.

Eychenne, J. (2019). On the deletion of word-final schwa in Southern French. *Phonology, 36*(3), 355–389.

Faitaki, F., & Murphy, V. A. (2019). Oral language elicitation tasks in applied linguistics research. In J. McKinley & H. Rose (Eds.), *The Routledge Handbook of Research Methods in Applied Linguistics.* https://doi-org.uoregon.idm.oclc.org/10.4324/9780367824471

Faust, N., & Scheer, T. (2025). Non-final final consonants in the Croissant. *Phonology, 42*, e8.

Feth, L. L., Fox, R. A., Jacewicz, E., & Iyer, N. (2006) Dynamic Center-of-Gravity Effects in Consonant-Vowel Transitions. In G. Meyer, S. Greenberg, & P. Divenyi (Eds.), *Dynamics of Speech Production and Perception.* IOS Press.

Fougeron, C., & Steriade, D. (1997). Does deletion of French schwa lead to neutralization of lexical distinctions? In *Proceedings of the 5th European Conference on Speech Communication and Technology (Eurospeech 1997)* (pp. 943–946). Rhodes, Greece. ISCA.

Gahl, S. (2008). Time and Thyme Are not Homophones: The Effect of Lemma Frequency on Word Durations in Spontaneous Speech. *Language, 84*(3), 474-496. doi: 10.1353/lan.0.0035

Gernsbacher, M. A. (1984). Resolving 20 Years of Inconsistent Interactions Between Lexical Familiarity and Orthography, Concreteness, and Polysemy. *Journal of Experimental Phonology, 113*(2).

Gordon, B. (1985). Subjective frequency and the lexical decision latency function: Implications for mechanisms of lexical access. *Journal of Memory and Language, 24*(6), 631-645.

Görs, K., & Niebuhr, O. (2012). Hocus Focus – How prosodic profiles of contrastive focus emerge and change in different elicitation contexts. *Speech Prosody, (6).*

Hall, K. C., Hume, E., Jaeger, T. F., & Wedel, A. (2018). The role of predictability in shaping phonological patterns. *Linguistics Vanguard, 4*(2).

Hagiwara, R. (1995). Acoustic Realizations of American /ɹ/ as Produced by Women and Men. *UCLA Working Papers in Phonetics, 90.*

Harper, S., Goldstein, L., & Narayanan, S. (2020). Variability in individual constriction contributions to third formant values in American English /ɹ/. *Journal of the Acoustical Society of America, 147*(6). doi: 10.1121/10.0001413.

Hay, J. B., Pierrehumbert, J. B., Walker, A. J., & LaShell, P. (2015). Tracking word frequency effects through 130 years of sound change. *Cognition*, *139*, 83–91.

Hock, H. H. (2017). Analogical Change. In B. D. Joseph & R. D. Janda (Eds.), *The Handbook of Historical Linguistics.* https://doi.org/10.1002/9781405166201.ch11

Hooper, J. B. (1976). *An introduction to natural generative phonology.* New York Academic Press.

Howson, P. J. (2018). *A phonetic examination of rhotics: Gestural representation accounts for phonological behaviour.* PhD dissertation, University of Toronto.

Hutin, M., Jatteau, A., Vasilescu, I., Lamel, L., Wu, Y., & Adda-Decker, M. (2021). A corpus-based study of the distribution of word-final schwa in Standard French and what it teaches us about its phonological status. *Isogloss: Open Journal of Romance Linguistics, 7*, 1–36.

Jongman, A. (2024). Phonetics of fricatives. In *Oxford Research Encyclopedia of Linguistics*. Oxford University Press. https://doi.org/10.1093/acrefore/9780199384655.013.908

Kainada, E., & Baltazani, M. (2012) Evaluating Methods for Eliciting Dialectal Speech. *Online Proceedings of the 5th International Conference on Modern Greek Dialects and Linguistic Theory.*

Kapatsinski, Vsevolod. (2021) Hierarchical Inference in Sound Change: Words, Sounds, and Frequency of Use. *Front. Psychol*, *12.* doi: 10.3389/fpsyg.2021.652664

Kelly, J., & Local, J. (1986). Long-domain resonance patterns in English. *IEE Proceedings, 133*(2).

Kirchner, R. (2001). *An effort-based approach to consonant lenition*. Routledge.

Labov, William. 1981. Resolving the Neogrammarian controversy. *Language* 57(2). 267–308.

Labov, William. 1994. *Principles of Linguistic Change, Vol. 1: Internal Factors*. Oxford: Blackwell.

Large, N. R., & Pisoni, D. B. (1998). Subjective Familiarity of Words: Analysis of the Hoosier Mental Lexicon. *Speech Research Laboratory, Indiana University.*

Lehrer, A. (1995). Prefixes in English Word Formation. *Folia Linguistica, 29*(1/2).

Lindau, M. (1978). Vowel Features. *Language*, *54*(3), 541–563. https://doi.org/10.2307/412786

Lindblom, B. (1990). Explaining phonetic variation: A sketch of the H&H theory. In W. J. Hardcastle & A. Marchal (Eds.), *Speech production and speech modeling* (pp. 403–439). Kluwer Academic Publishers.

Lyche, C. (1995). Schwa metathesis in Cajun French. *Folia Linguistica, 29*(3–4), 369–394.

McAllister, T., Preston, J. L., Benway, N. R., Hill, J., Lara, M. P., Leece, M. C., Liang, W., & Hitchcock, E. R. (2025). Rhotic acquisition is more rapid in biofeedback than motor-based treatment for

residual speech sound disorder: Primary outcome of a randomized controlled trial. *Journal of Speech, Language, and Hearing Research*. https://doi.org/10.1044/2025_JSLHR-24-00909

Munson, B. (2001). Phonological Pattern Frequency and Speech Production in Adults and Children. *Journal of Speech, Language, and Hearing Research, 44*(4), 778-792.

Nusbaum, H. C., Pisoni, D. B., & Davis, C. K. (1984). Sizing up the Hoosier Mental Lexicon: Measuring the Familiarity of 20,000 Words. *Research on Speech Perception Progress Report No. #10.*

Oh, G. E., & Redford, M. A. (2012). The production and phonetic representation of fake geminates in English. *Journal of Phonetics, 40*(1), 82-91. https://doi.org/10.1016/j.wocn.2011.08.003

Padgett, J., & Tabain, M. (2005). Adaptive dispersion theory and phonological vowel reduction in Russian. *Phonetica, 62*(1), 14–54. https://doi.org/10.1159/000087223

Pastizzo, M. J., & Feldman, L. B. (2004). Morphological processing: A comparison between free and bound stem facilitation. *Brain and Language, 90*(1-3), 31-39.

Patterson, D., LoCasto, P. C., & Connine, C. M. (2003). Corpora analyses of frequency of schwa deletion in conversational American English. *Phonetica, 60*(1), 45–69. https://doi.org/10.1159/000070453

Pierrehumbert, J. B. (2001). Exemplar dynamics: Word frequency, lenition and contrast. In J. Bybee & P. Hopper (Eds.), *Frequency effects and the emergence of linguistic structure*. John Benjamins.

Pierrehumbert, J. (2002). *Word-specific phonetics*. In C. Gussenhoven & N. Warner (Eds.), *Laboratory phonology VII* (pp. 101 - 140). Berlin: Mouton de Gruyter.

Phillips, B. S. (1984). Word Frequency and the Actuation of Sound Change. *Language, 60*(2).

Preston, J. L., & Koenig, L. L. (2012). Phonetic variability in residual speech sound disorders: Exploration of subtypes. *American Journal of Speech-Language Pathology, 21*(3), 168–182.

Roessig, S., Winter, B., & Mücke, D. (2022). Tracing the Phonetic Space of Prosodic Focus Marking. *Frontiers in Artificial Intelligence, 5.* https://doi.org/10.3389/frai.2022.842546

Rosemeyer, M. (2015). Modeling frequency effects in language change. In H. Behrens & S. Pfänder (Eds.), *Again on Frequency. Effects in Language.* Mouton de Gruyter.

Rosson, D. (2014). The Most Frequent Syllables in English: Estimations with Syllabified CMU Dictionary

and COCA. *Medium.* https://medium.com/wugs/ab75159618a0

Schwindt, L. C. (2001). O prefixo no português brasileiro: análise prosódica e lexical. *Documentação de Estudos em Lingüistica Teória e Aplicada, 17*(2).

Seyfarth, S., Buz, E., & Jaeger, T. F. (2016). Dynamic hyperarticulation of coda voicing contrasts. *Journal of the Acoustical Society of America, 139*(2), EL31–EL37.

Shadle, C. H. (2023). Refining and extending measures for fricative spectra, with special attention to the high-frequency range. *Journal of the Acoustical Society of America, 153*, 1397–1430.

Shaw, J., & Kawahara, S. (2018). Predictability and phonology: Past, present and future. *Linguistics Vanguard, 4*(2). doi: 10.1515/lingvan-2018-0042

Silbert, N., & de Jong, K. (2008). Focus, prosodic context, and phonological feature specification: Patterns of variation in fricative production. *The Journal of the Acoustical Society of America, 123.*

Smith, R., Baker, R., & Hawkins, S. (2012). Phonetic detail that distinguishes prefixed from pseudo-prefixed words. *Journal of Phonetics, 40*(5). https://doi.org/10.1016/j.wocn.2012.04.002

Tanaka-Ishii, K., & Terada, H. (2011). Word familiarity and frequency, *Studia Linguistica, 65*(1), 96-116.

Tucker, B.V., Brenner, D., Danielson, D.K. (2019). The Massive Auditory Lexical Decision (MALD) database. *Behavioral Research Methods (51*), 1187–1204.

Tunley, A. (1999). *Coarticulatory influences of liquids on vowels in English*. PhD dissertation, University of Cambridge.

Turnbull, R., Burdin, R. S., Clopper, C. G., & Tonhauser, J. (2015). Contextual predictability and the prosodic realisation of focus: a cross-linguistic comparison. *Language, Cognition and Neuroscience, 30.*

Turnbull, R. (2023). The Effect of Usage Predictability on Phonetic and Phonological Variation. In M. D. Campos & S. Balasch, *The Handbook of Usage-Based Linguistics.*

Wedel, A., Nelson, N., & Sharp, R. (2018). The phonetic specificity of contrastive hyperarticulation in natural speech. *Journal of Memory and Language, 100*, 61–88.

West, P. (1999). The extent of coarticulation of English liquids: An acoustic and articulatory study.

Proceedings of the 14th International Congress of Phonetic Sciences (ICPhS XIV), 3, 1901–1904.

Williams, K. (2018). Expressive Vocabulary Test | Third Edition. *Pearson Assessments.*

Zhou, X., Espy-Wilson, C. Y., Boyce, S., Tiede, M., Holland, C., & Haley, A. (2008). A magnetic resonance imaging-based articulatory and acoustic study of "retroflex" and "bunched" American English /r/. *Journal of the Acoustical Society of America*, 123(6), 4466–4481.

Zwicky, A. M. (1972). Note on a phonological hierarchy in English. In R. P. Stockwell & R. K. S. Macaulay (Eds.), *Linguistic change and generative theory* (pp. 275–301). Indiana University Press.