Against a Ternary Analysis of Syllable Strength:
Positional Variation in the Vowel Inventory of English

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by

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Abstract:

All of the vowels in Standard American English (SAE) are distinguishable from each other in stressed syllables, and it is generally accepted that none of them are contrastive in unstressed syllables. However, unstressed word-final syllables (or ultimas) without a coda consonant are able to host more vowel contrasts than unstressed syllables, evidenced by the minimal pair [ˈwɪndi] 'windy' and [ˈwɪndo͡ʊ] 'window,' but not as many contrasts as stressed syllables. Therefore, the standard analysis of syllable strength in SAE is a ternary one, where stressed syllables are Strong, unstressed non-final syllables are Weak, and unstressed open ultimas are Intermediate.

This work posits a binary analysis of syllable strength instead, arguing that word-final syllables can host as many vowels as stressed syllables can. The Intermediate strength level of the stressless open ultima is abandoned here; "Strong" syllables are tonics and ultimas, and "Weak" syllables are any other. The absence of lax vowels in word final position is motivated from a distributional and historical account, and tested experimentally. The reanalysis of vowel contrast hosting is consistent with several accepted facts about the phonology of English. The main contribution of this work is to unify these facts for a better explanation of the absence of lax vowels in word-final position.

1. Introduction

1.1 English Vowel Inventories: The Standard Story

Different syllable types and stress environments can host different types of vowel contrasts. In other languages, this is typically analyzed as a binary phenomenon, where "Strong" syllables host every different vocalic contrast, and "Weak" syllables do not host as many. In Standard American English, stressed syllables are indeed “Strong” and can host any of the possible full vowels,[1] which are listed are below in (1) and the chart in Figure 1.

(1) Stressed (Strong) Monophthong Inventory

a. [i] [bit] ‘b**ea**t’
b. [ɪ] [bɪt] ‘b**i**t’
c. [e͡ɪ][2] [be͡ɪt] ‘b**ai**t’
d. [ɛ] [bɛt] ‘b**e**t’
e. [æ] [bæt] ‘b**a**t’
f. [ɑ] [bɑdi] ‘b**o**dy’
g. [ɔ] [bɔdi] ‘b**aw**dy’
h. [ʌ] [bʌt] ‘b**u**tt’
i. [o͡ʊ][2] [bo͡ʊt] ‘b**oa**t’
j. [u] [but] ‘b**oo**t’
k. [ʊ] [pʊt] ‘p**u**t’
l. [ɝ] [bɝt] ‘B**er**t’

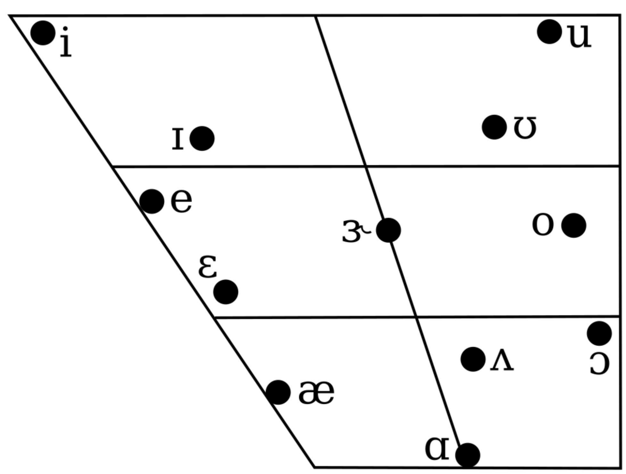

Figure 1- Standard American English monophthongs, as presented in Wells (1982). The phonemes [ɝ] and [ʌ] were not included in the analysis.[3]

[1] Both primary and secondary stressed syllables are referred to as “stressed” throughout.
[2] Despite being phonetically diphthongal in English, Hammond (1999) notes that these vowels pattern with the phonological grouping of monophthongs.
[3] [ɝ] stems exclusively from older vowel-rhotic sequences, and [ʌ] is not contrastive with the unstressed central vowel [ə] in SAE.

Unstressed syllables are “weak” and can only have one vowel, the exact quality of which is debated to resemble [ɨ] or [ə] (see Flemming and Johnson 2007). Crucially, though, there is no actual vowel contrast in unstressed non-final syllables, and so for the sake of simplicity, [ə] will be used in this account to represent the unstressed vowel. Examples are below in (2):

(2) Unstressed (Weak) Vowel Inventory

- a. [əpɑləˈd͡ʒɛɾək] ‘**a**pol**o**get**i**c’
- b. [ɑɹɾəˈfɪʃəl] ‘art**i**fici**a**l’
- c. [əˈtæk] ‘**a**ttack’

SAE also has a somewhat enigmatic third type of syllable: the unstressed codaless ultima. One would anticipate that this type of syllable, like any other stressless syllable in English, could only have [ə]. Instead, the vowel inventory of this type of syllable is larger than expected, given by Hammond (1999) to be the four vowels shown in (3).

(3) Hammond (1999) Word-Final Stressless Open (Intermediate) Vowel Inventory

a.	[i]	[ˈhæpi]	'happ**y**'
b.	[u]	[ˈmɪldu]	'mild**ew**'
c.	[o͡ʊ]	[ˈwɪndo͡ʊ]	'wind**ow**'
d.	[ə]	[ˈso͡ʊfə]	'sof**a**'

This is obviously more than just [ə] in a weak syllable, but is also not the full set of ten vowels that are allowed in a strong syllable. Hammond (1997, 1999) concludes that word-finally, there is a third vowel inventory, which I refer to as “Intermediate.” The possibility of a word-final intermediate-sized inventory is presumed to be connected to the tendency of word-final syllables to be a somewhat strong position.

1.2 Intermediate Strength and Final Lengthening

An Intermediate inventory like the one given in (3) above coincides with the crosslinguistic tendency noted by Barnes (2002) that open stressless ultimas can often resist reducing their vowel inventories as much as other stressless syllables do. He lists Central Eastern Catalan (Recasens 1981), dialects of Ukrainian (Shevelov 1979), and other such cases. This strength in final position is generally accepted as resulting from final lengthening (Steriade 1994, Barnes 2002).

Final lengthening is a process by which the rhyme of a syllable at the end of a larger phonological grouping is produced with more duration than would be typical for the same syllable in a non-final position. This is speculated by Johnson and Martin (2001) to be a property of motor performance generally, whereby a series of physical movements (insect chirps, musical performance, etc) typically exhibit an increase in the duration of a unit at the end of the series. Based on this and other evidence, phrase-final lengthening is thought to be a cross-linguistic phonetic phenomenon; experiments have reported it as present in Japanese (Ueyama 1999), Hausa (Newman and Van Heuven 1981), Jordanian Arabic (de Jong and Zawaydeh 1999), Italian (Farnetani and Kori 1990), and various others (see Barnes 2002). Hogoboom has reported finding final lengthening at the word-level in Norwegian and English (Lunden 2013, 2017).

Hogoboom and Lorber (2023) argued that the lengthening of word-final vowels is the phonetic motivator for a variety of strengthening and weakening phenomena at the right edge of a word, where the additional phonetic duration can interact with phonological length. Specifically, if a phonemic contrast can benefit from additional duration by having more time to be fully articulated, then the contrast will not be neutralized in final position (a "strengthening" effect). In some cases, a contrast may even be more likely to occur in final position. For example, Yip (1989) notes that contour tones are preferred at the right edge of the word, and Hogoboom and Lorber posit that this is because of the additional duration found in a finally-lengthened syllable. Separately, if a phonemic contrast depends on duration as an acoustic cue, that contrast is more likely to be neutralized in final position (a "weakening" effect). For example, vowel- and consonant-length distinctions are less common word-finally because final lengthening causes the duration of a final syllable's rhyme to be more variable, and therefore more difficult for a listener to apply a durational category (such as phonemic length) to (Hogoboom and Lorber, in prep).

Based on evidence below, the altered word-final vowel inventory of English seems to be a result of word-final lengthening. Barnes (2002) and others have argued that final syllables are intermediately strong in terms of hosting vowel contrasts, but I argue here that ultimas are in fact as strong as stressed syllables in this regard, due to the additional duration present. Looking more closely at which vowels can occur in different syllables will shed light on the status of their vowel contrasting strength.

1.3 Reexamining the English V# Unstressed Inventory

At first glance, the word-final unstressed vowel inventory {[i], [u], [o͡ʊ], [ə]} appears to be an unnatural class. Why it is specifically these four phonemes that occur in word-final position is left unexplained. Upon closer examination, though, more vocalic phonemes than these four can be found to occur in the in word-final unstressed position (pace Hammond 1999):

(4) Additional Tense Vowels Found without Stress in Word-Final Position

[e͡ɪ]

['ɛs<u>e͡ɪ</u>] 'ess**ay**'

['pɑɹl<u>e͡ɪ</u>] 'parl**ey**'

['ɹil<u>e͡ɪ</u>] 'rel**ay**'

[ɔ]

['bɑ͡ɪl<u>ɔ</u>] 'byl**aw**'

['skɹɪmʃ<u>ɔ</u>] 'scrimsh**aw**'

['sis<u>ɔ</u>] 'sees**aw**'

It can now be seen that every tense (or [+ATR])[4] vowel phoneme in English besides [ɑ] occurs in stressless, open, word-final position,[5] and also that [ə] seems to occur in its stead. Hogoboom (Lunden 2016, 2017) found that word-final schwas are articulated on a continuum between [ə] and [ɑ], as shown in Figure 2, from Lunden (2016).

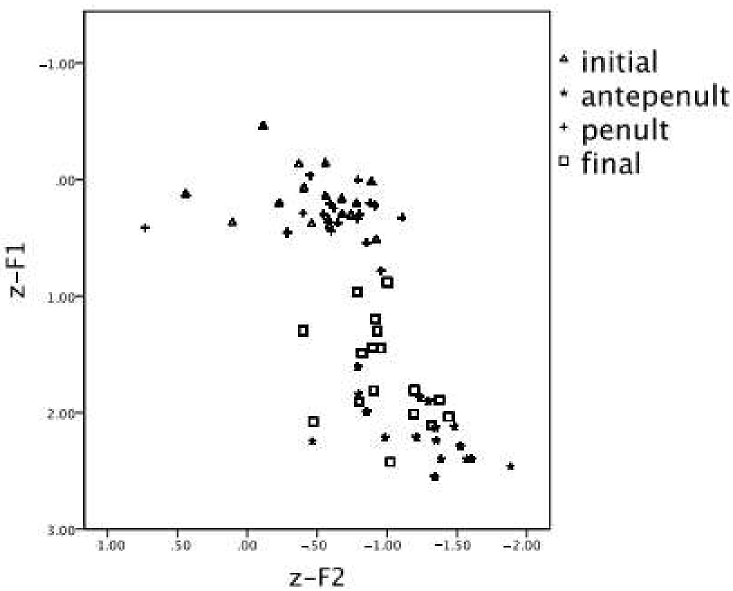

Figure 2- Realizations of /ɑ/, averaged by Subject and Position.
The realizations of the word-final low vowel range from [ə] in the upper end to [ɑ] in the lower-right.

This finding suggests that final [ə] may actually be a word-final allophone of /ɑ/ and is, in fact, sometimes notably [ɑ]-like in its pronunciation. Taking [ɑ]~[ə] to be the sixth monophthong in this word-final category maintains the integrity of the natural class of

[4] Notably, [ɑ] and [ɔ] are phonetically lax vowels, but are taken to be phonologically tense as they pattern with the tense vowel set (see Hammond 1999)

[5] The diphthongs [ɑ͡ɪ] as in ['kæktɑ͡ɪ] 'cacti,' [o͡ɪ] as in ['kɑnvo͡ɪ] 'convoy,' and [a͡ʊ] as in [ka͡ʊta͡ʊ] 'kowtow' also occur in this position.

phonologically tense vowels, and informs the decision to transcribe that phoneme as [ɑ] (shorthand for /ɑ/, or [ɑ]~[ə]) going forward. This assumes the absence of the COT-CAUGHT merger of [ɔ]→[ɑ]. I assume that speakers with this merger have [ɑ] in this environment as a separate phoneme (e.g. [ˈba͡ɪlɑ] ‘byl**aw**’) from the reduced [ə~ɑ] (e.g. [ˈko͡ʊɾə~ˈko͡ʊɾɑ] ‘cod**a**’). The subsequent theoretical analysis uses the unmerged tense vowel set.

At this point, the number of levels of syllable strength in SAE still appears to be three: Strong (stressed), Intermediate (unstressed open final), and Weak (unstressed nonfinal). Now, though, instead of a completely unnatural class of vowels in the Intermediate category, there is the perfectly natural class of phonologically tense vowels: [i], [e͡ɪ], [ɑ], [ɔ], [o͡ʊ], and [u]. I now turn to a description of the distribution of both tense and lax vowels in SAE, and show that their overall distribution supports collapsing these three inventories to two.

2. Distributional Evidence

While tense vowels have a large number of licit environments, I will show that lax vowels are much more constrained. Tense vowels can occur in the following environments:

(5) Tense Vowel Distribution[6]

a.	Stressed open syllable:	[ˈo͡ʊpn̩] ‘**o**pen’	[bəˈlo͡ʊ] ‘bel**ow**’
b.	Stressed closed word-final syllable:	[pɹəˈvo͡ʊk] ‘prov**o**ke’	[ˈspid] ‘sp**ee**d’
c.	Unstressed open word-final syllable:	[ˈhæpi] ‘happ**y**’	[ˈvuɾu] ‘vood**oo**’
d.	Unstressed hiatus-initial syllable:[7]	[ˈe͡ɪ.liən] ‘al**i**en’	[ˈɑɹd͡ʒuəs] ‘ard**u**ous’

Lax vowels can occur in the following environments:

(6) Lax Vowel Distribution

a.	Stressed closed syllables:	[ˈkæp.tn̩] ‘c**a**ptain’	[ˈwɪn.di] ‘w**i**ndy’
b.	Stressed “open” syllables:	[ˈhæ.pi] ‘h**a**ppy’	[ˈlɛ.mən] ‘l**e**mon’
c.	Unstressed closed word-final syllables:	[ˈme͡ɪ.ni.æk] ‘mani**ac**’	[ˈtɑ.nɪk] ‘tonic’

The distribution in (6) appears to show that lax vowels can occur in open or closed syllables, as long as the open syllable bears stress. However, Giegerich (1992) asserts that they do not occur in open syllables, and I take this position as well. The syllables

[6] The tense vowel distribution is a somewhat simplified version of Hammond’s (1999) account. Specifically, tense vowels can also occur in word-medial closed syllables if the coda is coronal, as in [ˈple͡ɪn.tɪf] ‘pl**ai**ntiff.’
[7] These are restricted to the [-low] subset of the tense vowels (Hammond 1999).

containing the lax vowels in (6b) are, in fact, also closed due to ambisyllabicity, the phenomenon by which a consonant is shared between neighboring syllables.

Briefly, ambisyllabic consonants are theorized to belong to both the coda of the syllable to their left and the onset of the syllable to their right. Psychological evidence for this syllable sharing comes in part from an experiment conducted by Treiman and Danis (1988). In it, participants were asked to reverse the order of syllables in a word, such as *lemon*, which could have the possible responses *monle*, *onlem*, or *monlem*. The third type of response demonstrates an ambisyllabic treatment of the [m] phoneme. This syllable-sharing effect was more likely to be found on consonants that follow a lax, stressed vowel. In a similar experiment, Elzinga et al. (2015) also found that ambisyllabicity is more likely to occur directly after a lax vowel. This syllable-sharing effect is reflected in the phonetic properties of ambisyllabic consonants as well; ambisyllabic consonants share properties with both onsets and codas. Durvasula et al. (2013) found that nasal consonants in ambisyllabic position cause the same amount of nasalization of a preceding vowel as a nasal in coda position does, unlike a subsequent nasal onset. However, Rosalsky (2007) found that the duration of ambisyllabic consonants is not different from onsets, and do not meet the minimum duration to be a full coda. Therefore, from both psychological and phonetic perspectives, ambisyllabic consonants seem to have the characteristics of both onsets and codas.

Because ambisyllabic consonants so strongly correlate with the presence of lax vowels, I argue that lax vowels, in fact, require a closed syllable. Below is a review of which vowels can occur in open syllables:

(7) Vowels in Open Syllables

a.	Nonfinal, stressed:	Tense only?	[ˈo͡ʊ.pn̩] ‘**o**pen’, *[ˈlɛ.mən] ‘l**e**mon’
b.	Nonfinal, unstressed:	[ə] only	[əˈtæk] ‘**a**ttack’, [ɑɹ.ɾə.ˈfɪʃəl] ‘art**i**ficial’
c.	Final, stressed:	Tense only	[bəˈlo͡ʊ] ‘bel**ow**’, [dəˈsple͡ɪ] ‘displ**ay**’
d.	Final, unstressed:	Tense only	[ˈhæpi] ‘happ**y**’, [ˈvu.ɾu] ‘vood**oo**’

Here, it can be seen that the only time a lax vowel could have occurred is in a syllable that would be closed due to ambisyllabicity. The asterisk indicates that the ‘lemon’ entry in (7a) is an ungrammatical syllabification. Based on the evidence from ambisyllabicity, I concur with Giegerich’s (1992) position that unreduced lax vowels only occur in closed syllables. This would explain why English speakers often have the intuition that a single consonant following a lax vowel is a coda rather than the less-marked option of behaving as an onset, as seen in the studies mentioned above. It would also explain why a lax vowel can never occur as the first vowel in hiatus (see (5d)). Hammond (1997, 1999) comes to a similar conclusion, but with a different approach. His Optimality Theory account requires that stressed lax vowels have a coda consonant and thus views the phenomenon as a stress-based requirement, where stressed syllables must be heavier than a lax vowel without a coda. I am instead applying Giegerich's (1992) more broad analysis to this position specifically: since lax vowels cannot occur in any open syllables, they cannot occur in absolute word-final position, either. Given this hypothesis, the the distribution of lax vowels in SAE is updated from the set in (6) to that in (8):

(8) Lax Vowel Distribution (revised)

a.	Stressed closed syllables:	[ˈkæp.tn̩] ‘c**a**ptain’	[ˈwɪn.di] ‘w**i**ndy’
		[ˈhæ,p,i] ‘h**a**ppy’	[ˈlɛ,m,ən] ‘l**e**mon’
b.	Unstressed closed word-final syllables:	[ˈme͡ɪ.ni.æk] ‘mani**ac**’	[ˈpʊl.pɪt] ‘pulp**it**’

If lax vowels only occur in closed syllables, the answer to the question of why lax vowels are absent in word-final open syllables falls out. They do not occur in this position because a word-final vowel by definition requires that the syllable containing the vowel be open, and lax vowels are limited to closed syllables. From here, the ternary analysis of SAE syllable strength can now be simplified to a binary one.

Strong syllables are now defined as those with sufficient duration to host all of the vowel contrasts present in SAE. This duration is found both in stressed syllables and unstressed ultimas.[8] Weak syllables have less duration than strong syllables, and include unstressed word-medial syllables. Strong syllables can host any vowel that is otherwise phonologically licit, and Weak syllables can only host [ə].

The distributional evidence has allowed a clear pattern to be identified: lax vowels are disallowed in open syllables. However, a motivation for this pattern has yet to be determined. A review of the historical developments of English vowels will provide further insight.

3. Historical Evidence- Vowel Developments

The view that lax vowels are phonotactically restricted to closed syllables, while not widely adopted explicitly, is completely consistent with the known facts of vowel development throughout the history of the English language.

The tense/lax distinction of modern English used to be primarily a vowel quantity distinction, rather than one of quality. In the Old English period, it was the case that length was one of the main phonemic contrasts in the vowel inventory, and [ATR] value

[8] This assumes that lax vowels in closed ultimas are completely stressless, a finding supported by Griffin (in prep).

may or may not have alternated alongside it (Fennell 2001, Minkova 2013). What is of particular interest is when and why short/lax vowels stopped occurring in open syllables, if they ever did in the first place.

Short vowels in non-final position will be considered first. These short vowels could only occur in stressed syllables, because unstressed syllables neutralized quantity and quality distinctions to [ə] throughout the Old English period– roughly 55 B.C.E to 1066 C.E. (Minkova 2013). These short vowels could occur in open stressed syllables at one point, but underwent different types of lengthening described by Fennell (2001) and others. One example is the compensatory lengthening from dropped final schwas that resulted in the English "silent e" being a diacritic for a long vowel in the preceding syllable (e.g. OE [ˈnamə] → SAE [ne͡ɪm] 'name'). By Early Modern English (roughly after 1509 C.E.) open stressed syllables consisted only of long vowels and diphthongs. Short vowels could still occur in stressed closed syllables, but some of these syllables were closed by the first segment of a geminate consonant. Britton (2012) notes that geminates lost their contrastive duration by the Middle English (ME) period (after 1066 C.E.). This is traditionally analyzed as causing geminate-closed syllables to become open, where the newly-shortened singleton consonant is syllabified as the onset of the following syllable. However, given the evidence above, an alternative proposal seems more appropriate. Rather than becoming completely open, I propose that, after degemination, syllables closed by a former geminate remained closed by a newly ambisyllabic singleton. In essence, it is consistent with the available evidence to posit that ME degemination is a historical source of ambisyllabic effects in English, and therefore contributes to the preservation of the closed status of syllables containing lax vowels.

Moving now to final vowels, Minkova's note that unstressed syllables only contained [ə] throughout the Old English period remains pertinent. All word final unstressed vowels were [ə][9] by the Middle English period, so short/lax vowels were never distinct in final position to begin with. Additionally, all instances of [ə] were apocopated by the start of Early Modern English (Minkova 2013). At the same time, though, new word-final unstressed vowels were developing from older VC# sequences, but these never had the option of surfacing as short/lax vowels. They arose from a process of vocalizing coda [j], [w], and [ɣ] to join the nucleus of the syllables they were in. This is proposed as vocalic assimilation rather than apocope because these formerly consonantal segments contributed their coda duration to the nucleus, rather than completely deleting. The formerly consonantal segment contributing its duration to the nucleus inevitably results in only long vowels arising in this way– additional duration causes these vowels to belong to the phonemic category of "long."

[9] "With the exception of [-i] in the affix <-y> (> OE -iġ)..." (Minkova 2013). This vowel in this position appears to have persisted unchanged since the Middle English period.

It can be seen from the above that lax vowels have a set of historical reasons for being absent from open syllables. Outside of word-final position, they either lengthened to stay open in certain stressed syllables, or resisted becoming open from degemination via ambisyllabicity. Word-final laxes were never able to occur because of various constraints on the vowel length contrast, and because any subsequently arising word-final vowels were necessarily long.

Now that a diachronic motivation has been identified for the absence of lax vowels in word-final position, a synchronic motivation would lend further support to the argument. In this case, I turn to the potential phonetic motivation of word-final lengthening and any effect it may have on the perception of vowel contrasts.

4. Perceptual Evidence- Listening Study

4.1 Testing the Effect of Duration on Perceptibility

In order to test the possibility that the incidental additional duration from word-final lengthening affects how perceivable certain vowel contrasts may be, I designed a listening study to compare perceptibility of different vowel qualities under different stress environments. Specifically, the study is concerned with the relative perceptibility of vowel qualities in stressed syllables (predicted to be Strong, i.e. robust), in non-final unstressed syllables (predicted to be Weak, i.e. compromised), and in final syllables (predicted to be Intermediate, i.e. less compromised, not fully robust). This last category crucially includes the additional duration of final lengthening, but not the other additional strengths of a stressed syllable (e.g. increased intensity and pitch). If there are three levels of strength, the perceptual behavior of each of these syllable types will differ. Specifically, lax vowels must be harder to distinguish in final position than in the stressed syllable for this to be true, which would then provide perceptual evidence for the absence of lax vowels in open ultimas. However, if there are only two levels of strength, final unstressed ultimas should pattern more closely with stressed syllables than unstressed ones, which would show that the perception of lax vowels is indeed boosted by additional, non-phonological duration.

4.2 Study Methods

4.2.1 Participants

Participants in the listening study were all undergraduate students from William & Mary, and were compensated with participant pool research credit. Prior to the study, participants were given a consent form and a brief survey, which were used to collect demographic information about age (between 18 and 21 years old), gender identity (F=54, M=8), and hearing ability (all reported having non-disabled hearing).

4.2.2 Stimuli

4.2.2.1 Design

Stimuli were 4-syllable nonce words of the shape: CVCVCVCVC. By using nonce words, every vowel in English could be tested in each type of stress environment, regardless of their actual distribution in real words. The syllables were: stressless initial, primary-stressed peninitial, stressless but artificially lengthened penult, and secondary-stressed ultima. The penult was artificially lengthened in order to mimic the incidental additional duration of word-final lengthening without the other factors of word-finality. This was in order to test the effect that non-phonologically meaningful duration has outside of the environment in which it usually occurs. The ultima carried secondary stress in order to contribute to the well-formedness of the rhythm of the word, and was not included in the later analysis.

The consonants of the nonce words were selected in order to avoid interference with the perceived duration of any of the vowels. Only obstruent consonants were used, in order to maximize their discriminability from the vocalic phonemes, both perceptually and in a spectrogram. The initial consonant was [b], selected for its lack of aspiration, given that additional voice-onset time could possibly affect perception of vowel duration. The next three consonants (all medial) were [ʃ], [s], and [t͡ʃ], continuants chosen in order to avoid the subphonemic alternation caused by English voiced plosives that can have a lengthening effect on a preceding vowel (Raphael 1972). The last consonant was [f], chosen primarily because it was another non-plosive that would be appropriately distinct from the surrounding phonemes.

The vowels were taken from the full vocalic inventory of Standard American English, with three exceptions. The first is the exclusion of [ɝ], as it is the only rhotic monophthong in the inventory and is therefore expected to not be at all confusable with any other vowels. The second is that, because [ɔ] and [ɑ] are significantly merged across SAE, I omitted [ɔ] from the dataset, in order to avoid a confound with this merger.

Finally, because the main difference between [ʌ] and [ə] is taken to be one of stress, the former was also excluded from the dataset. The non-test vowels were all [ə], and the test vowels could be any of the following: [ə], [i], [ɪ], [e͡ɪ], [ɛ], [æ], [ɑ], [o͡ʊ], [u], or [ʊ]. The exact pronunciation of the [e͡ɪ] and [o͡ʊ] phonemes were more monophthongal, so that the formants were steadier and less prone to undue distortion upon manipulation of duration. Figure 3 is a spectrogram of one of the stimuli:

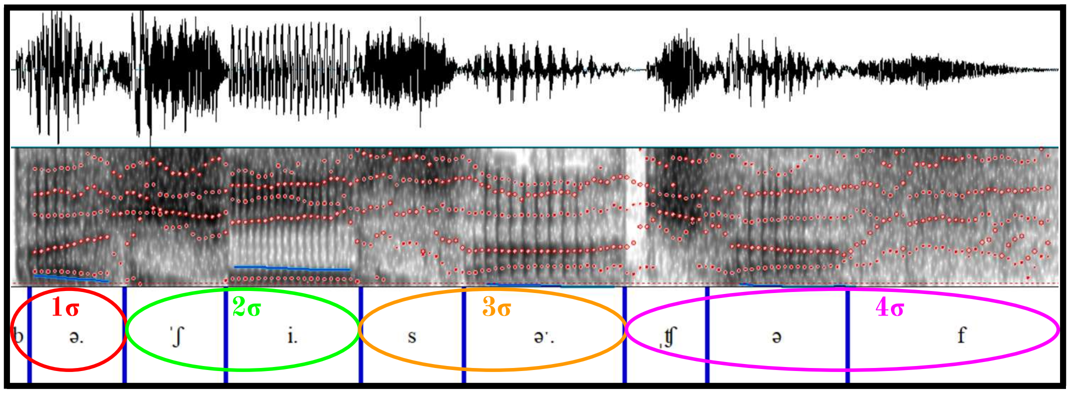

Figure 3- Stimulus 0100: [bə.ˈʃi.səˑ.ˌt͡ʃəf].

4.2.2.2 Generation

I elected to systematically record the stimuli myself, instead of synthesizing the stimuli with one of the typical pieces of software used for this purpose. This was in order to preserve as much naturalness as possible. Then I regularized the pitch and intensity contours of each word using Praat (Boersma & Weenik 2024) and the Praat Vocalic Toolkit (Corretge 2023). I have had roughly eight years of vocal training (both speech and singing) that allows me to be distinctly aware of my mouth shape and exact articulation of speech sounds, such that each sound was appropriately comparable to other tokens of the same phoneme, while also yielding a more naturalistic production than speech synthesis can typically achieve. Instead of recording each of the hundreds of four-syllable nonce words individually, I produced many fewer two-syllable nonce words, regularized their durations, and concatenated them in the appropriate orders. The durations for each vowel were based on natural production, in line with those found by Lunden (2016). For example, in order to have a test vowel of [i] in the stressed peninitial syllable, I recorded the nonce words [bə.ˈʃi], [ˈʃi.sə], and [sə.ˌt͡ʃəf], and then edited them together to yield the stimulus [bə.ˈʃi.sə.ˌt͡ʃəf]. This was also done to remove the possibility of any decrease in verisimilitude due to unnatural coarticulation cues.[10] After concatenation, I regularized the

[10] The nature of continuous (natural) articulation necessitates a certain amount of transitional adjustment between phonemes. For example, the /s/ in [si] would sound slightly different from the /s/ in [sa], and putting /s/ clipped from [si] next to [a] could present enough of a perceptual mismatch to distract a listener.

pitch and intensity contours of each stimulus in order to have more uniform-sounding pronunciations. The exact pitch and duration details are below in (9):

(9) Stimuli Syllable Durations and Pitches

Position 1 (unstressed): 60-80ms, ~260Hz,

Position 2 (stressed): 115-130ms, ~600Hz

Position 3 (artificially lengthened): 150-200ms, 50-120Hz

Position 4 (secondary stressed ultima, not analyzed): 100-120ms, <50Hz

The first and second formants of each of the vowels in each of the relevant positions as articulated for the stimuli is shown in Figure 4.

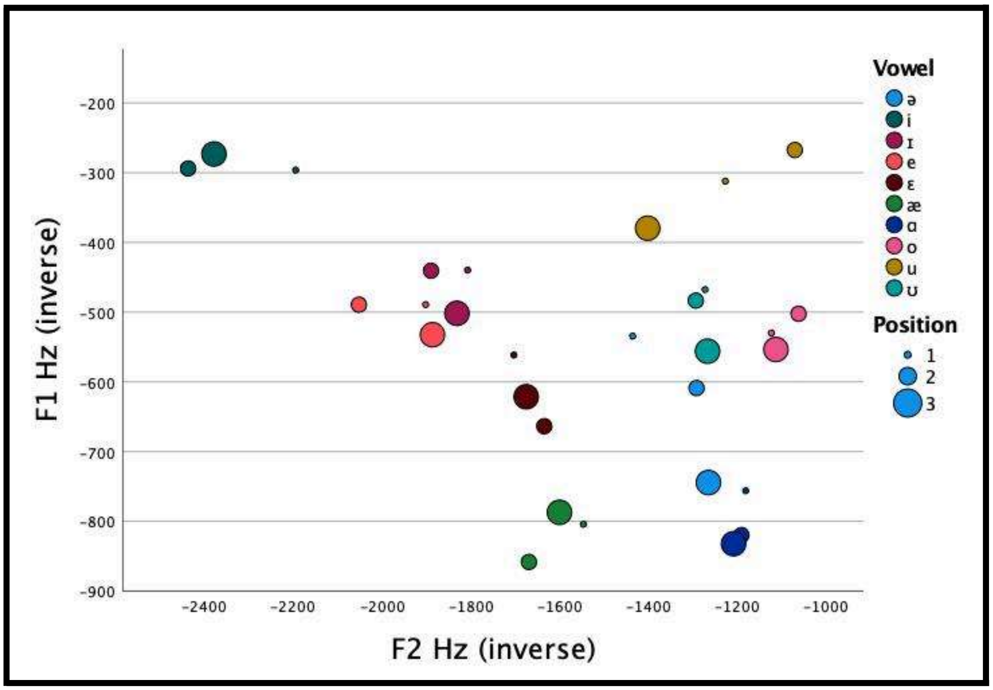

Figure 4- Chart of Stimuli Vowels. Recall that [ʌ] was not transcribed as distinct from schwa, but could be argued to occur in stressed position.

The ultima was excluded from the data analysis because the final position was not the target, and would have presented confounds due to the presence of a coda consonant and secondary stress, both of which stand a chance of affecting the perception of duration in unexpected ways.

4.2.2.3 Pairings for Perception Study

In order to avoid having 90 different stimulus pairs in 4 different syllable positions, I elected to only pair stimuli with vowels that differed by only one relevant feature. A pair was formed if they shared values for three of the following four phonological features: [high], [low], [back], and [ATR]. Each phonetically lax vowel was also paired with [ə] due to the relatively small Euclidean distance between them. For instance, I paired [i] with [e], because they are both [-back], [-low], and [+ATR], but differ with respect to [high]. Another pairing example is [i] with [ɪ], which are both [-back], [-low], and [+high], but differ with respect to [ATR]. Each of these vowel pairs were tested in each of the four syllables (e.g. [bə.ˈʃi.sə.ˌt͡ʃəf] and [bə.ˈʃe.sə.ˌt͡ʃəf], [bi.ˈʃə.sə.ˌt͡ʃəf] and [be.ˈʃə.sə.ˌt͡ʃəf]). The following is a list of each of the pairings, split by contrastive feature:

(10) Vowel Pairings

Height Pairs
- [i] and [e]
- [ɪ] and [ɛ]
- [ɛ] and [æ]
- [o] and [ɑ]
- [u] and [o]

Backness Pairs:
- [i] and [u]
- [ɪ] and [ʊ]
- [e] and [o]
- [ɑ] and [æ][11]

Laxness Pairs:
- [i] and [ɪ]
- [u] and [ʊ]
- [e] and [ɛ]

Central Pairs
- [ɪ] and [ə]
- [ʊ] and [ə]
- [ɛ] and [ə]
- [ɑ] and [ə]
- [æ] and [ə]

Regarding the Laxness pairs, one member of such a pair has roughly the same formant frequencies as the other member of the pair. Based on the fact that the main acoustic cue

[11] Notably, the members of this pair also are distinguished by [ɑ] being phonologically tense and [æ] being lax. This pair was grouped with the Backness pairs instead of Laxness pairs because the backness contrast is generally accepted to be more salient than the [ATR] contrast.

to a given vowel contrast is typically a formant difference, I expected that these pairs would be notably less distinguishable than the others.

Additionally, half of the stimuli pairs contained the same vowels both times, in order to avoid the confound of participants realizing that the vowels were always different.

4.2.3 Procedure

The experiment was deployed via Praat (Boersma and Weenik 2023) as a multiple forced choice AX discrimination task. Participants were seated in a sound-attenuated booth two at a time, and were equipped with Sennheiser HD 280 Pro headphones connected to two desktop computers running Windows 7. Before the start of the experiment, participants were briefed on the nature of the task– namely that they would hear two nonce words, which would sometimes differ with respect to which vowels were in them. Participants were also encouraged to trust their first intuition, instead of pondering over each different stimulus pair. The start text of the experiment read: "This is a listening experiment. For each pair, decide whether the two made-up words had all the same vowels in them, or if they had any different vowels." The run text read: "Did the two words have all the same vowels in them?" Results were extracted subsequent to each pair of participants completing the experiment, and statistical analysis was performed in SPSS once sufficient data were collected.

4.3 Study Results

The graph below shows the percentages of responses that indicate a correct differentiation between two different vowel phonemes. The possible different vowel pairs are sorted by contrast type and syllable, where Position 1 is the initial, unstressed syllable, Position 2 is the antepenultimate, primary stressed syllable, and Position 3 is the artificially lengthened but stressless penultimate syllable. Height Pairs differed only with respect to the feature [high] or [low] (e.g. [i]/[e]), Backness Pairs with respect to [back] (e.g. [i]/[u]), Laxness pairs with respect to [ATR] (e.g. [i]/[ɪ]), and Central Pairs with respect to whether the vowel in the central [-ATR] region was reduced or full (e.g. [ɪ]/[ə]). A generalized linear model was developed in SPSS, where the participant Response was the dependent variable (Correct or Incorrect), and the independent variables were Position ($p<0.001$) and Contrast ($p<0.001$). The interaction term between Position and Contrast was statistically significant ($p<0.001$), and Subject was a blocking factor.

Test of Model Effects

Source	Wald Chi-Square	df	Sig.
(Intercept)	649.370	1	0.000
Position	766.984	2	0.000
Contrast	116.803	3	0.000
Position * Contrast	56.695	6	0.000
Subject	527.254	61	0.000

The following chart is a visualization of the study responses, only including the stimuli pairs that contained different vowels.

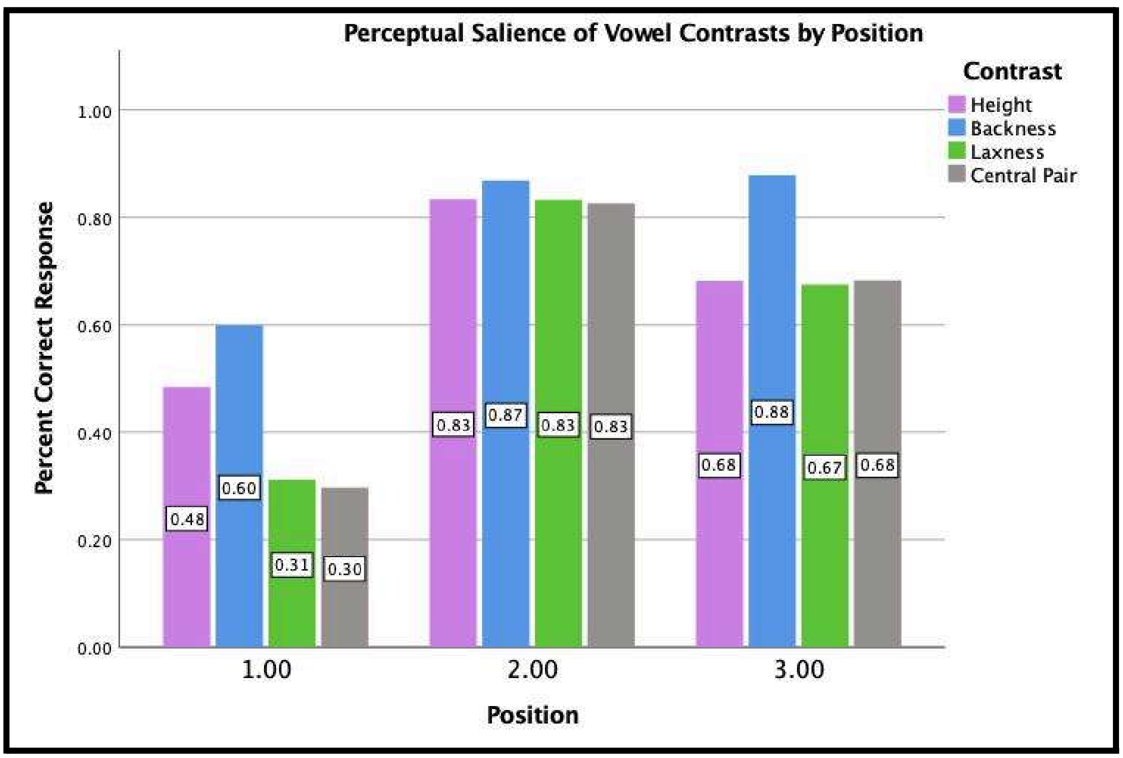

Figure 5- Percentages of Correct Differentiations of Contrasts by Word Position

The stressed syllable (Position 2) has the highest differentiability, and the unstressed syllable (Position 1) has the lowest. Position 3 appears to be overall less differentiable than Position 2 but is much more so than Position 1. The pairwise comparisons (with Bonferroni correction) show no significant difference between any of the Position 2 contrasts (p=1) or between any Laxness pairs and Central Pairs (p=1), a significant difference between Height pairs and Laxness pairs in Position 1 ($p<0.001$), but no significant difference between Height pairs and Laxness pairs in Position 3 ($p=1$).

The performance of each individual pair in each position is presented below in Table Set 1. Cells in the table are colored based on which quintile the percentage of correct differentiation falls into: First- , Second- , Third- , Fourth- , and Fifth- .

Height Pairs	1σ	2σ	3σ
i/e	52%	91%	85%
ɪ/ɛ	7%	78%	18%
ɛ/æ	50%	60%	45%
ɑ/o	64%	95%	94%
o/u	63%	89%	92%

Backness Pairs	1σ	2σ	3σ
i/u	74%	98%	96%
ɪ/ʊ	48%	94%	88%
e/o	74%	95%	94%
ɑ/æ	31%	68%	74%

Laxness Pairs	1σ	2σ	3σ
i/ɪ	44%	85%	85%
e/ɛ	18%	81%	32%
u/ʊ	32%	84%	85%

Central Pairs	1σ	2σ	3σ
ɪ/ə	26%	88%	82%
ʊ/ə	22%	67%	69%
ɛ/ə	14%	89%	84%
ɑ/ə	37%	81%	37%
æ/ə	50%	88%	69%

Table Set 1- Percent Correctly Differentiated of Individual Vowel Pairings

Laxness Pairs and Central Pairs tend to be less perceptible than Height and Backness pairs overall, and pairs that include lax vowels and schwa tend to be less perceptible than other pairs in the same syllable. The Laxness Pairs were more perceivable than predicted, but interestingly, the non-high Laxness Pair (e/ɛ) is much less perceptually salient than the high Laxness pairs. This is likely due to the fact that the [+ATR +high] region is much further away from the [-ATR +high] region than the [+ATR -high] region is from the [-ATR -high] region. More simply put, a high lax vowel has a larger Euclidean distance from its tense counterpart than a mid or low lax vowel does, making it more differentiable. This is also evidenced by the lower perceptibility of the Height Pairs that contain two lax vowels;

the general salience of a height difference appears to be muddled by the lower amounts of dispersion when confined strictly to the [-ATR] region. Additionally, Backness Pairs perform notably better than any other pair type. This is likely due to the fact any backness distinctions in English are accompanied by a rounding difference as well, which is an additional cue to contrast.

5. Discussion

Recall that Position 3 in the stimuli discussed above was designed to mimic the word-final position. While not bearing stress, it had increased, non-phonologically meaningful duration, and therefore functioned as a proxy for final position. Pairs with only tense vowels behaved as anticipated, staying nearly as perceptually distinct in Position 3 as in the stress-bearing Position 2. For example, the Height Pair [i]/[e] was 95% differentiable in Position 2, and 85% differentiable in Position 3.

Notably, the lax vowels in Position 3 did not behave as would be expected if they are excluded from final position because they are not sufficiently perceptually distinct; Laxness Pairs and Central Pairs were as distinguishable as Height Pairs. For example, in Position 3, the Height Pair [i]/[e] was 85% differentiable, the Laxness Pair [i]/[ɪ] was also 85% differentiable, and the Central Pair [ɪ]/[ə] was 82% differentiable. Crucially, because the Laxness contrast and Central Pair contrast both performed as well in Position 3 as a feature that does actually contrast in final position (height), this shows that lax vowels would contrast as saliently as tense vowels if they were to occur in that position. From this, it can be seen that lax vowels are not absent from unstressed open ultimas because of a lack of perceptual salience; there is no such lack.

However, there is a distinct lack of perceptual salience in Position 1, especially in pairs involving lax vowels. For example, the Laxness Pair [u]/[ʊ] was only 32% differentiable in Position 1 (compared to 84% in Position 2). This different behavior of the lax vowels between positions emerged as a convenient diagnostic for syllable strength. Position 1, which is known to be Weak, was also signaled to be Weak because the lax vowels are notably not perceptually distinct there. Position 2, known to be Strong, was also signaled to be Strong because the lax vowels are perceptually salient there. As seen above, Position 3 patterns more closely with Position 2 than Position 1, signaling that this position is also Strong. Therefore, the findings support the revised, binary analysis of syllable strength that I propose, where word-final syllables (represented by Position 3) are as Strong as stress-bearing syllables (represented by Position 2) with regards to hosting vowel contrasts.

With this in mind, it is also worth noting that the resistance to final vowel reduction that Barnes (2002) describes as partial in English is actually total. Ultimas can host as many vowel contrasts as stress-bearing syllables, completely resisting unstressed vowel reduction. This raises the possibility that the word minimality constraint (McCarthy and Prince 1986), at least in English, could be reenvisioned as a final-syllable minimality constraint, given that the distributions match nearly perfectly, but this matter will be left to future research.

6. Conclusion

This account has challenged previous analyses of the word-final vowel inventory of Standard American English. I presented evidence that the natural class found in open ultimas is that of tense (or [+ATR]) vocalic phonemes, and proposed that this allows stressless ultimas to be analyzed as Strong syllables, instead of warranting their own "Intermediate" strength category. In order to determine why lax vowels are disallowed word-finally, I first looked at the distributional evidence. With added insight from ambisyllabicity, I showed that lax vowels are actually prohibited from all open syllables, not just stressless open ultimas. Then, I reviewed the body of historical evidence to determine if there is a diachronic motivation. This revealed that older stages of English stopped allowing lax vowels in open syllables, due to a series of phonological changes that began before the 9th century. In order to uncover any perceptual evidence behind the absence of word-final lax vowels, I designed and conducted a listening study. The findings of this study were that lax vowels were still perceptually distinct from their tense counterparts in final position, which indicates that their absence in that position is not due to a synchronic lack of salience. The study also showed that lengthened syllables (i.e. naturally-produced ultimas) behave like Strong syllables when considering vowel contrasts. The incidental additional duration present due to final lengthening allows ultimas to host as many different vowel contrasts as stressed syllables, with lax vowels requiring a coda in both syllable types. This is direct support for the reanalysis of SAE syllable strength as binary rather than ternary, and concordant with the position that full lax vowels cannot occur outside of closed syllables.

Final syllables disallowing lax vowels without a coda seems to indicate that they have some constraint on minimality. Monosyllabic words also have a minimality constraint that disallows lax vowels without a coda, so it may be that these two constraints are one and the same. This may leave English not with a Word Minimality constraint, but an Ultima Minimality constraint, which also happens to apply to monosyllables. Further theoretical argumentation on this point will be left to future work. Additional areas of research include running an altered version of the same study above, but causing the length in Position 3 to be as variable as the additional duration from natural final lengthening is. This would allow the effect of durational variability to be tested in earnest.

As far as I am aware, although some (like Hammond 1999) point out that lax vowels do not occur word-finally, and others (like Giegerich 1992) have noticed that lax vowels seem to be absent from open syllables, no previous unification of these two theories has been proposed.

References

Barnes, Jonathan 2002. Positional neutralization: A phonologization approach to typological patterns. Berkeley: University of California dissertation.

Boersma, Paul & Weenink, David. 2024. Praat: doing phonetics by computer [Computer program]. Version 6.4.07, retrieved 17 March 2024 from http://www.praat.org/

Britton, Derek. 2012. Degemination in English, with special reference to the Middle English period. D. Denison, R. Bermúdez-Otero, CB McCully, & E. Moore, with the assistance of A. Miura (Eds.), *Analysing Older English*, 232-244.

Corretge, Ramon 2012-2023. Praat Vocal Toolkit. https://www.praatvocaltoolkit.com

De Jong, Kenneth., & Zawaydeh, Bushra Adnan. 1999. Stress, duration, and intonation in Arabic word-level prosody. *Journal of Phonetics*, 27(1), 3-22.

Durvasula, Karthik, Ho-Hsin Huang, and Rose, Merrill. 2013. Word-internal ambisyllabic consonants are codas. *The Journal of the Acoustical Society of America* 134 (5)

Elzinga, Dirk, & Eddington, David. 2014. An experimental approach to ambisyllabicity in English. *Topics in Linguistics*, 14(1), 34-47.

Farnetani, Edda, & Kori, Shiro. 1990. Rhythmic structure in Italian noun phrases: A study on vowel durations. *Phonetica*, 47(1-2), 50-65.

Fennell, Barbara A. 2001. *A History of English: a Sociolinguistic Approach.* Wiley-Blackwell, UK.

Flemming, Edward, and Johnson, Stephanie. 2007. Rosa's roses: Reduced vowels in American English. *Journal of the International Phonetic Association* 37.1 83-96.

Giegerich, Heinz J. 1992. *English phonology: An introduction.* Cambridge University Press.

Griffin, Lulu, in prep. An Investigation of Prominence Alternations in English. Expected as an Undergraduate Honors Thesis, William & Mary.

Hammond, Michael. 1997. Vowel quantity and syllabification in English. *Language*, 1-17.

Hammond, Michael. 1999. *The phonology of English: a prosodic optimality-theoretic approach: a prosodic optimality-theoretic approach.* Oxford University Press, UK.

Hogoboom, Anya, & Lorber, Joseph. 2023. Word-final strength and weakness. *Proceedings of the Linguistic Society of America*, 8(1), 5562-5562.

Johnson, Keith, & Martin, Jack. 2001. Acoustic vowel reduction in Creek: Effects of distinctive length and position in the word. *Phonetica*, 58(1-2), 81-102.

Lunden, Anya. 2013. Reanalyzing final consonant extrametricality: A proportional theory of weight. *The Journal of Comparative Germanic Linguistics*, 16, 1-31.

Lunden, Anya. 2016. Effects of position and stress on English and Norwegian vowel quality. Ms. William & Mary.

Lunden, Anya. 2017. Duration, vowel quality, and the rhythmic pattern of English. *Laboratory Phonology*, 8(1).

McCarthy, John. J., & Prince, Alan. 1999. Prosodic morphology 1986. *Phonological theory: the essential readings*, 238-288.

Minkova, Donka. 2013. *Historical phonology of English.* Edinburgh University Press.

Newman, Roxana Ma, & Van Heuven, Vincent J. 1981. An acoustic and phonological study of pre-pausal vowel length in Hausa. *Journal of African Languages and Linguistics*, 3: 1-18.

Raphael, Lawrence J. 1975. The physiological control of durational differences between vowels preceding voiced and voiceless consonants in English. *Journal of Phonetics*, 3(1), 25-33.

Recasens, Daniel 1986. *Estudis de fonètica experimental de Català oriental central.* Biblioteca Milà i Fontanals.

Rosalsky, Alexa. 2017. Ambisyllabic Consonant Lengthening in English. *Undergraduate Honors Theses*. William & Mary. Paper 1089.

Shevelov, George Y. 1979. *A Historical Phonology of the Ukrainian Language.* Heidelberg: Carl Winter Universitätsverlag

Steriade, Donca 1994. Positional neutralization and the expression of contrast. Ms. University of California, Los Angeles; revised text of 1993 NELS talk.

Treiman, Rebecca and Danis, Catalina. 1988. Syllabification of intervocalic consonants. *Journal of Memory and Language* 27 (1), 87–104

Ueyama, Motoko. 1999. An experimental study of vowel duration in phrase-final contexts in Japanese. *UCLA Working papers in Phonetics*, 174-182.

Wells, John C. 1982. *Accents of English. Vol. 1: An Introduction* (pp. i–xx, 1–278), Vol. 3: Beyond the British Isles (pp. i–xx, 467–674). Cambridge University Press.

Yip, Moira. 1989. Contour tones. *Phonology*, 6(1), 149-174.