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Word-final strength and weakness

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Abstract. Word-final syllables are known to show phonological strength, presumably due to final lengthening (Steriade 1994; Barnes 2002), but also phonological weakness. We propose that final weakening effects are also due to final lengthening under the assumption that duration due a phonetic source (i.e. final lengthening) is not on linguistic par with duration from a phonological source. We show further support for our proposal through the results of perception studies with adults that show less sensitivity to word-final duration differences. We note that child language phonology often shows unexpected final syllable strength and include two such diary studies with English-learning children. We propose that this difference between child and adult phonology is due to children not yet having learned to differentiate the import of duration based on its source.

Keywords. word-final; right edge; final lengthening; child phonology

1. Introduction. Word-final syllables are known to behave as both phonologically strong and phonologically weak. The strength of the word-final position is generally taken to be due to final lengthening (e.g. Steriade 1994; Barnes 2002) while its weaknesses are typically associated with the domain-final processes of final devoicing and pitch drop (e.g. Barnes 2002). No proposals, to our knowledge, have clarified when we should expect which effect to "win out" or otherwise predict when final syllables would be expected to behave as stronger or weaker than equivalent non-final syllables. While not disputing a role for final devoicing and pitch drop, we suggest that both word-final strength and weakness are due to final lengthening, and propose that we should see final syllables behaving as strong only when the phonological phenomenon in question uses inherently-present duration to be realized.

Final lengthening is known to affect domain-final syllables and segments at the word, phrase, and utterance levels, with stronger effects at higher domains (Wightman et al. 1992). All three levels of final lengthening were first documented by Oller (1973) for English. More recently, final lengthening at the word level has been demonstrated by Hogoboom for Norwegian (Lunden 2013) and English (Lunden 2017). We will focus on word-level final lengthening, leaving open the question of whether some processes motivated by final lengthening are in fact due to domain-final generalization, where a higher level of final lengthening is responsible for word-final effects (e.g. Myers & Padgett 2014).

Final lengthening can be clearly seen to occur at the word-level in the following study by Hogoboom (2016). Hogoboom's dataset comprised 1622 vowels spoken by 17 native English speakers who read question/answer pairs containing a four-syllable nonce word, such as those in (1).

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(1) Example task item

Which baDAfasa did her brother notice?
Her brother noticed the baDAfasa that smelled funny.

Measurements were taken of the nonce-word's vowels in the answer, where the nonce-word noun is part of a complex noun phrase, meaning that the test word's final vowel is not phrase final. Words with orthographic <i>, <u>, and <a> were used. The durations of each syllable (shown as z-scores for comparison across different subjects) are shown in Figure 1.

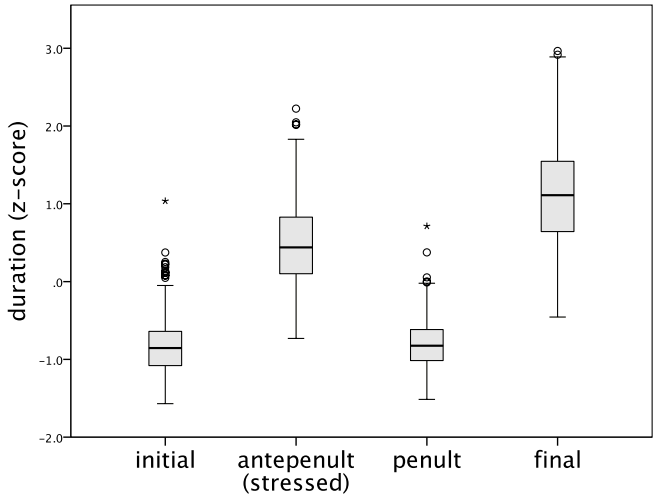

Figure 1. Vowel duration in nonce words with antepenultimate stress

As would be expected, the stressed, antepenultimate vowels are much longer than vowels in the two non-final, unstressed positions. The final unstressed vowel, however, shows durations that overlap and extend longer than the stressed vowel, clearly demonstrating word-level final lengthening.

Since strong positions often show longer duration (e.g. long vowels, stressed syllables), the additional duration due to final lengthening is a very plausible motivator for word-final strength effects, such as those discussed in the following subsection.

2. Final syllable behavior.

2.1. FINAL SYLLABLE STRENGTH. Phonological phenomena for which the final syllable seems strong include their resistance to unstressed vowel reduction (Barnes 2002) and their greater ability to host contour tones (Yip 1989). Further, Hogoboom (Lunden 2019) has shown that final syllables can perceptually continue a word's rhythmic pattern. Additionally, multiple researchers have noted that the final syllable acts as a strong position in children's language (Snow 1998; Kehoe & Stoel-Gammon 1997; Curtin 2002).

Barnes (2002) documents 13 languages that have vowel quality reduction in non-final unstressed syllables but in which word-final unstressed syllables "resist" this reduction to some degree. English is one such language, and the vowel qualities in the four syllables in the nonce

words from Hogoboom (2016) can be used to illustrate. The difference between stressed and non-final unstressed syllables is clearest in words with orthographic <i> and those with <a>, both shown in Figure 2. In both cases, we see that unstressed word-final syllables have a stronger vowel than that of other unstressed syllables. In Figure 2 (left) we see that unstressed word-final [i]s were pronounced very similarly to stressed antepenultimate [i]s. In Figure 2 (right) we see that word-final [ə]s were pronounced with vowel qualities ranging from that of unstressed non-final [ə]s to those of stressed antepenultimate [ɑ]s. In both cases, we see a fuller vowel quality in word-final syllables than in unstressed syllables in other positions. Barnes suggests that effects like these are due to the durational differences between word-final syllables and other unstressed syllables. He posits that because word-final syllables are longer, the speaker has time to reach a fuller vowel quality. The data from Hogoboom (2016) show some support for this, as the word-final vowels that make up the by-speaker averages clearly group differently than non-final unstressed vowels.

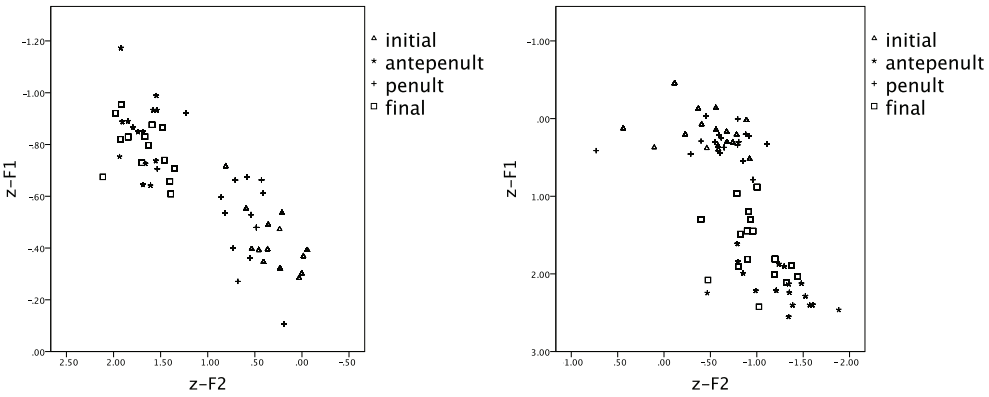

Figure 2. Average /i/ (left) and /ɑ/ (right) in each position for each speaker

Yip (1989) noted that contour tones are drawn to final syllables. Zhang (2001) surveyed 187 tonal languages and found that 47 of them allowed more complex contour tones on the final syllable (collapsing over both word-final and phrase-final positions). While it was previously known that phonological length due to long vowels is a good host for contour tones, Zhang shows typologically that phonetic duration due to final lengthening or monosyllabicity is also a good host for contour tones.

Hogoboom (Lunden 2019) showed that the combination of final lengthening and less-neutralized vowel quality caused the perception of a continued rhythm even when the final syllable was not stressed. She had native English speakers listen to concatenated syllable strings consisting of alternating stressed and unstressed syllables, which were either fully alternating between stressed and unstressed, or which ended with two short unstressed syllables with reduced vowel quality, or which ended with a final syllable with full(er) vowel quality and longer duration but low intensity and a pitch drop. She found that listeners identified the syllable strings that had an unstressed but long final syllable as alternating about 60% of the time. This shows that an unstressed final syllable may perceptually continue the rhythm of a word.

Another place that word-final syllables may act as strong is in children's phonology. Kehoe & Stoel-Gammon (1997) found that children (22–32 months) commonly produce the stressed

syllable and the (unstressed) final syllable in truncations, even when they are not a single prosodic unit, for example, [pɑmɪs] 'hippopotamus.' Snow (1998) suggests that this tendency is due to the added duration of final syllables. We add to this literature with two new diary studies that further support a special role for the final syllable in child language.

J, an English-learning child (2;6), regularly truncated to only the final syllable, as shown in (2).

(2) J's truncation to the final syllable

a.	[sɑ(r)]	dinosaur	e.	[si]	Percy
b.	[tɑr]	guitar	f.	[ɹɛt]	piglett
c.	[mɪs]	hippopotamus	g.	[ni]	Stephanie
d.	[hr]	letter	h.	[gl]	triangle

E, an English-learning child (2;11) could produce labial, coronal, and dorsal stops in onset position, shown in (3), but neutralized all stops to [ʔ] in non-final coda position, as in (4).

(3) Un-neutralized stops in onset position

a.	[p̲ɑ.p̲ə]	'papa'	d.	[b̲æd]	'bad'
b.	[t̲ut]	'toot'	e.	[d̲ʌn]	'done'
c.	[k̲ɪdi]	'kitty'	f.	[g̲rin]	'green'

(4) Neutralized stops in non-final coda position

a.	[teɪʔ̲.wə]	stapler
b.	[keɪʔ̲.wɪn]	Caitlin
c.	[ʧɑʔ̲.wɪt]	chocolate

E's word-final coda position, however, showed resistance to full neutralization. As shown in (5), he maintained labials and coronals in word-final position (a-d), while neutralizing dorsals to coronals (e-h).

(5) Partially-neutralized stops in word-final coda position

a.	[kʌp̲]	'cup	e.	[koʊt̲]	'coat'
b.	[woʊb̲]	'robe'	f.	[hɑt̲]	'honk'
c.	[tut̲]	'toot"	g.	[bæd̲]	'bag'
d.	[boʊt̲]	'boat'	h.	[hʌd̲]	'hug'

The fact that E contrasted two oral places of articulation word-finally, while debuccalizing all non-final codas, is a further example of the relative strength of word-final position for children's phonology. Just as final lengthening is thought to make the final syllable syllable salient when children truncate, it is reasonable to assume that final lengthening also increases the saliency or perceived importance of a word-final consonant.

2.2. FINAL SYLLABLE WEAKNESSES. In contrast to the phonological phenomena discussed in the previous subsection, we see the word-final syllable behaving as a weak position with respect to the ability to host obstruent voicing contrasts or vowel length contrasts, and we also commonly see languages avoiding placing stress on the final syllable.

Coda devoicing (i.e. German /liːb/ → [liːp] 'love') is presumably a more generalized form of final devoicing as evidenced by languages such as Polish, Russian, and Walloon (Wetzels &

Mascaró 2001). For example, Polish contrasts voicing in onsets and non-final codas but not word-finally (Sanders 2003). The fact that we find fewer voicing contrasts hosted in the word-final position shows a relative weakness of the position.

In a similar vein, many languages with vowel length contrasts neutralize this contrast word-finally (Myers & Hansen 2007). For example, Japanese has underlying /sense:/ 'teacher' which surfaces as [sense] (Nakai 2013), due to what is generally referred to as final shortening. Again the fact that languages often avoid maintaining a vowel length contrast word-finally is behavior associated with a weaker position. Geminate consonants also tend to be avoided word-finally, which could be argued to be another instance of word-final weakness, although given the analysis that a consonant only geminates when its required to be both a coda and an onset (Hayes 1989), this dispreference for word-final geminates can be understood as being independently motivated.

Finally, the final syllable often avoided for stress. Stress is often drawn to word edges, which is generally understood as a two-syllable window word-initially (initial, peninitial) and a three-syllable window word-finally (antepenult, penult, final). The asymmetry between the two edges is due the fact that many languages avoid including the final syllable in the metrical structure of the word. This has been encoded in phonological theory as extrametricality (Liberman & Prince 1977) and Non-Finality (Prince & Smolensky 1993). While many languages do allow final stress, there is also clearly a pressure to avoid it.

Thus, word-final weakness effects are phenomena that either exhibit some kind of avoidance of the final position, or limit the number of phonemic contrasts that can be hosted.

3. Proposal. The fact that the word-final position exhibits strength in some phonological patterns and weakness in others is somewhat mystifying on the face of it. We propose that final lengthening at the word level is the cause of both the final syllable's strengths and its weaknesses. We suggest that phenomena in which the final position are strong are those that *use* independently-present duration from a phonetic or phonological source. Vowel reduction resistance can be seen as using the "implicit" duration of the word-final position in order to realize a fuller vowel. It makes sense that contour tones, as discussed by Zhang (2004), are drawn to longer syllables, as multiple tone targets need time to be realized. Hogoboom's (Lunden 2019) finding that an unstressed word-final syllable can contribute a "strong" beat to the rhythm of a word relies on the increased duration from final lengthening. On the other hand, final syllables can be understood as weak in cases where longer duration either increases production difficulty or for phenomena which *add* phonologically-important duration. Because voiced obstruents are more difficult to produce (as glottal airflow must be maintained while a significant oral constriction is made), a word-final obstruent, subjected to final lengthening, is even more difficult to produce, as the marked articulatory configuration is prolonged. Long vowels (and consonants) of course add phonological duration, which could be difficult for a listener to piece apart from the duration due to implicit, phonologically-meaningless final lengthening. Languages that signal stress through increased duration might likewise find the phonologically-important duration perceptually lost in the duration due to final lengthening.[1]

The above proposal does not make the correct prediction in terms of the treatment of the fi-

[1] Our proposal that phonologically-important duration is at risk of getting perceptually lost in phonetic duration must not be true of phonologically-important duration occurring with (other) phonological duration. Presumably, in the former case, the phonologically-important duration is at risk of being perceptually misattributed to unimportant, implicit duration.

nal syllable in child phonology, however. The first diary study presented here, in line with previous literature, exhibits a truncation pattern that privileges the final syllable by preserving it, in a way that unstressed word-final syllables are not generally privileged. The second diary study also gives special status to the final syllable, in this case the coda of the final syllable, which resists most of the place neutralization found in non-final codas of the child's speech by maintaining two oral places of articulation. Neither of these patterns can be said to be using inherently-present duration to realize something phonologically; rather they seem to be treating the final syllable as a strong position because of the inherently-present duration. Therefore, we hypothesize that children start by treating phonetic duration as being as strong as duration due to a phonological source. Under this hypothesis, they must in time learn to discount, to some extent, the extra duration they hear at the end of words once they notice that it is not phonologically-meaningful. We would then expect that there is some stage where children outperform adults in noticing durational differences in word-final position.

4. Perception studies. Our proposal predicts that adults (but not children) should be less sensitive to word-final duration changes than they are to duration changes non-finally. We tested adults' sensitivity to duration changes non-finally and word-finally through a series of perception studies.

All three studies used [CiCi] nonce words synthesized with MBROLA, voice us3 (Dutoit et al. 1996). Versions of each nonce word were created with the target vowel (either the first vowel (V1) or the final vowel (V2)) having durations of 100, 120, 140, 160, 180, and 200 ms. The non-target vowel in each word was held constant at 150 ms. These durational patterns were created once with medial consonant (C2) [m] and again with [n]. The initial consonant (C1) was varied, taken from the set of [f, v, s, z, ʃ, ʧ, ʤ, h]. Pairs of stimuli were created in Praat (Boersma & Weenink 2022) with a ISI of 200 ms. and each study was run using Praat's MFC interface.

4.1. STUDY 1: AX TASK, 6 DURATION PAIRINGS. Fifty-four participants were recruited from the participant pool at William & Mary and received course credit (age range 18-20, average age=19; 40 female, 12 male, 2 non-binary).

Each of the six duration levels were paired with the shortest duration (level 0: 100 ms.) and with the longest duration (level 5: 200 ms), creating six different duration pairings with level 0 and six different with level 5. Reversing the order of each pair creates 24 pairs. One such set was created for target-V1 pairings and another for target-V2 pairings, resulting in 48 pairs. This set of 48 was created for each of the two medial consonants [m] and [n], producing 96 tokens. Different initial consonants were pseudo-randomly used in each pair. (The study was run with another two sets of 48 pairs with the medial consonants [p] and [b] for a different research question, not reported on here, resulting in a total of 192 tokens for participants.)

Participants were told that they would hear a pair of made-up words which were either pronounced exactly the same or not quite the same and that they should identify which of these two categories each pair they heard fell into. As examples they were played two pairs that were not exactly the same, both of which had the maximum difference, one in which the difference was due to the duration of the first vowel and one in which it was due to the duration of the second.

The results are shown in Figure 3, indicating how frequently participants selected the response that the words were not exactly the same (i.e. were different) for each of the six duration pairings. Level 0 of duration difference are cases that were the same, where the target vowels were either both 100 ms. or both 200 ms. Duration differences increase by 20 ms. up until the

maximally-different duration difference of 100 ms. (target vowel was 100 ms. in one member of the pair and 200 ms. in the other member).

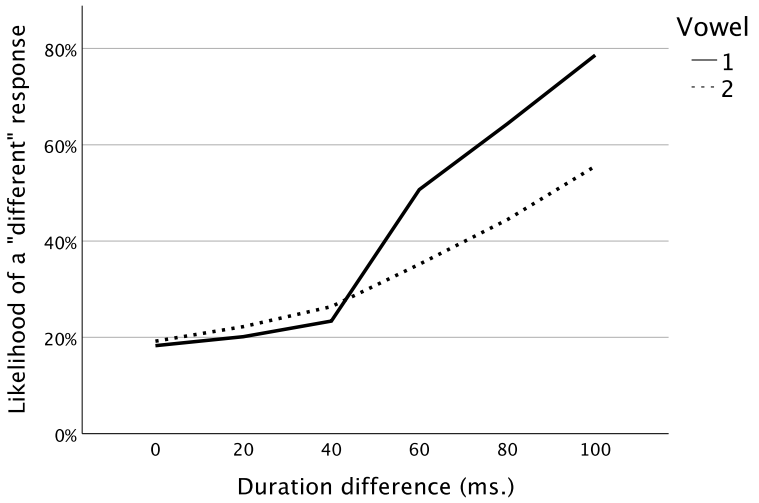

Figure 3. Results from Study 1: AX task with 5 duration levels

A binomial logistic Generalized Linear Mixed Model (GLiM) was run in SPSS for each durational difference, with dependent variable *response* and independent variable *vowel_position.* The responses for the target vowels were found to be statistically significantly different at the three highest duration differences (60, 80, 100) ($p < 0.001$), meaning that differences in final vowels (V2) were detected significantly less often by listeners compared to the same durational difference in non-final vowels (V1).

4.2. STUDY 2: MFC, 3 DURATION PAIRINGS. Twenty-three participants were recruited from the participant pool at William & Mary and received course credit (age range 18-22, average age=19; 14 female, 8 male). None had taken the previous study.

Each of the three highest duration levels (60, 80, 100 ms.) were paired with the shortest duration (100 ms.) creating three different duration pairings. Reversing the order of each pair creates 6 pairs. One such set was created for target-V1 pairings and another for target-V2 pairings, resulting in 12 pairs. This set of 12 was created for each of the two medial consonants [m] and [n], producing 24 pairing types. Each pairing was made eight different times, once with each of the different initial consonants, resulting in 192 total tokens.

Participants were told that they would hear a pair of made-up words in which one member of the pair had a long vowel, and for each they should indicate whether the long vowel was in the first or second word. As examples they were played two pairs that had the maximum duration difference, one in which the difference was due to the duration of the first vowel and one in which it was due to the duration of the second, and were told which member of each pair had "the long vowel." (Example stimuli were the same as were used in Study 1.)

The results are shown in Figure 4, indicating how frequently participants selected the correct location of the longer duration for each of the three duration pairings.

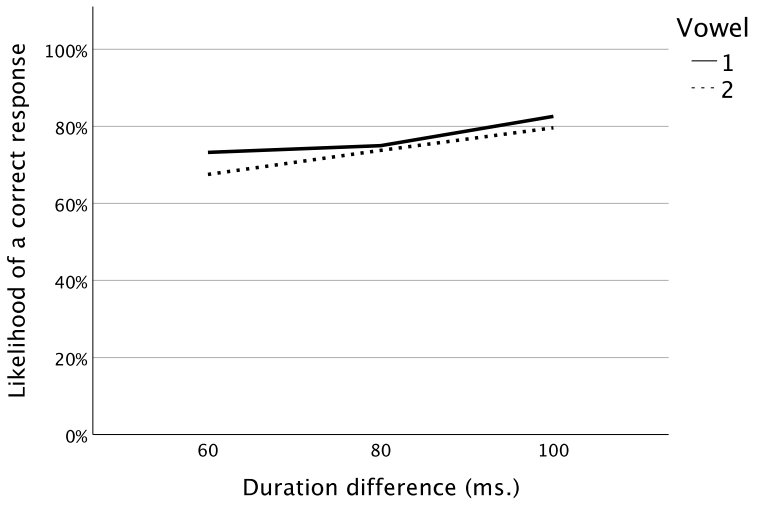

Figure 4. Results from Study 2: MFC task with 3 duration pairings

A binomial logistic Generalized Linear Mixed Model (GLiM) was run in SPSS for each durational difference, with dependent variable *response* and independent variable *vowel_position*. The responses for the target vowels were found to not be statistically significantly different when the duration difference was 80 or 100 ms. ($p \geq 0.124$), meaning that differences in final vowels (V2) were equally likely to be detected by listeners as they were in non-final vowels (V1).

4.3. STUDY 3: AX, 3 DURATION PAIRINGS. Twenty-one participants were recruited from the participant pool at William & Mary and received course credit (age range 18-21, average age=19; 9 female, 12 male). None had taken either of the previous studies.

The stimuli were exactly those used in Study 2, but in this instance participants were given the Study 1 instructions. They were told that they would hear a pair of made-up words which were either pronounced exactly the same or not quite the same and that they should identify which of these two categories each pair they heard fell into. They were played the same example pairs as in the first two studies, and told they were examples of the pair not being pronounced exactly the same.

The results are shown in Figure 5, indicating how frequently participants selected the response that the words were not exactly the same for each of the three duration pairings.

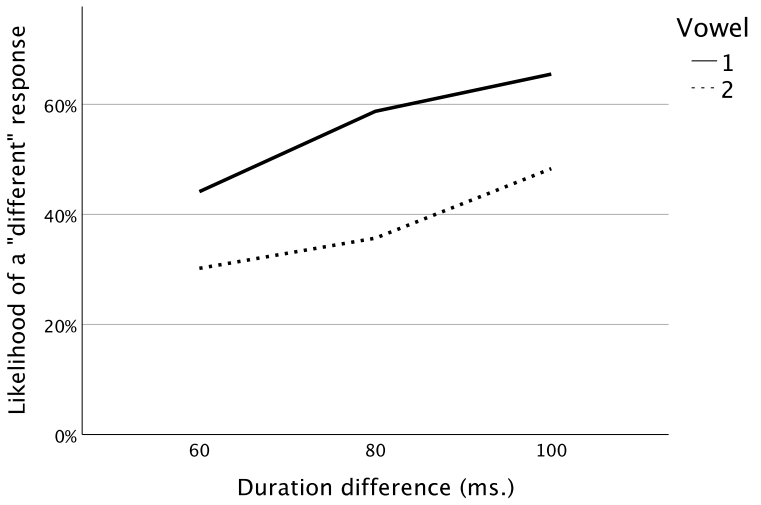

Figure 5. Results from Study 3: AX task with 3 duration pairings

A binomial logistic Generalized Linear Mixed Model (GLiM) was run in SPSS for each durational difference, with dependent variable *response* and independent variable *vowel_position*. The responses for the target vowels were found to be statistically significantly different for all three duration differences ($p < 0.001$), meaning that differences in final vowels (V2) were detected significantly less often by listeners compared to the same durational difference in non-final vowels (V1).

4.4. PERCEPTION STUDIES DISCUSSION. Pairings in Study 1 with different durations in the final position were much more likely to be missed compared to the same differences in the non-final position. Therefore the results show that durational differences are indeed less perceptually salient in the final position than they are in a non-final position. This gives support for the current proposal that the final position is a poor perceptual host of durational differences. Presumably, listeners are used to final lengthening and have learned that duration differences word-finally are not as important as they might be in other positions, and are therefore less sensitive to them.

We see from the results of Study 2, however, that duration differences can be perceived equally well in final position if the listener knows in advance that there is a difference.[2] Study 3 used the same stimuli as Study 2 but rather than asking which word had the long vowel, instead asked the Study 1 question of whether the words in the pair were pronounced exactly the same or not quite. We see from the results of Study 3 that the equalizing effect goes away if listeners do not already know they will be different, again providing support for the proposal that listeners are less sensitive to the presence of duration word-finally.

Our hypothesis predicts that children, on the other hand, should do equally well identifying duration differences in a word-final vowel as in a non-final vowel in a same/different task such as

[2] While not a direct concern to the current work, it is interesting to note that the Study 2 participants knowing ahead of time that there would be vowels with different durations in each pair led them not only to hear the difference in a final vowel equally well as in a non-final vowel, but to both be much more accurate overall (peak of 83% accuracy compared with 65% peak in Study 3) and get a much smaller boost from additional durational differences (maximum increase of 12% correctness, compared with 21% in Study 3 between duration difference 60 and 100 ms.)

Study 1 or Study 3.

5. Conclusion. Previous literature has noted the potentially contradictory nature of the final syllable, which can behave as a strong position or a weak position phonologically. We have proposed that both effects are due to the final lengthening that is found w ord-finally. This additional duration due to final lengthening is a strength for processes that rely on raw duration (duration that can have a phonetic or phonological source), as with, for example, the realization of contour tones (Zhang 2004). Final lengthening, however, also can cause the final syllable to behave as a weak position when it comes to realizing a length-based phonological contrast (as with long vowels) or when the increased duration would lead to a more difficult pronunciation (as with voiced obstruents).

The instance of final syllable strength that does not fit with this generalization is that children tend to treat a final syllable as a strong position (for truncation or place contrasts) as known from prior work with child truncation and as seen in the two new diary studies presented here. The hypothesis put forward is that children have yet to learn that word-final duration is not as important as duration from phonological sources (segment length or duration-marked stressed). They therefore treat duration in the final syllable as being on par with phonologically-meaningful duration.

The perceptual studies with adults found that, when asked to decide whether two pronunciations of a made-up word differed (without explicit information as to the fact that it was the vowel length that might be different or that the difference might be located in either the first or second syllable) adult listeners were statistically significantly less likely to notice the pair was different when the durational difference was in the final vowel, as compared to being in the non-final vowel. This is the expected result if adult listeners, as hypothesized, factor out some amount of durational differences word-finally because of the phonetically-variable and not phonologically-meaningful duration present in the position due to word-level final lengthening.

We have proposed that added duration due to phonetic final lengthening is not on linguistic par with duration from phonological sources. We therefore expect to find it successfully used (and therefore allow the final syllable to act as a strong position) only by phenomena that only need independently-present duration to be realized, while we expect it to be a relatively poor basis for any phenomena that add duration (and therefore cause the final syllable to act as a weak position). The discrepancy seen with the treatment of the final syllable as strong for non-duration-employing phenomenon in children's language can be explained if we assume that children do not at first realize that all increased duration does not signal phonological i mportance. This hypothesis predicts different patterns of final strengths effects between adults and children and leads to the (as yet untested) expectation that children would do equally well on a same/different task of the type in Study 1 or Study 3.

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