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Effects of Rhythmic Stress on Unstressed Syllables

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Effects of Rhythmic Stress on Unstressed Syllables

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by
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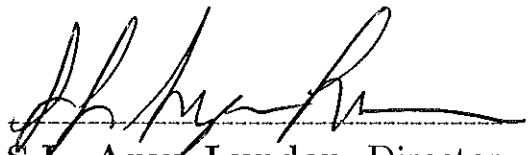

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1. Introduction

1.1. *Background*

Binary stress

Binary patterns of syllable prominence, in which no two consecutive syllables may be both prominent or both non-prominent, are common cross-linguistically. It is common to describe such patterns by pairing adjacent syllables into groups called feet. For example, English syllables group into trochees (i.e. a stressed followed by an unstressed syllable). This creates a binary prominence pattern which relies on the number of syllables in a given word; for example, the first and third syllables in *Mà.ssa.chú.setts* are stressed, while only the second syllable in *a.ró.ma* is stressed. The order in which English assigns stress ensures that the word is not for example *à.ro.má*, even though this would follow a binary pattern.

It is possible for the binary pattern to be interrupted. For example, many English words with five or more syllables (such as *à.bra.ca.dá.bra*) contain internal stress lapses. There is also a common phenomenon in which word-final or phrase final syllables may be both unstressed and following another unstressed syllable if the final syllable is light. For example, while *Mà.ssa.chú.setts* has a binary pattern, *a.spá.ra.gus* has two adjacent unstressed syllables. It it fairly common for English nouns to follow the 'asparagus' pattern and have adjacent unstressed syllables at the right edge of the word. The pattern is not limited to English; languages such as Pintupi also have words with final stress lapses despite having an overall binary pattern, as in e.g. *tʲú.ɻa.ya* 'many' (Hansen & Hansen, 1969).

The driving force behind word-final lapses has been described as extrametricality by e.g. Hayes (1982). Extrametricality occurs when the word-final syllable is ignored when assigning stress, and then the binary pattern is maintained for the remainder of the word. That is, syllables are still paired into feet, but it is as though the right-most syllable did not exist. If we ignore the final syllable of *a.spá.ra.gus*, we see that the remaining syllables are no different from *a.ró.ma* in terms of stress. As extrametricality is described as a phonological process, it would be expected to apply to all words within a category (e.g. nouns). However, 'asparagus' and 'Massachusetts' are both four-syllable English nouns and have differing stress patterns. Various reasons for this apparent inconsistency have been suggested (as e.g. segmental extrametricality by Steriade 1980) which are not relevant here.

Duration

Many stress-related phenomena, such as the location of primary stress, are the result of higher-level phonological processes such as footing structures. However, the way a speaker marks stress on a phonetic level varies widely by language. Languages may use duration, pitch, intensity or a combination of the three to mark stress. English uses duration as its main stress correlate; pitch has been found to unreliably correlate with stress and speakers tend to more reliably pay attention to duration over intensity (Fry, 1955; Lieberman, 1960).

While phonological stress is one of the biggest factors in determining a syllable's duration, syllable duration can also be affected by a number of other phonetic factors. These factors include the syllable's location in a word or phrase, the number of segments it contains, and its vowel quality (Nooteboom, 1999). For example, one would expect an unstressed word-final CV

syllable to be much longer than an unstressed word-medial CV syllable due to a phonetic process known as final lengthening (Wightman et al., 1992).

Proportional increase

Lunden (2010) and Gordon (2002) found that the phonetic factors affecting syllable duration can determine whether a syllable is a candidate for stress. Lunden found that speakers who heard two word-medial syllables where one was x milliseconds longer than the other (see Figure 1a) due to previously mentioned factors such as vowel quality, they would categorize the two syllables differently (i.e. unstressed vs. stressed). However, if the same two syllables were played word-finally, speakers would not necessarily categorize them differently. This is due to an additional phonetic factor in final-syllable duration, final lengthening. If x milliseconds are 60% of a syllable's duration word-medially, they may only be 30% of the same[1] syllable's duration word-finally, as shown in Figure 1b. It appears that it is the relative duration of a syllable, not its absolute duration, which determines whether speakers perceive it as a candidate for stress.

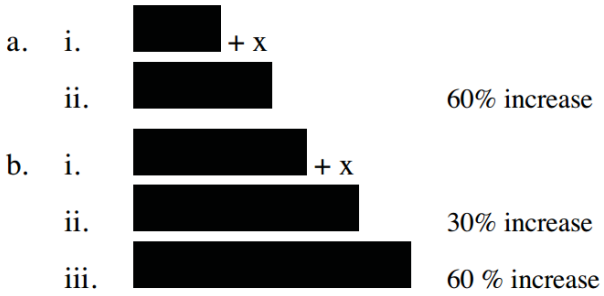


Figure 1: Proportional durations (Lunden, 2010)

1.2. *Research question*

Many word-final syllables are not candidates for stress according to speakers' perceptions of their prominence relative to other syllables in the word. However, those same syllables are sometimes in a position where a binary prominence pattern would suggest that the syllable should be a candidate for prominence. The fact that such syllables are *perceptually* non-prominent does not mean that they are *produced* identically to syllables which a binary prominence pattern would predict to be non-prominent. As noted above, the duration of a syllable is largely determined by whether it is phonologically stressed, and is also influenced by a variety of phonetic factors. The question is whether the binary prominence pattern is one of those phonetic factors.

Hypothesis

Specifically, it seems plausible that words such as 'asparagus' and 'Abracadabra' maintain some sort of binary syllable prominence despite having phonological stress lapses. Such a binary prominence pattern would imply that an unstressed syllable which follows a stressed syllable (i.e. which complies with a binary pattern of prominence) would behave differently from an unstressed syllable which followed another unstressed syllable. That is, it seems possible that the final syllable of 'asparagus' is phonetically strengthened but not stressed, while the final syllable of 'Massachusetts' is neither stressed nor phonetically strengthened. Similarly, a binary

[1]Same in terms of vowel quality, coda consonants, etc

strengthening pattern would imply that the third syllable of 'Abracadabra' would have a greater duration than the second, despite the fact that they are both unstressed. Note that phonetic strengthening seems less likely in the word medial case, as it has the potential to create clashes in the binary pattern (i.e. if the [ka] and [da] in 'Abracadabra' are both prominent, this also interrupts the binary pattern).

Comparisons of syllables from words with binary stress lapses to syllables from words without lapses are needed to test this hypothesis.

Possible confounds

Varying numbers of syllables

Because it would be beneficial to have as wide a variety of token words as possible, and because it can be somewhat difficult to find a large number of words with the required stress patterns, a portion of the words selected will need to be compared to words with a different number of syllables. Because the lengths of individual syllables may shorten when a word contains more syllables (described as polysyllabic shortening by Yang 1998), a method of correcting for the number of syllables in the word was needed. The proposed solution for correcting the length of each token was as follows:

$$\frac{(syllable)}{(word)} \times n \tag{1}$$

For each word in the pair, the target syllable rime's duration is divided by its word's duration. The resulting syllable-word ratio is multiplied by the number of syllables in the word, resulting in a number that represents how close the target syllable was to taking up its expected share of the word. For example, the final syllable of a four-syllable word might be expected to take up approximately 25% of the word (although this exact percentage is unlikely due to stress, final lengthening, etc.).

The validity of this correction was tested along with the binary prominence question.

Feet

As mentioned previously, English syllables group into pairs called feet (specifically trochees), which have a strong (i.e. stressed) member followed by a weak member. Feet are typically said to not form over extrametrical final syllables (Hayes, 1982). For example, an English verb (with no extrametrical syllables) may be footed like (*stú.dy*) while an English noun is more likely to have the final syllable unfooted, as in *a.*(*spá.ra*).*gus*. However, as there still exist English nouns which stress the penultimate syllable, and because English feet form as trochees, it is not unreasonable to suppose that a word such as '(*táćk.le*)' may be footed differently from '(*pí.nna*).*cle*', even though the noun 'tackle' should have an extrametrical final syllable.

If unfooted syllables are realized in the same way as syllables which are the weak members of feet, then any differences in the prominence of a syllable following a stressed syllable and of a syllable following an unstressed syllable can be attributed to binary strengthening effects. However, it is also possible that being the weak member of a foot makes the syllable extra "weak", which may cause an unfooted syllable to seem slightly prominent in comparison. In order to rule out the possibility that any significant results are due to footing and not to a binary strengthening pattern, comparisons were made between syllables from internal lapses in long words with varied footing patterns.

Testing the effects of footing requires finding words with internal stress lapses which can be categorized according to two footing patterns: $(\grave{\sigma}\sigma_1)\sigma_2(\acute{\sigma}\sigma)$ (like e.g. '(Abra)ca(dabra)') and $(\grave{\sigma})\sigma_3\sigma_4(\acute{\sigma}\sigma)$ (as in e.g. '(Ti)conde(roga)'). There are four possible ways in which footing and phonetic strengthening could affect the duration of a target syllable, shown in Table 1.

Post-lapse affects duration	Foot membership affects duration	A : B where A > B	A : B where A ∼ B
no	no	——	$\sigma_2 : \sigma_1$
no	yes	$\sigma_3 : \sigma_1$	$\sigma_4 : \sigma_3$
yes	no	$\sigma_4 : \sigma_3$	$\sigma_3 : \sigma_1$
yes	yes	$\sigma_4 : \sigma_3$	?

Table 1: Possible footing comparisons in medial lapses

σ_2 would be expected to have a greater duration than σ_1 if either footing or binary strengthening were influencing the durations of the syllables. σ_3 would be expected to be more prominent than σ_1 if it were the case that weak members of feet were less prominent than unfooted syllables regardless of proximity to a stressed syllable. The second and third cases in Table 1 show how it would be possible to distinguish a purely foot-based effect from a purely binary-prominence-based effect. However, it would be difficult to distinguish a purely binary effect from a case in which both footing and binary prominence affected a syllable's prominence.

2. **Methods**

2.1. *Subjects*

20 students of the College of William and Mary (11 female, median age of 20) were recruited through the linguistics department listserve, linguistics classes and personal acquaintances. Data was coded for 16 of these subjects (7 female, median age of 20).

2.2. *Experimental design*

Tokens

Rhyming pairs of real English words, in which one word followed a binary stress pattern and the other contained a lapse, were used to test the phonetic strengthening hypothesis. Each word was embedded into a pair of sentences in question and answer format, as in the sample sentence below:

"Q. Did you walk past Oklahoma Avenue by the bank? (2)
No, I walked past Oklahoma Avenue by the train station."

This was done so that subjects would place contrastive emphasis on the answer to the question (e.g. 'the train station') rather than on the target word (e.g. 'Oklahoma'), which did not change between the question and the answer.

Rhyming words were selected so that the vowel quality of the target syllables would match (recall that the length of a vowel can change depending on its quality). For example, the words 'tackle' and 'pinnacle' were paired, and the durations of the final syllabic [l]s were compared. Real English words (as opposed to nonce words) were selected because the desired stress patterns are not the most typical for English, and may not have been successfully elicited with nonce words.

Individual syllable rimes were compared only with their partner syllable from the same subject. The duration of each *post-lapse syllable* (i.e. the syllable which was hypothesised to be strengthened) was divided by the duration of its matching *post-stress syllable*. This *subject-specific ratio* is considered *corrected* if the syllable length correction method was applied to the syllables before the ratio was calculated. The subject-specific ratio is *uncorrected* if only raw durations are compared and *partially corrected* if the rime duration was divided by the word duration but not multiplied by the number of syllables. The *mean post-stress ratio* for each rhyming pair (e.g the mean of all subject-specific ratios where the target syllable was [l]) was then calculated. If a mean post-stress ratio is significantly greater than 1, then it is reasonable to say that the post-lapse syllable is significantly more prominent than the post-stress syllable for that rhyming pair.

The calculations used to obtain the mean post-stress ratio for a specific token pair are outlined below:

$$
\begin{array}{lcl}
\textbf{post-lapse rime} & = & \acute{\sigma}\sigma\boldsymbol{\sigma} \\
 & & \text{target syllable follows an unstressed syllable} \\
\textbf{post-stress rime} & = & \sigma\acute{\sigma}\boldsymbol{\sigma} \\
 & & \text{target syllable follows a stressed syllable} \\
\textbf{uncorrected rime} & = & r \text{ ms} \\
 & & \text{measured duration of the rime of the target syllable} \\
\textbf{word} & = & w \text{ ms} \\
 & & \text{measured duration of the target syllable's word} \\
\textbf{partially corrected rime} & = & \frac{r}{w} = p \\
 & & \textbf{uncorrected rime/ word} \\
\textbf{corrected rime} & = & p \times n = c \\
 & & (\textbf{partially corrected rime}) \times (\text{num. of syllables in word}) \\
\textbf{subject-specific ratio} & = & \frac{r_1}{r_2} = s \text{ OR } \frac{p_1}{p_2} = s \text{ OR } \frac{c_1}{c_2} = s \\
 & & \textbf{post-lapse rime / post-stress rime} \\
\textbf{mean post-stress ratio} & = & E(s) \\
 & & \text{avg}(\textbf{subject-specific ratio})
\end{array}
\tag{3}
$$

Word sets

There were four sets of token words used to test the phonetic strengthening hypothesis. All of the words were read by subjects, although some were omitted from the data during coding. A full list (including details about the reasons for selecting or omitting individual words) is given at the end of this section.

Testing the length correction

Set 1 contained two pairs of words ('aroma' and 'llama', and 'beluga' and 'toga'). As these words have varied numbers of syllables but share penultimate stress, comparing their final syllables using the syllable length correction was used to rule out the possibility that significant

differences in syllable duration in the other word sets are due to variations in the number of syllables in the target word rather than to syllable stress patterns, as well as to test the validity of the syllable length correction.

Word-final syllables

Set 2 contains pairs words of matching lengths and either penultimate or antepenultimate syllable stress. In the event that the syllable length correction did not work, words pairs from Set 2 can still be compared with one another.

Because of the difficulty in finding rhyming, same-length words with the required stress patterns, another set of words with final-syllable rhyming but varying numbers of syllables was used. Set 3 relies on the validity of the syllable length correction, and is therefore not included in the results as the syllable length correction proved unreliable.

Word-medial syllables

Set 4 contains four-, five-, and six-syllable words and relies on the syllable length correction. Set 4 has two purposes: first, words with internal stress lapses (such as '*Kì.li.man.já.ro*)' were used to test the lengthening effect word-medially by treating syllables which came after the secondary stress as the post-stress syllables. For example, in 'Kilimanjaro' [lɪ] would be the post-stress syllable and [mæn] would be the post-lapse syllable. Words were selected so that they "rhymed" word-medially; e.g. 'Kili**man**jaro' and 'in**can**tation' were compared.

The second purpose of Set 4 was to test whether significant results could be due to footing. Words were chosen so that all possible combinations of post-stress/ post-lapse and footed/unfooted were present in the data. The ideal token words for Set 4 were five-syllable words with the stress pattern of '*Kì.li.man.já.ro*'. These words were divided into two footing patterns as described in Table 1 on page 4.

To put the footing effect hypothesis on page 4 into the terms outlined above in (3), a subject-specific ratio in which an unfooted post-stress syllable was compared to a footed post-stress syllable would have an expected value significantly greater than 1 if and only if footing were a factor in unstressed syllable duration. Otherwise, such a subject-specific ratio would have an expected value of 1.

Unfortunately, due to problems in coding and measuring the majority of the Set 4 tokens, most of the word-medial comparisons were not made.

2.3. *Experimental methodology*

Experiments were run with the experimenter present in a sound-attenuated booth with a unidirectional Tascam microphone. Subjects first signed consent forms and gave their demographic information (age and gender), which was recorded on the experimenter's copy of that subject's reading list. The subject received their own copy of the reading list and heard the task explanation (see (4), below). Recording began and the subjects were asked to begin reading out loud at question number one. While the participants were reading, the experimenter kept notes of fumbled sentences, incorrect pronunciations and sentences which the subject spontaneously read multiple times. The last line of the sentence list asks the subjects about difficult or unfamiliar words; these words were also written down. Finally, subjects were asked to repeat fumbled sentences and then recording stopped.

Because the experimenter was in the room, there were several times when a subject talked to them, stopped mid-sentence and asked to restart a sentence, asked if they had pronounced a word correctly, etc. Subjects were told to repeat sentences when they asked to do so. Otherwise, a fumbled or mispronounced word was noted and the subject repeated the entire question-response sequence after completing the rest of the reading.

Task explanation

> "Your job is to read this list of sentences. Please read both the question and the reply, like in this example: 'Did you walk past the magician on your way to lunch? No, I walked past the magician on my way to breakfast.' This will get a little repetitive and tedious, but try to read them all at the same speed and as naturally as possible. Any questions?" (4)
>
> *Begin recording* "Begin reading at number one whenever you are ready".

2.4. *Coding and Measurement*

Measurements of the target syllable included the entire rime and nothing else. However, if a word ended in a stop consonant, it was not measured as it was usually unclear where the consonant ended. If there was a clear change in the voicing bar or other sharp break in the spectrogram, that point was used as the beginning of the rime. It was often quite difficult to separate the vowel from a preceding nasal or voiced consonant; in these cases, changes in the waveform and in the sound of the target syllable were considered, as shown in Figure 2.

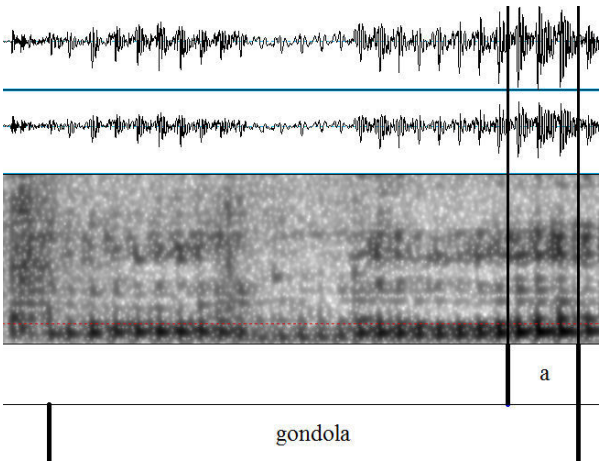


Figure 2: Using waveform and spectrogram changes to determine a syllable boundary

If no change could be seen in the waveform, then the beginning of the rime was marked as the rightmost point at which no vowel sounds can be heard in the preceding consonant. Formant transitions were not used as they were not often useful in already ambiguous cases. In cases where e.g. one vowel transitioned into another (Figure 3), the measurements were considered too unreliable to be included in the results.

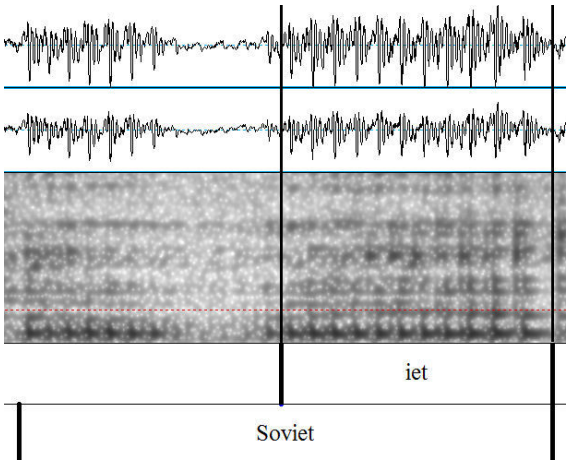


Figure 3: Uncodable word containing consecutive vowels

For each viable measured syllable, the duration of the embedding word was also measured (to be used with the length correction). Each target word was preceded by the word 'past'. Because in many cases the final [s] or [t] in 'past' was indistinguishable from the initial [s] or stop consonant in the token word, the beginning of each word was measured from the beginning of the first vowel.

The end of each target word was measured conservatively, so that no devoiced vowels were measured and care was taken to make sure that none of the following word was measured.

After coding, word and syllable durations were measured using Daniel Hirst's 2009 tier analysis Praat script (Boersma, 1982). The ratio of each syllable's duration to its rhyming partner's duration was then calculated.

Table 2 (on the next page) describes all of the words selected to be read by subjects. Primary- and secondary-stressed syllables are indicated in bold. Segments which were included in coding (i.e. syllable rimes excluding final stop consonants) are also in bold. 'N = n' indicates the number of subjects (out of 16) who pronounced that word or word pair satisfactorily. 'N = —' indicates tokens which were discarded before coding, due to either poor rates of correct pronunciation (e.g. 'Winnipesaukee' was discounted because so few subjects pronounced it as desired) or due to being uncodable (as seen in Figure 3). If a single word was unusable (either within a subject or overall) then its rhyming partner was also discarded. Word pairs which were discarded for all subjects (indicated in grey) will not be considered further. Note that many of the words appear twice in the list. For all duplicates in Set 4, two of the word's syllables were measured; 'aroma' appears in Set 1 and Set 2 with different partners.

Table 2: Full list of words selected for experiment

Set	Word	IPA	Target Syllable	Is target in a foot?	N=	Reason for Deletion
1	toga	**to**.gə	gə	—	15	
	beluga	bə.**lu**.gə	gə	—		
	llama	**la**.mə	mə	—	15	
	aroma	ə.**ɹo**.mə	mə	—		
2	excitement	ɛk.**sait**.mɛnt	m**ɛn**t	—	16	N/A
	element	**ɛ**.lɨ.mɛnt	m**ɛn**t	—		
	assassin	ə.**sæ**.sɪn	s**ɪn**	—	14	
	moccasin	**mɔ**.kə.sɪn	s**ɪn**	—		
	umbrella	um.**bɹɛ**.lə	lə	—	13	
	gondola	**gɔn**.də.lə	lə	—		
	aroma	ə.**ɹo**.mə	mə	—	16	
	cinema	**sɪ**.nɪ.mə	mə	—		
3	tackle	**tæ**.kl̩	kl̩	—	13	Set 3 was not used because it relied on the syllable length correction.
	pinnacle	**pɪ**.næ.kl̩	kl̩	—		
	Molly	**mɔ**.li	l**i**	—	11	
	Emily	**ɛ**.mɪ.li	l**i**	—		
	asset	**æ**.sɛt	s**ɛ**t	—	—	
	Soviet	**so**.vi.ɛt	**ɛ**t	—		
4	Oklahoma	**o**.klə.**ho**.mə	klə	No	13	In Set 4, 3 target vowels were devoiced and indistinguishable from the preceding consonant; 4 were V syllables following or preceding V syllables; 4 were indistinguishable from a nearby liquid.
	ukulele	**ju**.kə.**le**.li	kə	No	14	
	Massachusetts	**mæ**.sə.**tʃu**.sɛts	s**ə**	Yes	15	
	Abracadabra	**æ**.bɹə.kə.**dæ**.bɹə	b**ɹə**	Yes	13	
	Abracadabra	**æ**.bɹə.kə.**dæ**.bɹə	kə	No	13	
	Machiavelli	**mɔ**.ki.ə.**vɛ**.li	**ə**	No	15	
	incantation	**ɪn**.kæn.**te**.ʃn̩	k**æn**	No	15	
	Kilimanjaro	**kɪ**.li.mæn.**dʒa**.ɹo	m**æn**	No	15	
	Indianapolis	**ɪn**.di.æn.**æ**.po.lɪs	**æn**	No	—	
	Indianapolis	**ɪn**.di.æn.**æ**.po.lɪs	d**i**	No	—	
	Machiavelli	**mɔ**.ki.ə.**vɛ**.li	k**i**	No	15	
	Kilimanjaro	**kɪ**.li.mæn.**dʒa**.ɹo	l**ɨ**	Yes	15	
	Winnipesaukee	**wɪ**.nɨ.pɨ.**sɔ**.ki	n**ɨ**	Yes	11	
	Mediterranean	**mɛ**.di.tɨ.**ɹe**.ni.n̩	d**i**	Yes	—	
	Mediterranean	**mɛ**.di.tɨ.**ɹe**.ni.n̩	t**ɨ**	No	—	
	Winnipesaukee	**wɪ**.nɨ.pɨ.**sɔ**.ki	p**ɨ**	No	11	
	Ticonderoga	**taɪ**.kɔn.dɨ.**ɹɔ**.ga	d**ɨ**	No	—	

3. Results

3.1. *Validity of the length correction*

The results of the syllable length correction test are inconclusive. As hypothesised, there seems to be little difference between the uncorrected post-stress means[2] and the corrected post-stress means, as seen in Figure 4.

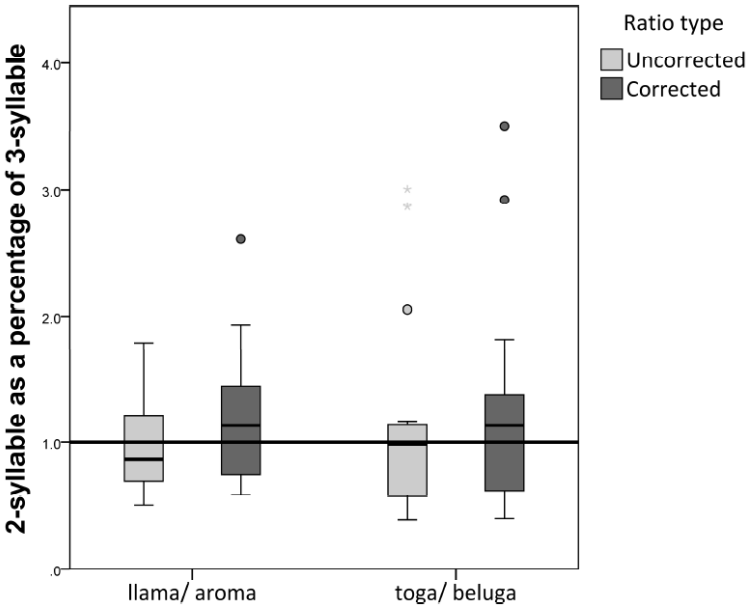
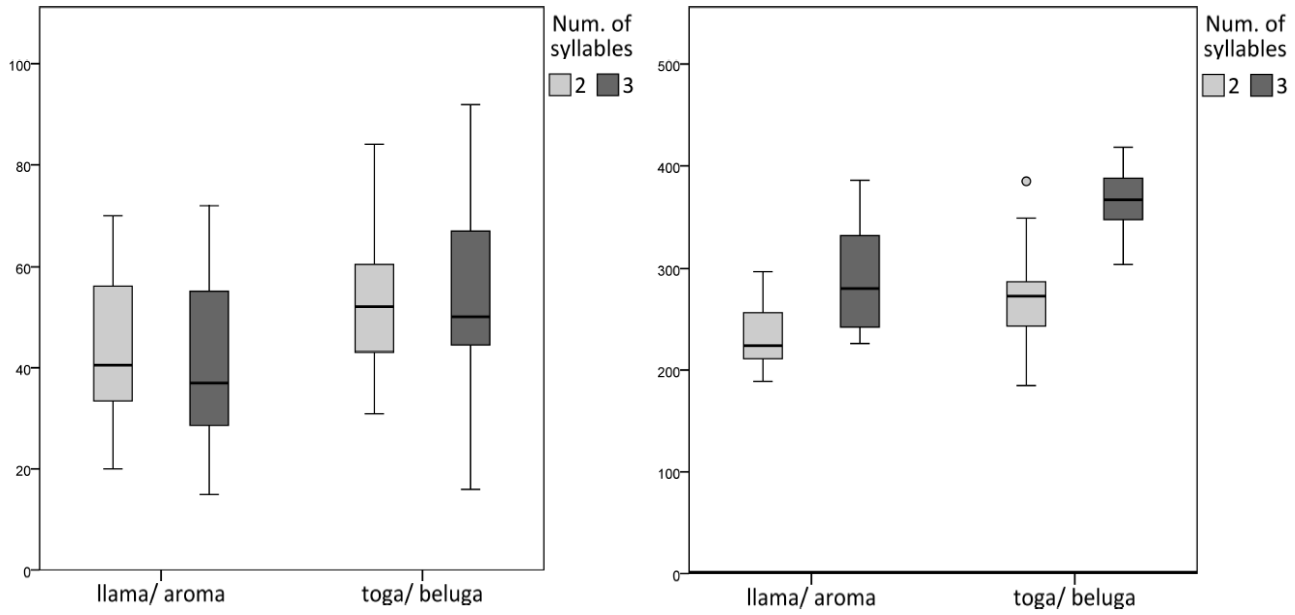


Figure 4: Post-stress ratios for Set 1

All of the means shown in Figure 4 appear very close to one. Recall that because the post-stress mean is a mean of ratios, a value close to one indicates that there is no difference between the two durations (e.g. between the final schwas in 'llama' and 'aroma') being compared. If the post-stress mean were significantly greater than one, that would indicate that one syllable was significantly longer than the other. T-testing both the uncorrected and the corrected post-stress means confirms that neither is significantly different from one ($p < .336$ for the uncorrected means and $p < .093$ for the corrected means).

However, the results of the syllable length correction test may be less reliable than they seem. The intended purpose of the syllable length correction was to account for syllables which are similar in vowel quality, distance from stressed syllables and word edges, etc., but which come from words with different numbers of syllables. It was expected that syllables from longer words would have less duration due to polysyllabic shortening (Yang, 1998); however, all of the syllables measured tended to have around the same duration (Figure 5a) and the word durations measured varied widely (Figure 5b).

[2]Although this is the same terminology used when comparing post-lapse syllables to post-stress syllables, in this case the subject-specific means were calculated by comparing two post-stress syllables.



(a) Syllable duration (ms)

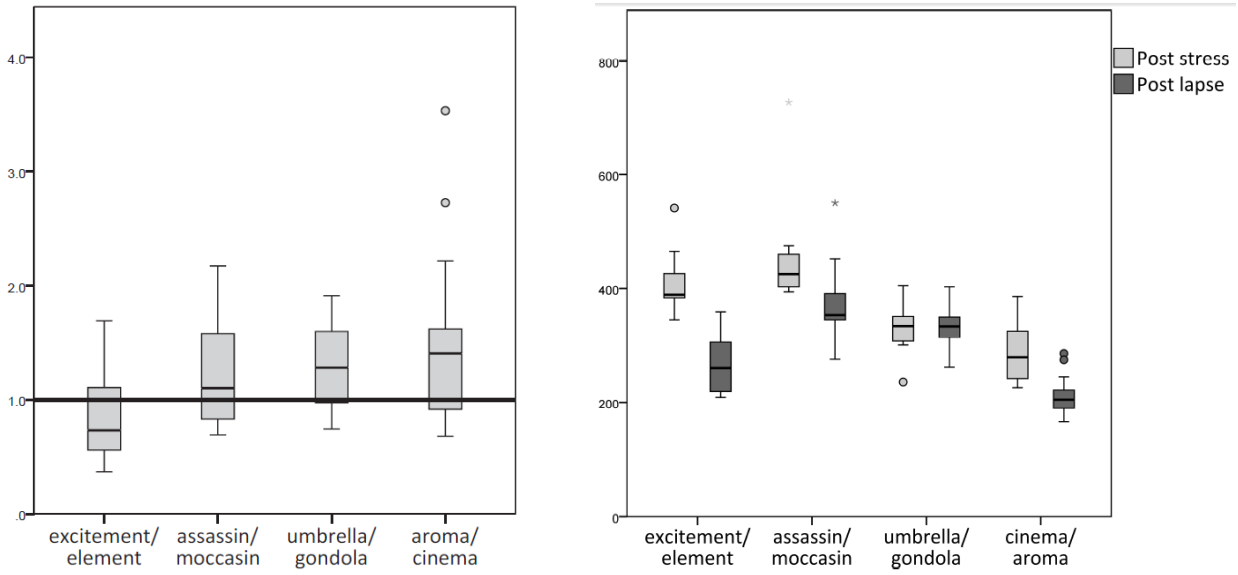
(b) Word duration (ms)

Figure 5: Raw durations for Set 1

Due to this unexpected discrepancy between the type of duration differences the length correction was intended to fix and the actual durations found in the data, the syllable length correction will not be used for the remainder of the discussion. There is no concrete evidence that the correction is completely invalid; however, determining why the test cases did not show polysyllabic shortening as expected, and whether this is enough to render the length correction useless, is outside the scope of this experiment.

3.2. *Word-final strengthening*

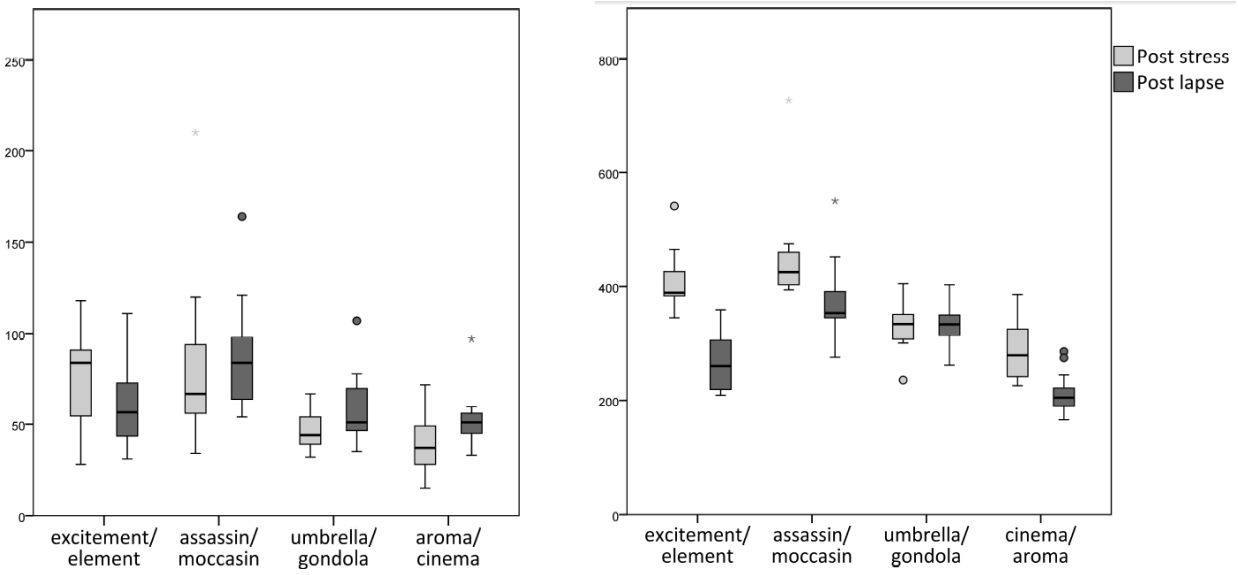
The mean lapse-stress ratio for the word-final strengthening tokens (Figure 6a) is 121.6%, which is significantly greater than one ($p < .007$). Note that the 'excitement'/'element' post-stress mean, unlike the rest of the post-stress means, is not significantly different from one ($p < .128$). This is most likely due to the extreme differences between the raw word durations of 'excitement' and 'element', as seen in Figure 6b.



(a) Uncorrected post-stress means (b) Raw word durations (ms)

Figure 6: Word-final strengthening in Set 2

However, it does not seem likely that the significant means of the other three pairs are because of differences in word duration. The 'umbrella'/'gondola' pair, whose raw word durations are nearly identical, has a post-stress mean greater than one. Additionally, the post-lapse (dark grey) tokens of both the 'aroma'/'cinema' and the 'assassin'/'moccasin' pairs each have a shorter average word duration while also having a longer average uncorrected syllable duration (Figure 7a). That is, the post-lapse syllable not only has more duration in 3 out of the 4 pairs, it does so in spite of the shorter duration of its word.



(a) Raw syllable durations (ms) (b) Raw word durations (ms)

Figure 7: Raw durations for Set 2

3.3. *Word-medial strengthening*

Taken together, the mean post-stress ratios were not significantly greater than one ($p < .11$) for the two word-medial comparisons. However, the two word pairs used did not behave at all similarly, as shown in Figure 8.

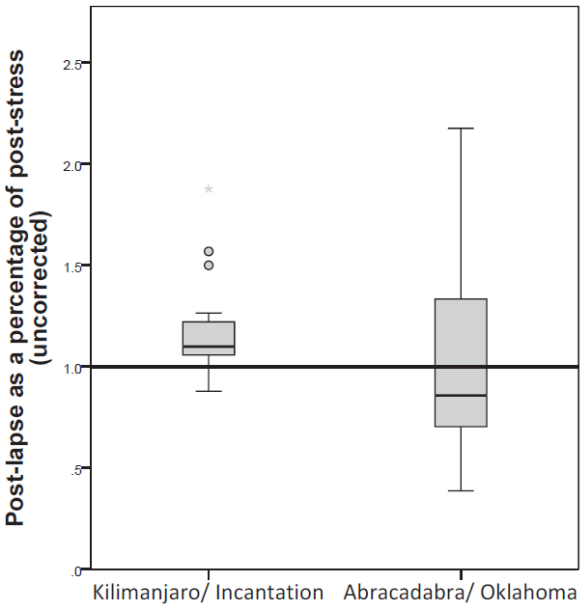
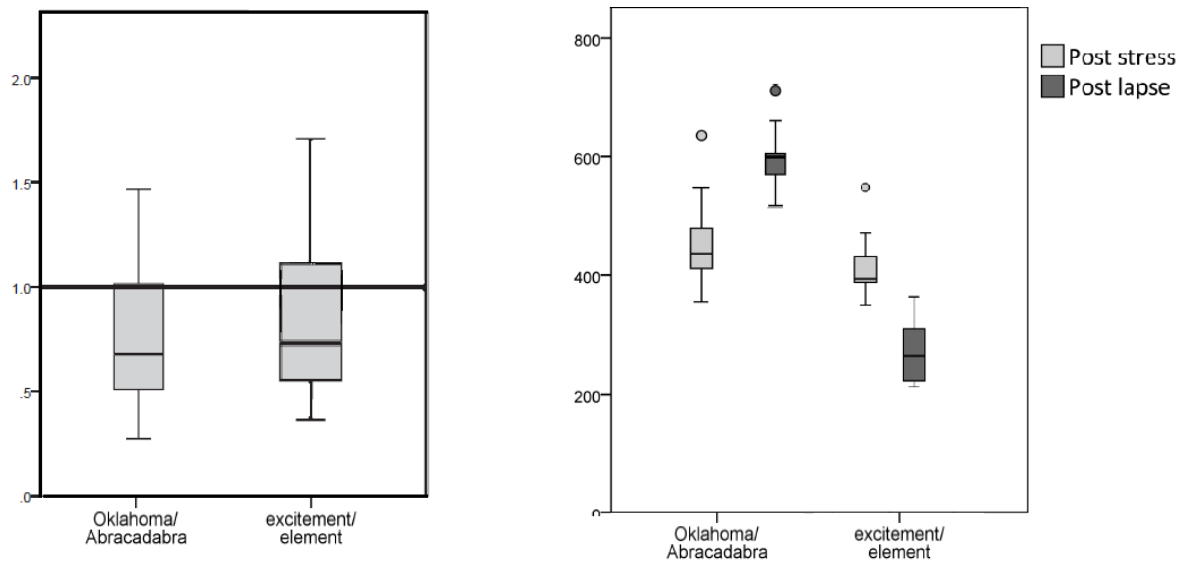


Figure 8: Post-stress means for Set 4

The 'Kilimanjaro'/ 'incantation' pair behaved more like the word-final pairs in that the uncorrected post-stress mean was significantly greater than 1 ($p < .015$). The uncorrected post-stress mean for the 'Abracadabra'/ 'Oklahoma' pair, on the other hand, was not significantly different from 1 ($p < .9$).

A casual observation of the 'Abracadabra'/ 'Oklahoma' post-stress mean in Figure 9a might suggest that it is very similar to the 'excitement'/ 'element' pair . However, recall that the non-significant results for the 'excitement'/ 'element' pair were most likely due to an extreme difference in word durations rather than to the fact that 'element' does not exhibit a strengthened final syllable (see Figure 9b). As the 'Abracadabra'/ 'Oklahoma' pair does not have such a discrepancy, it seems plausible that there is in fact no binary-prominence-based strengthening in the third syllable of 'Abracadabra'. Note that there does appear to be a fairly large difference between the durations of 'Oklahoma' and 'Abracadabra'; however, the difference is in a direction which should raise the duration of the post-lapse syllable (compared to the word durations in the word-final data, which showed the opposite tendency). Why the 'Abracadabra'/ 'Oklahoma' pair should behave this way, while the 'Kilimanjaro'/ 'incantation' pair appears to show evidence of binary-based strengthening, is unclear.



(a) Uncorrected post-stress ratios (b) Raw word durations (ms)

Figure 9: Contrasting 'Abracadabra'/ 'Oklahoma' and 'excitement'/'element'

4. **Discussion**

The data make a strong case for the existence of a strengthening effect in word-final stress lapses in English nouns (see Figures 6 and 7 on page 12). It is reasonable to suppose that strengthening occurs to maintain a binary rhythm in words whose binary stress pattern has been interrupted on a phonological level. However, it is difficult to say with certainty that an overall binary prominence pattern is maintained given that word-medial data were inconclusive.

Word-final strengthening

Most of the word-final post-stress means (with the exception of the 'excitement'/ 'element' pair) tended to be near 120%. Recall the percentages of increase given in Figure 1 on page 2, and repeated below:

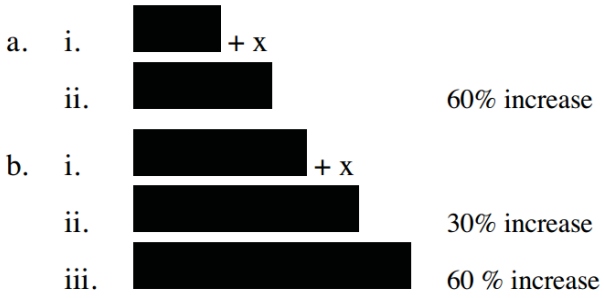


Figure 10: Proportional durations (Lunden, 2010)

120% (i.e. a 20% increase) is not a large increase; it is presumably not enough to make a syllable stressed (as all the syllables measured in this experiment are unstressed). Such an increase is also too slight to make a word eligible for stress; as b(ii) shows in the graph above, a syllable which shows a 30% increase is not eligible for stress. However, due to final lengthening, increasing a syllable by an amount which causes a 30% increase word-finally may cause a larger increase word-medially (Lunden, 2010). As discussed on page 2, this often means that a syllable may be eligible for stress word-medially but not word-finally. Further study would be needed to determine whether the amount of raw increase shown by the final syllables in this experiment is enough to make a syllable eligible for stress word-medially; however, it is fairly clear from the data that some amount of increase which is not large enough to make a syllable eligible for stress occurs in unstressed post-lapse syllables.

It seems possible that alternating syllables increase by the same *raw* amount (i.e. not the same amount proportional to overall size) in a binary pattern. This interpretation of the data follows this experiment's word-final strengthening hypothesis very closely; as predicted, there is evidence of strengthening on a phonetic level which is not perceived by speakers. The syllables which are strengthened appear at the end of a pattern of prominent and non-prominent syllables, and increase by a raw duration which would be much larger relative to the size of the syllable word-medially. This seems to indicate that some kind of motor process which influences syllable durations, perhaps by adding to the raw of duration of each alternating syllable, and which does not care about other factors such as final lengthening, might be at play.

Another possible explanation for the existence of binary syllable prominence (which is not necessarily in conflict with the ideas outlined above) is perceptual saliency, i.e. it helps listeners to determine syllable boundaries. A perceptual study comparing syllables with no durational differences to those with some measure of binary durational differences could give some insight into whether this is true. Another possible explanation is that the phenomenon is more closely tied to production than perception; it is possible that speakers continue a pattern of higher and lower duration on a motor level once it has been suggested by the phonology.

Word-medial syllables

The word-medial data are inconclusive, due to the small sample size and the inconsistent behavior of the two word pairs. By using more word-pairs or by using word-internal comparisons (e.g. by comparing the two schwas in 'Abracadabra') it would be possible to fix the sample size problem. With a larger number of word pairs it would be possible to determine whether the 'Abracadabra'/'Oklahoma' case (i.e. with no strengthening) or the 'Kilimanjaro'/'Incantation' case (with apparent strengthening) is more typical for words with internal stress lapse.

As noted in section 3.3., the non-significant post-stress ratio of the 'Abracadabra'/'Oklahoma' pair does not seem to be due to badly matched word durations (as in the 'excitement'/ 'element' pair). By casual observation it seems as though 'Abracadabra' pair does not exhibit binary strengthening at all, while 'Kilimanjaro' does.

One simple reason for the difference between the two word-medial comparisons may be due to their differing vowel qualities. The measured schwas in 'Abracadabra' were very short (Figure 11), whereas the segments measured in the 'Kilimanjaro'/'Incantation' each contained a full vowel and a coda consonant.

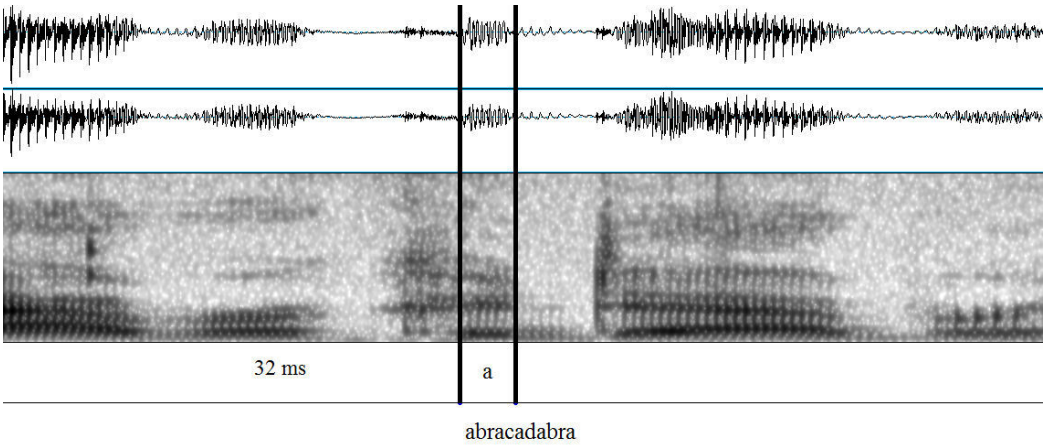


Figure 11: Short schwa duration in 'Abracadabra'

To give some context to the syllable duration given in Figure 11, the majority of syllable rimes measured had durations in between 40ms and 60ms.

It may be that the different behaviors of the two word-medial post-stress means is due to more than differences in vowel quality, and that a more complete study of word-internal lapses would reveal that some words tend to pattern like 'Abracadabra'/'Oklahoma' and others like 'Kilimanjaro'/'Incantation'. That is, it may be that neither word pair is an anomaly, but instead representative of two classes of words; one which shows binary strengthening and one which does not. This does not seem likely in light of the original premise behind the binary strengthening pattern (i.e. that it applies on a phonetic level to all stress lapses).

However, it is also possible that the premise that the second syllable of an internal lapse is a candidate to be phonetically strengthened not valid. There a number of reasons to expect strengthening word-finally which do not apply word-medially. For example, the divide between perceived and produced prominence word-finally (as discussed above) seems to stem from final lengthening and would not apply word-medially. It is also not the case that strengthening creates or maintains an overall binary pattern in word-medial lapse; in fact, strengthening a syllable such as the [mæn] in '*Kì.li.man.já.ro*' would create a clash with the primary-stressed syllable. In the case of 'Kilimanjaro', there is evidence that strengthening does in fact occur in this position. However, it is as reasonable to suppose that syllables may be strengthened based on distance from the primary stress as it is to suppose a left-to-right binary pattern word-medially. That is, rather than the [mæn] syllable being strengthened due to coming to the right of a lapse, the [lɪ] syllable would be strengthened due to its distance from [dʒa].

Binary strengthening and phonological stress

The fact that so many of the commonly studied aspects of stress systems appear to have chiefly phonetic motivations (discussed by e.g. Broselow et al. 1997 and Gordon 2002) raises the question of whether there are any parts of a stress system which are entirely phonological. This must be the case; an English word consisting of four light syllables will not necessarily have the same prominence pattern as a word consisting of four light syllables in another language, due to the fact that their foot types, their ways of determining which stress is primary, and so on may be different. These aspects of stress systems are arbitrary, non-gradient (i.e. a syllable is

either stressed or unstressed), and language-specific, and therefore it seems very likely that they are purely phonological. On the other hand, a syllable's prominence (i.e. a syllable's duration relative to other syllables in its environment, in terms of ratios or otherwise) is a gradient, quantifiable aspect of a stress system. While it true that the gradient aspects of stress may affect the less gradient aspects (such as when relative durations and final lengthening combine to make a syllable ineligible for phonological stress), it is also true that the more phonological features of a stress system can drive the lower-level phonetic processes (for example, the way a language phonological primary stress determines where in a word lapses may occur). It seems that, like many other phonetic processes, binary strengthening both affects and is affected by the phonology of a language.

The various factors which can affect a syllable's duration[3] have been crucial to the motivation, design and analysis this experiment. The findings presented here indicate that proximity to a phonologically stressed syllable can now be added to the list of factors which may determine a word-final unstressed syllable's duration.

[3]Nooteboom's list is given on page 1.

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