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A phonetic study of Sinhala syllable rhymes

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The shortening of lexically long vowels in closed syllables has been claimed to be a phonetic universal. This study therefore explores the phonetic duration of vowels and consonants of Sinhala in various syllable rhymes. Three primary questions are addressed: 1) Do lexically long vowels shorten in closed syllables? 2) Do consonants following long vowels shorten? and 3) Is there any phonetic evidence for trimoraic shortening? Two native Sinhala speakers read prepared word lists, providing a total of approximately 940 tokens, each of which was digitized and segmented using both a spectrogram and wave form. The results indicate that in Sinhala, lexically long vowels do not shorten significantly in closed syllables, although following consonants do shorten significantly after lexically long vowels. Implications of these results are discussed, as well as how the durational results pertain to the phonological issue of trimoraic shortening.

The following paper is the result of a preliminary acoustic phonetic study of Sinhala syllables which focuses primarily on what has traditionally been called the "syllable rhyme" in the phonological literature. It seeks to begin to establish timing relationships between various sub-parts of the rhyme in Sinhala. Section 1 presents a brief review of previous phonetic studies which have explored these same types of timing relationships in other languages. Section 2 gives a brief description of possible Sinhala syllables, setting them within the phonological context of Moraic Theory and discussing some possible phonetic implications of their representation. Section 3 explains the methodology of the experiment and Section 4 presents the results. Section 5 concludes with a discussion of the implications of the results for the relationship between phonological and phonetic representations of timing.

1. Review of phonetic literature

A number of researchers have explored the timing relationships between the sub-parts of the syllable rhyme in diverse languages. Maddieson (1985) surveyed a variety of studies done on various languages regarding the duration of vowels before consonants, and concluded that "vowel shortening in closed syllables is a relatively common phenomenon across languages", which may even be a phonetic universal. He noted that many languages have phonologized the effect, such as Arabic (Al-Ani 1970), Hausa (Abraham 1959), Hindi (Ohala 1972), Estonian (Lehiste 1966), and Ulithian (Sohn and Bender 1973), while in many others, phonetic vowel shortening is known to occur. Some of the languages he cites as undergoing phonetic vowel shortening are Tamil, Telugu, Italian, Icelandic, Norwegian, Finnish, Hungarian, Shilha (Berber), Dogri, Rembarrnga (Australian), and Sinhala[1].

Another study, that of Munhall, Fowler, Hawkins and Saltzman (1992), describes the fact that the general contexts for vowel shortening include: vowels in closed syllables (citing Maddieson's 1985 review); vowels before voiceless consonants (citing Chen 1970); and vowels before bilabials, as opposed to alveolars or velars (citing Lehiste's 1970 review). They note also that longer vowels tend to be followed by shorter consonants, citing Scripture 1902[2], and that increases in the duration of the following coda are associated with decreases in vowel duration (Bell 1849; Lehiste 1970; Lindblom, Lyberg and Holmgren 1981). In Munhall et al.'s (1992) experiment using English monosyllables which contrasted in having either final single or cluster codas, all (three) subjects shortened vowels when the duration of the coda increased, and two of the three subjects shortened the coda after longer vowels. One common interpretation of these experimental results is that they reflect a tendency to compress the vowel duration to a more regular duration for the syllable as a whole.

2. Sinhala syllables

Sinhala is an Indo-Aryan language spoken by approximately 75% of the inhabitants of Sri Lanka (about 12 million people). Among other features, the language has six underlying vowel qualities[3], each of which exhibits contrastive length, as represented below in the table in (1):

(1) Sinhala Vowels

	FRONT	BACK
HIGH	[i]/[ii]	[u]/[uu]
MID	[e]/[ee]	[o]/[oo]
LOW	[æ]/[ææ]	[a]/[aa]

[1] This observation is based on Maddieson's analysis of a few tokens of Sinhala in the UCLA database. Since the UCLA database of Sinhala words is quite limited, this study will extend his initial observations by systematically examining Sinhala vowels in a variety of contexts based on recordings of several native speakers.

[2] However, Jongman and Sereno (1991) did not find any difference in consonant duration following long vowels as compared to consonants following short vowels in Dutch. They did find differences in total word duration in disyllabic words whose initial syllables varied in whether or not they contained long or short vowels. Interestingly, they found that the durational differences were, however, not only reflecting the differences in the lengths of long and short respective vowels, but that in addition, onset consonants and following syllable durations contributed to the differences.

[3] There is some debate in the literature as to the underlying status of schwa [ə]; for the present paper, it is assumed that schwa is derived from underlying [a].

The consonant inventory of the language includes several series at five places of articulation: labial, dental, retroflex, palatal, and velar. All of the obstruents also demonstrate contrastive length, as do most of the sonorant consonants[4]. The underlying consonant qualities distinctive in Sinhala appear in (2) (adopted from Gair 1988):

(2) Sinhala Consonants:

	LABIAL	DENTAL	RETRO.	PALATAL	VELAR
STOPS					
VOICELESS	p	t	T	c	k
VOICED	b	d	D	j	g
NASALS	m	n			(ŋ)
PRENASALIZED STOPS	^{m}b	^{n}d	^{N}D		^{ŋ}g
SPIRANTS	(f)	s		ß	
RESONANTS/ GLIDES	w	r l		y	h

One way of representing the difference in contrastive length in vowels and consonants is through the use of the mora, a unit of phonological weight (Hyman 1985; McCarthy and Prince 1986; Hayes 1989). The representations in (3) below demonstrate one way of representing these contrasts within Moraic Theory:

(3) Moraic Representation of Long and Short Segments:

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 μ       μ μ      μ
 |        V       |
a) V     b) V    c) C     d) C
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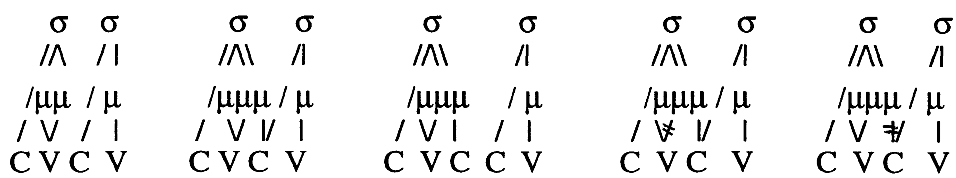
In Hayes' (1989) version of Moraic Theory, underlyingly a short vowel contrasts with a long vowel in bearing one versus two moras, as in (3a) versus (b), and geminate consonants contrast with single consonants in that they underlyingly bear a single mora, whereas singleton consonants do not, as in (3c) versus (d) (see Hayes 1989 for a discussion of this asymmetry). In addition, consonants which appear in the syllable coda are assigned a mora by a rule of "Weight by Position" in languages where closed syllables behave phonologically heavy - as is the case in Sinhala (see Letterman 1992 for discussion).

[4] Exceptions to this include [r], [h], and [h].

Sinhala syllables allow an optional single onset and/or coda consonant to be present along with either a long or short vowel nucleus. Unlike many languages, Sinhala allows long vowels to be followed by geminate consonants. Given the above moraic representation of the long versus short contrasts between segments, the following are some possible representations of Sinhala syllables containing long vowels (VV= long vowel):

(4) Possible Syllables in Sinhala Containing Long Vowels



a) CVVCV b) $CVVC_1C_1V$ c) $CVVC_1C_2V$ d) $CVVC_1C_1V$ e) $CVVC_1C_1V$

In (4a), a long vowel appears in an open syllable; thus, the syllable containing the long vowel may be said to be "bimoraic" since it contains only two moras. In (4b), a long vowel appears in a syllable closed by a geminate consonant. Since the geminate consonant itself bears a mora, the syllable containing the long vowel followed by the geminate consonant may be said to be "trimoraic" since it contains three moras. In (4c), a long vowel is followed by a non-geminate coda consonant. Since this consonant is assigned a mora by the rule of Weight-by-Position, it too bears a mora and thus makes the syllable containing the long vowel trimoraic. There continues to be discussion among phonologists espousing the Moraic Theory as to the status of trimoraic syllables, given the widespread idea that the phonological system can "only count to two" (McCarthy and Prince 1986) and the fact that many languages disallow trimoraic syllables in the phonology. Aside from the fact that the assumed representation of long vowels and geminates generates these trimoraic syllables in Sinhala, phonological justification for them is still unclear. Although no stress facts are known to differentiate heavy and "superheavy" (trimoraic) syllables from each other, and no other phonological processes/rules are known to make reference to them, De Silva (1959) does argue for superheavy syllables on the basis of prosodic scansion of Sinhala verse. The question remains as to whether or not these apparently trimoraic syllables in Sinhala undergo any phonetic shortening, based on the claimed tendency that languages disallow trimoraic syllables. If Sinhala demonstrates this tendency, one might expect that either the vowel or the consonant in the trimoraic syllable would delink a mora (such as in (4d) or (e) above), which might in turn affect the duration of the relevant segment.

Although phonologists typically disclaim any direct relationship between the abstract representation of phonological weight (i.e. the mora) and phonetic timing, some researchers have begun to systematically explore this relationship (Beckman 1982; Port et al. 1987; Maddieson and Ladefoged 1992; Hubbard 1993; etc.). The present study continues this line of inquiry by examining phonetic timing of constituents within the syllable in relation to their phonological representations in Moraic theory.

3. Methodology

In order to test the hypotheses that long vowels are shortened in closed syllables, that consonants are shortened after long vowels, and that (potentially) trimoraic syllables are phonetically shortened, as well as to explore in general the relationship between the nucleus and coda of syllables in Sinhala, a phonetic experiment was constructed and carried out as follows.

The six Sinhala vowels in both their short and long forms ([i]/[ii], [u]/[uu], [e]/[ee], [o]/[oo], [æ]/[ææ], and [a]/[aa]) were combined with each of sixteen different consonants in both their short and long/geminate forms ([p]/[pp], [b]/[bb], [t]/[tt], [d]/[dd], [T]/[TT], [D]/[DD], [c]/[cc], [j]/[jj], [k]/[kk], [g]/[gg], [l]/[ll], [m]/[mm], [n]/[nn], [s]/[ss], [w]/[ww], and [y]/[yy][5]) in order to create a paradigm of six syllable types for each vowel and consonant type: CV (open, light); CVV(open, heavy); CVC(closed with a singleton consonant, heavy); $CVC_1.C_1$(closed with a geminate, heavy); $CVVC_1.(C_2)$ (closed by a singleton, superheavy) and $CVVC_1.(C_1)$ (closed with a geminate, superheavy). The various syllable rhyme combinations were set in the first syllable of a disyllabic word whose second syllable was open and light (this was done in order to control for possible stress effects)[6]. Whenever possible, actual lexical items which fit these parameters were used. However, given the limited number of disyllabic forms with a second light syllable, not all possible combinations actually appear as lexical words. Thus, in order to have a complete phonetic paradigm, nonsense words were created when actual lexical items were not available.

When nonsense words were necessary, their onset was generally [k][7]; for example, for the vowel [a] in combination with [D], the nonsense tokens were created as shown in (5):

[5] These are the consonants which most Sinhala scholars agree to be underlying and to geminate.

[6] The status of stress in Sinhala is negligible. It has been claimed that in many cases, stress occurs word-initially. Since it is often the case in languages that heavy syllables attract stress, keeping the second syllable light eliminated this potentially confounding factor.

[7] If an actual lexical item was possible in part of the paradigm, the first consonant was matched to it so that comparisons could be made within the set for the particular vowel and consonant in question.

(5) [kaDə] [kaaDə]
[kaDDə] [kaaDDə]
[kaDsə] [kaaDsə]

This same process was followed for all of the various vowel and consonant combinations, for a total of 576 tokens, including both true lexical items and nonsense words (Word lists for the tokens analyzed in this experiment may be found in the Appendix).

Nonsense words and actual lexical items were presented to readers as such in separate word lists. Three repetitions of each token were randomized into the appropriate word lists, and tokens were grouped into sets of ten. Each set of ten words began and ended with a "filler" word in order to control for list effects. Participants in the experiment were presented with the word lists (in Sinhala script) and were given time to familiarize themselves with them. They were then asked to read each of the words inserted into the frame sentence in (6):

(6) [sita ____________ kiyələ kiwwa]
Sita ____________ that said
'Sita said ____________'

Participants were instructed to read at a natural pace, and to feel free to stop and take a break if they felt it necessary (actual reading time was approximately two hours for each consultant). Two Sinhala native speakers participated in the experiment, one male and one female, both of whom speak the Colombo region dialect.

The two speakers were recorded in the sound-proofed booth in the Cornell Phonetics Laboratory using a Marantz tape recorder and a unidirectional microphone. Tokens were digitized at 12kHz using the software program "WAVES+" on a SUN workstation. For the purposes of the present study, only tokens for the vowels [i], [u], and [a] were analyzed in relation to the simple stop consonants [p], [b], [t], [d], [T], [D], [k] and [g] (938 actual analyzable tokens). Durational measurements were made using both a waveform and a spectrogram of each relevant token after they were excised from their carrier sentences.

A sample waveform may be seen in Figure 1 with a description of the corresponding segmentation criteria listed in (7) below it.

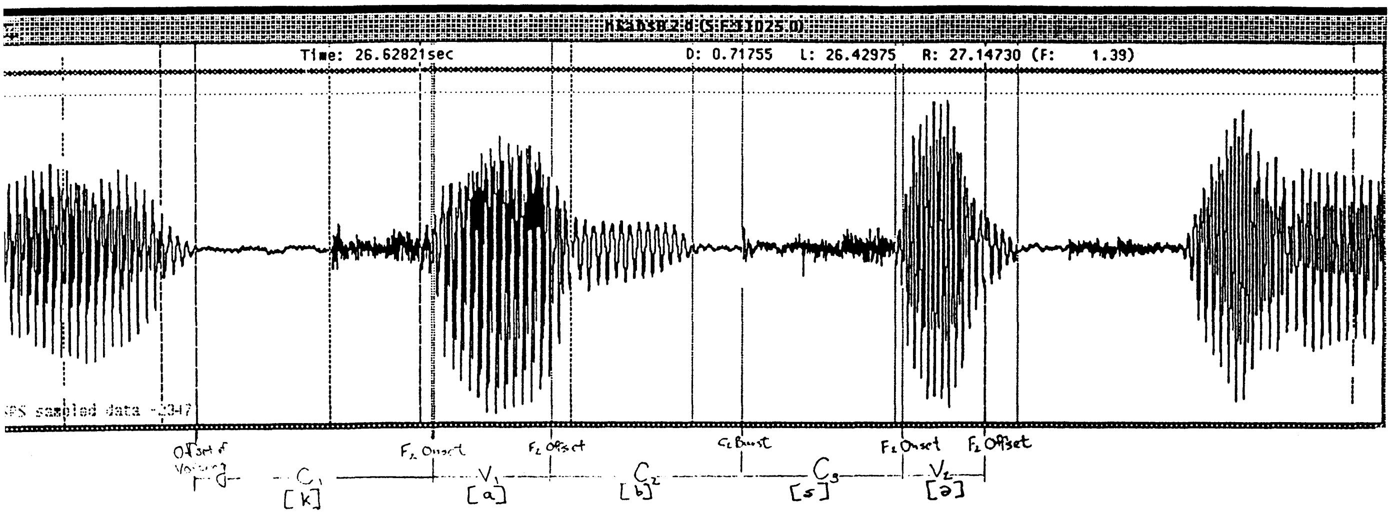


Figure 1. Sample waveform showing segmentation.

(7) Segmentation Criteria

1. C1 - Total duration was assumed to be the offset of voicing of the preceding [a] vowel of 'Sita' through the onset of F2 of the following vowel. In addition, any voicing present initially in the consonant was measured.

2. V1 -Total duration was measured from the onset of F2 to the offset of F2 (determined from both a spectrogram and a waveform). The onset of F2 was taken to allow direct comparison with vowel durations of the second syllable which were preceded by voiced segments.

3. C2 - Total duration was measured, starting from the offset of F2 in the preceding vowel. In the case where it was not followed by another consonant, its end was marked by the onset of F2 of the following vowel. In addition, any voicing during closure (following the offset of F2 of the preceding vowel) was measured, as was the location of the burst. If another consonant followed, the burst of C2 was considered the end of C2 and the beginning of C3, since this was the clearest landmark for this measurement.

4. C3 - Total duration was assumed to be from the burst of C2 to the onset of F2 in the following vowel. In the case of a voiced C3, the onset and offset of voicing was also marked.

5. V2 duration - Total duration was taken as the duration between the onset of F2 and the offset of F2.

While all of the above measurements were recorded, the focus of the following discussion will be on the rhyme constituents of the first syllable. The results of the durational measurements were statistically analyzed for significance by means of a six-factor ANOVA (Speaker x (Categorical) Vowel Length x Vowel Quality x Following Consonant's Place of Articulation x Following Consonant's Voicing x Following Consonant's Syllable Position) and were tested both for main effects and two-factor interactions. Results reported as "significant" were statistically significant at the .05 level, with all main interactions confirmed by Scheffe's post hoc tests and all two-way interactions confirmed by Least Squares Means t-tests. All means and standard deviations presented in the following section are in milliseconds.

4. Results

As mentioned previously, the focus of this experiment is the rhyme constituent of the first syllable in disyllabic tokens (hereafter referred to as the "target" syllable). There are three questions of primary interest:

1) Do lexically long (and/or short) vowels in Sinhala shorten in closed syllables?

2) Do consonants following long vowels in Sinhala shorten?

3) Is there any phonetic evidence for trimoraic shortening?

Keeping these issues in mind, we turn to the empirical results of the experiment.

<u>Sinhala Vowel Duration</u>

What are the factors that influence the duration of vowels in Sinhala? The Six-factor ANOVA demonstrated main effects for all six independent variables: Lexical Vowel Length x Vowel Quality x Voicing of the Following Consonant x Following Consonant's Place of Articulation x Speaker x Following Consonant's Syllable Position. I examine each of these in turn, as well as any related two-factor interactions.

The difference between Lexical Vowel Length, that is, between lexically short and long vowels, is statistically significant [$F(4,100)=1774.87$, $p=.0001$], as would be expected. The second variable, Vowel Quality, reflects the inherent durational differences between /i/, /u/, and /a/, and also demonstrates a main effect for vowel duration [$F(4,100)=155.49$, $p=.0001$]. While differences between the durations of /i/ and /u/ are not statistically significant, the differences in duration between both these high vowels and the low back vowel /a/ are (in Scheffe's post hoc analysis, p= .0001 in both cases). Consider the means in Table 1:

	Mean (StDev.)
/i/ short	49 (14)
long	105 (25)
/u/ short	55 (24)
long	103 (28)
/a/ short	70 (19)
long	141 (22)

Table 1. Mean duration and standard deviation (in ms) of short and long /i/, /u/, and /a/.

While the mean durations of short /i/ and /u/ are 49ms and 55ms respectively, the mean duration of /a/ is 70ms. Since high vowels are known to be inherently shorter than low vowels, this result is not surprising. Note also that in the long vowel counterparts of all three vowels, the long vowels are all approximately twice as long as the short vowels. Lexical Vowel Length and Vowel Quality also interact significantly [$F(4,100)=25.56$, $p=.0001$]. This interaction is between /i/ and /u/, which results from the difference in duration between short and long [u] being somewhat less than that of the other two vowels [$t(2)=21.49$, $p=.0001$].

Yet another variable which demonstrated a main effect on vowel duration was the Voicing of the consonant following the vowel [$F(4,100)=56.23$, $p=.0001$]. Vowels followed by voiced consonants were significantly longer than those followed by voiceless consonants. The Place of Articulation of the Following Consonant also showed a main effect for vowel duration [$F(4,100)=5.55$, $p=.0009$]. The crucial difference was between the labials and the other places of articulation; vowels followed by labials were significantly shorter than those followed by dental, retroflex, or velar consonants (Scheffe's post hoc analysis showed significance at $p< .0003$ between vowels followed by labials and each of the other three cases). These two factors, Voicing and Place of Articulation of the following consonant, also interacted in affecting the preceding vowel's duration. Consider Table 2, which lists the duration means (averaged across both long and short tokens) of vowels followed by the various permutations of these two factors:

	VOICELESS Mean (StDev.)	VOICED Mean (StDev.)
Labial	73 (33)	90 (40)
Dental	**78** (39)	**104** (40)
Retroflex	87 (37)	98 (40)
Velar	84 (39)	94 (40)

Table 2. Mean vowel duration and standard deviation (in ms) as a function of voicing and place of articulation of the following consonant.

The interaction here is between dentals and voicing. While it is the case that vowels preceding voiced consonants are longer than those preceding voiceless consonants within all four places of articulation, this is particularly strong in the case of the dentals, where the difference in means between vowels before the voiced and voiceless counterparts is 26ms [t(3)=-6.01, p=.0001], as opposed to 17ms for labials, 11ms for retroflex consonants and 10ms for velars.

Differences in vowel duration also showed a main effect for Speaker [F(4,100)=34.69, p=.0001]; the difference in overall means between the two speakers' vowel durations was about 13ms. This difference becomes more salient in the context of the interaction between Speaker and Lexical Vowel Length. While both speakers had virtually the same mean overall for short vowels (57 and 58 ms respectively), Speaker 1's long vowels averaged 127ms as opposed to Speaker 2's long vowel mean of 108ms (this difference is significant:[t(1)=9.89,p=.0001]); that is, Speaker 1's long vowels were much longer than Speaker 2's long vowels overall. There was also a significant interaction between Speaker and Vowel Quality ([t(2)=-3.41,p=.0007]), as shown in Table 3 below. While the difference between the overall means of /u/ and /i/ for Speaker 1 was significant, the same comparison was not significant for Speaker 2. However, even though this difference was statistically significant, it was only a 4ms difference (as compared to a 2ms difference), and resulted from averaging over both long and short vowels. Thus, its linguistic significance is questionable.

	/i/ Mean (StDev.)		/u/ Mean (StDev.)		/a/ Mean (StDev.)	
Speaker 1	**84**	(41)	**88**	(40)	121	(49)
Speaker 2	75	(29)	73	(30)	103	(34)

Table 3. Mean vowel duration and standard deviation (in ms) per speaker.

The final main effect for vowel duration was the Following Consonant's Syllable Position [F(4,100)=13.07, p=.0001]; this factor encoded whether the vowel was followed by a consonant which served as the onset to the following syllable, the coda of the syllable in which the vowel being measured was the nucleus, or both, in the case of the vowel being followed by a geminate consonant. For clarity of exposition, I will refer to these three contexts as an open syllable, a closed syllable, and a syllable closed by a geminate, respectively. A Scheffe's post hoc test demonstrated that the significant difference in vowel durations, when the means of vowels were averaged over different Lexical Vowel Lengths and Qualities, was between vowels which appeared in open or closed syllables as opposed to those in syllables closed by geminate consonants. That is, when vowel duration was compared based solely upon syllable context, vowels in syllables closed by geminates were significantly longer than vowels in either open syllables or those closed by non-geminates. In order to understand more accurately the nature of this difference, examine the interaction between Lexical Vowel Length and Syllable type [F(4,100)=6.50, p=.0016] as demonstrated in Table 4, which presents a summary of the relevant measurements in relation to each syllable context across both speakers.

Syllable Type	SHORT VOWEL mean	(StDev.)	LONG VOWEL mean	(StDev.)
Open	51	(18)	114	(28)
Closed	59	(20)	115	(31)
Closed gem.	61	(25)	119	(32)

Table 4. Mean vowel duration and standard deviation (in ms) as a function of lexical vowel length and syllable type.

The leftmost column lists the various syllable contexts in which the target vowels appeared: open (C<u>V</u>CV), closed (C<u>V</u>C_1.C_2V) and closed by a geminate (C<u>V</u>C_1C_1V). The next two columns to the right list the means and standard deviations of the short vowels respectively, and the last two columns list the same information for the long vowels (the data is pooled for [i], [u], and [a]). In the case of the short vowels, it is obvious that no shortening is occurring based on syllable context in closed syllables; in fact, the vowels lengthen (or perhaps they are shortening in open syllables) significantly in both types of closed syllables regardless of whether the syllable is closed by a geminate ([t(2)=-5.58, p=.0001]) or non-geminate ([t(2)=4.66,p=.0001]). In the case of the long vowels, the means are within 5ms in all three contexts; although it looks as if the long vowels show a similar pattern to the short vowels in terms of lengthening in closed syllables, none of the differences between the three contexts are statistically significant. Crucially, however, these results contradict Maddieson's (1985) claim that long vowels in Sinhala shorten in syllables closed by geminates. The results of the present study demonstrate that long vowels in Sinhala do *not* shorten significantly in closed syllables.

In addition to the interaction between Lexical Vowel Length and syllable type, there is also an interaction between Speaker and Syllable Type [F(4,100)=7.17, p= .0008]. Consider the means in Table 5:

	SPEAKER 1 Mean (StDev.)	SPEAKER 2 Mean (StDev.)
Open	**91** (45)	83 (36)
Closed	**91** (44)	82 (32)
Clos.gem.	**106** (47)	85 (34)

Table 5. Mean vowel duration and standard deviation (in ms) as a function of speaker and syllable type.

The crucial comparison here may be seen in the means for Speaker 1. While the means of vowels in open and closed syllables versus vowels in syllables closed by a geminate are significantly different for Speaker 1 ([t(2)=-5.29,p=.0001] and [t(2)=-2.04, p=.0419] respectively), Speaker 2 shows no such difference. Again, it is important to keep in mind that these means result from averages taken over both long and short vowels, and thus, while statistically significant, are most helpful in pointing out that the effect of syllable type on vowel duration is not at all straightforward, nor is it evidenced for all speakers.

Yet another significant interaction occurred between Syllable Type and Place of Articulation of the consonant following the vowel [F(4,100)=3.29, p=.0033]. Means of vowels as related to both the place of articulation of the following consonant and syllable context are presented in Table 6:

	OPEN Mean (StDev.)		CLOSED Mean (StDev.)		CLOS.GEM. Mean (StDev.)	
Labial	80	(39)	80	(35)	86	(41)
Dental	90	(45)	88	(38)	99	(43)
Retroflex	90	(36)	89	(39)	100	(40)
Velar	**84**	(37)	**93**	(41)	90	(40)

Table 6. Mean vowel duration and standard deviation (in ms) as a function of syllable context and consonant place of articulation.

While the means of the vowels preceding labials, dentals and retroflex sounds are not significantly different in the contexts of open versus closed (by non-geminate consonant) syllables, in the case of a following velar, the change in vowel duration between open and closed syllables is significant [t(6)=-4.89, p=.0001]. In addition, except in the case of vowels followed by labials, the differences in the means between syllables which are open versus those closed by geminates are significant (p<.0063 in all cases). Note again that vowels are lengthening in syllables closed by geminates.

I have examined a variety of factors which affect vowel duration in Sinhala and confirmed such observations as inherent durational differences between high and low vowels and durations of vowels which are lexically specified as "long" or "short". Also, the effects of following consonant voicing and place of articulation on preceding vowel duration have been examined and have confirmed other results in the literature. Crucially, however, I have not found evidence for Maddieson's (1985) claim that vowels shorten in closed syllables in Sinhala. In fact, I have found evidence to the contrary in the case of short vowels.

Sinhala Consonant Duration

Consider now the duration of the consonant following the vowel in the target syllable. This consonant may either be functioning as an onset to the following syllable, or as a non-geminate coda consonant, or as a geminate which serves as both the coda of the first syllable and the onset of the following one. A six-factor ANOVA tested for main effects and all two-factor interactions. Five main effects were evidenced: Speaker x Voicing x Place of Articulation x Preceding Vowel Length x Consonant's Syllable Position.

One of the main effects on consonant duration was Speaker [F(4,100)=36.86, p=.0001]. Speaker 1's consonants were on an average longer than Speaker 2's consonants (means were 116ms versus 106ms overall, respectively).

A second main effect was found for voicing [F(4,100)=122.20, p=.0001]. Voiceless consonants were significantly longer than voiced consonants overall: means were 120ms versus 102ms. Upon examining the interaction of Voicing and Place of Articulation [F(4,100)=18.06, p=.0001], we can see that this is the case for all but the velars (for the velars, [t(3)=1.53,p=.1264]). The mean consonant durations as a function of their interaction with place and voicing are represented in the Table 7:

	VOICELESS Mean (StDev.)	VOICED Mean (StDev.)
Labial	118 (51)	101 (35)
Dental	140 (38)	95 (38)
Retroflex	118 (50)	103 (39)
Velar	107 (44)	107 (40)

Table 7. Mean consonant duration and standard deviation (in ms) as a function of voicing and place of articulation.

The differences in means between voiced and voiceless consonants at the labial, dental and retroflex places of articulation are all significant (p=.0001 in all three cases according to t-tests); however, the velars have no significant difference.

A third main effect was found for Place of Articulation [F(4,100)=12.12, p=.0001], where the velars were found to be the shortest (with an overall mean of 107ms) and the dentals the longest (116ms mean) as compared with the labial and retroflex consonants (both with an overall mean of 110ms). Scheffe's post hoc tests showed that only the difference between the velars and dentals was significant. Besides the interaction between place and voicing discussed above, there was also a significant interaction between Place of Articulation and Syllable Position [F(4,100)=7.6, p=.0001]. Table 8 presents the means of consonants in terms of this interaction:

	ONSET Mean (StDev.)		CODA Mean (StDev.)		CODA/ONSET(Geminate) Mean (StDev.)	
Labial	**87**	(23)	**97**	(41)	**154**	(33)
Dental	**85**	(23)	**114**	(44)	**156**	(33)
Retroflex	**80**	(24)	**88**	(26)	**153**	(40)
Velar	**94**	(16)	**75**	(28)	**149**	(34)

Table 8. Mean consonant duration and standard deviation (in ms) as a function of place of articulation and syllable position.

Since the consonants in "Onset" and "Coda" positions are non-geminate, it is not surprising to find that they are all significantly different from the geminate means (recall that geminates serve as both the coda of the preceding syllable and the onset of the following syllable). More interesting is the fact that, again, in the case of both the dentals and the velars, the differences between the means of the consonants in onset versus coda positions is also significant, while the same difference between labial and retroflex consonants is not. Note, however, that even the significant difference seen in the dentals and velars is somewhat different in nature. In the velars, as opposed to the dentals, the coda consonant is shorter than the corresponding onset consonant ([$t(6)=-3.74, p=.0002$]), whereas the dentals show the opposite pattern ([$t(6)=5.29, p=.0001$]). Thus, even though the velars and dentals both show significant differences in duration between onset and coda consonants, the difference in duration goes in opposite directions and is thus qualitatively different .

The categorical Length of the vowel preceding the consonant also had a main effect on consonant duration [$F(4,100)=126.32$, $p=.0001$]. The effect indicated that consonants shorten significantly overall when they follow a lexically long vowel (mean consonant duration 101ms) versus a short vowel (mean consonant duration 120ms). Categorical vowel length interacted significantly with Speaker [$F(4,100)=26.35$, $p=.0001$]; Speaker 1 had much longer consonants after short vowels than Speaker 2 (means were 132ms versus 112ms, respectively), whereas both speakers had basically the same consonant means (101ms and 102ms respectively) after long vowels.

The final significant main effect was for the Syllable Position of the Consonant. Since the Consonant's Syllable Position encoded not only whether or not the consonant was serving as an onset or coda in the syllable, but also whether or not the consonant was a geminate, this factor's significance was not surprising [$F(4,100)=490.25$, $p=.0001$], since it encoded a lexical categorical distinction in terms of consonant length. Scheffe's post hoc tests demonstrated that the significant differences overall were between the geminate and non-geminate consonants and not between onsets and codas. The Syllable Position of the Consonant interacted significantly with several other factors, including Speaker [F(4,110)=8.85, p=.0002]. While Speakers 1 and 2 shared similar means for consonants in onset position (85ms and 88ms, respectively) and geminate consonants (155ms and 151ms, respectively), Speaker 1's coda consonants were much longer in duration than Speaker 2's coda consonants (107ms versus 83ms: [t(2)=8.01, p=.0001])). Another significant interaction involving the Syllable Position of the Consonant was with Voicing [F(4,100)=3.83, p=.0220]. Consider the means as presented in Table 9:

	VOICELESS Mean	(St Dev.)	VOICED Mean	(St Dev.)
Onset	102	(14)	**74**	(26)
Coda	102	(46)	**86**	(19)
Coda/Onset (geminate)	167	(38)	142	(28)

Table 9. Mean consonant duration and standard deviation (in ms) as a function of syllable position and voicing.

The means of both voiceless and voiced consonants differ significantly in terms of the contrast between onsets and codas on the one hand versus geminate Coda/Onsets on the other, as discussed previously. However, while voiceless consonants do not differ significantly in their means based on whether they are in either onset or coda position, in the case of the voiced consonants, onsets are significantly shorter than the coda consonants ([t(2)=3.07, p=.0022]).

One final significant interaction involving the Syllable Position of the Consonant was found with the categorical Vowel Length of the preceding vowel. The means are summarized in Table 10:

	SHORT VOWEL Mean (StDev.)		LONG VOWEL Mean (StDev.)	
Onset	95	(22)	81	(20)
Coda	102	(45)	86	(28)
Coda/Onset (geminate)	171	(35)	137	(27)

Table 10. Mean consonant duration and standard deviation (in ms) as a function of syllable position and lexical vowel length.

The left hand side of the table represents consonants which followed lexically short vowels, whereas the right side of the table represents consonants which were preceded by lexically long vowels. Note first that in every case, the consonant means are consistently shorter after a long vowel as compared with the consonant means of those segments which followed a short vowel, no matter what the syllable position. Note also that this is true whether or not the consonant is a geminate (as is the case when the consonant is serving as both a coda and an onset) or not. The difference between the durational mean of consonants in onset position following a short versus a long vowel is 14ms (approximately 15%); the corresponding difference between consonants in coda position is 16ms (about 16%), whereas the same comparison between geminate consonants in coda/onset position is 34ms (approximately 20%). This difference in shortening in the geminate consonants following long vowels is significantly more than in the non-geminate consonants in onset and coda positions.

5. Discussion

The results of this study corroborate many of the findings of previous phonetic work on other languages. Vowels in Sinhala demonstrate durational differences reflecting categorical length contrasts as well as inherent differences based upon quality (high vowels are shorter than low vowels). Vowels are also shorter before voiceless consonants than before voiced ones (Chen 1970) and are shorter before labials than other places of articulation (Lehiste 1970), including the retroflex consonants. In addition, there was a significant interaction between the place of articulation and the voicing of the following consonant on vowel duration, in that vowels which preceded voiced dentals were significantly longer than vowels which preceded voiced consonants of other places of articulation. Reasons for this interaction are unclear; in terms of a "tradeoff" relationship between the vowel and coda consonant of a syllable rhyme, one might expect this to be the case if the dentals were the shortest consonants. That is, if there was an abstract syllable target length which the various segments attempt to "fill in", then if the dentals were the shortest consonants following vowels, one might expect the vowels to lengthen to help reach the target duration. However, just the opposite is the case; dentals are inherently the longest consonants as compared to the other places of articulation. While the reported interaction is across various syllable contexts, two thirds of the cases would have involved the following consonant serving as a coda in one form or another (either as a single coda consonant or as a geminate consonant which serves as both a coda and an onset to the following syllable); thus, it seems that an explanation based upon an overall syllable target duration is not feasible.

There were also several interactions involving Speaker; for example, while both speakers had remarkably similar overall short vowel durations, one speaker's long vowels were significantly longer than the other speaker's long vowels. Also, as mentioned earlier, one speaker had a consistent difference in the inherent length of [i] versus [u] while the other speaker did not; however, this difference was only 4ms, so that while it was consistent, it is not likely to be of linguistic significance. One speaker also had an overall greater mean duration in vowels appearing before geminates as opposed to vowels appearing before non-geminates (whether the following vowels were acting as onsets or codas) while the other speaker showed no such differences. Because of the nature of idiolectal variation in the speech signal from one individual to the next, these differences are not at all surprising.

One of the primary questions posed at the beginning of this study was whether or not *long* vowels would shorten in closed syllables. Based on Maddieson's (1985) review of this phenomenon occurring cross-linguistically in many languages (including Sinhala[8]), I assumed that this would be the case in Sinhala. However, the results of this study do not demonstrate long vowel shortening in closed syllables and thus do not confirm this as being a "phonetic universal." Still, the question remains why Sinhala does not evidence what appears to be a rather robust phonetic tendency; several possibilities come to mind.

First, it may be that long vowel shortening is not really a universal tendency. Perhaps it is not so much crucial that the vowel shortens, but that some sub-constituent of the syllable shortens in order to maintain an abstract syllable target duration. Recall that

[8] Since Maddieson did not have an extensive data set available to analyze, it may simply have been chance that his results demonstrated this effect. One of the two speakers in this study did shorten long [uu] in closed syllables versus open ones ([uu] = 102ms in an open syllable, 95ms in a syllable closed by a non-geminate consonant, and 87ms in a syllable closed by a geminate). However, this was not the case for either [ii] or [aa], nor was it the case at all for the other speaker.

Sinhala *does* confirm previous findings that consonants following long vowels shorten. One possibility might be that in some languages, it is not the long vowel that shortens in closed syllables, but a coda consonant instead. However, one drawback to this argument, given the present data, is that it is also the case that consonants which follow long vowels but serve as *onsets* also shorten; that is, shortening of consonants following long vowels is not a within-syllable phenomenon, but occurs across syllable boundaries. It might be argued, however, that this is not extremely problematic, based on hypotheses that it is not the syllable and its constituents alone (including inherent segment qualities) which determine durational patterns, but that higher level prosody is involved as well, such as the phonological foot, phrase, etc. Some researchers have argued that segments and moras interact with higher-level prosodic structure to contribute to duration (Hubbard 1993; Port, Dalby and O'Dell 1987); however, precise relations between phonological representation and phonetic duration are not yet clearly understood.

Another possibility may be that Sinhala allows the linguistically "marked" option of trimoraic syllables; that is, it may be the case that the tendency to disallow trimoraic syllables is related to the tendency many languages have to shorten long vowels in closed syllables. In other words, if a language allows trimoraic syllables, then there would be no reason to shorten any part of the syllable in terms of the moraic structure. This is an empirically testable hypothesis which would call for the cross-linguistic comparison of both phonological syllabic representations and acoustic phonetic data on duration. The prediction would then be that if a language did not treat closed syllables as heavy unless they contained a long vowel (that is, if the coda consonant did not bear a mora), there would be no long vowel shortening since there would be no violation of a bimoraic constraint and therefore no impetus for shortening to occur.

The second question of primary interest in this study was whether or not consonants shorten after long vowels as compared to short vowels and, as mentioned previously, they do. In addition, several other factors affected consonant duration. Except in the case of the velars, voiced consonants were significantly shorter than their voiceless counterparts. Consonants also demonstrated inherent differences based upon their place of articulation, with velars being the shortest compared with the dentals; labial and retroflex consonants did not differ significantly in duration from one another or the other two places of articulation. There were also some differences between speakers: one speaker had longer consonants overall than the other speaker, particularly in coda position and after short vowels. In addition, syllable position interacted with both place and voicing factors in influencing consonant duration. For example, voiced onset consonants tended to be longer than voiced coda consonants (no such contrast held for voiceless consonants), velar onsets tended to be longer than velar codas, and dental onsets tended to be shorter than dental codas.

It is clear that factors on several levels influence the duration of segments - individual speaker differences, inherent qualities of the segments themselves, coarticulation effects, prosodic variables (of mora, syllable, foot, word, phrase), etc.; thus, while one of the factors may be focused on, it is important to keep in mind the interaction of all these variables. Having noted that, our third question posed at the beginning of this study may be addressed: does Sinhala demonstrate any phonetic evidence for the shortening of trimoraic syllables?

Recall again the structures for Sinhala trimoraic syllables, repeated from (4) under (8):

(8) Trimoraic Syllables in Sinhala

a) $CVVC_1C_1V$ b) $CVVC_1C_2V$

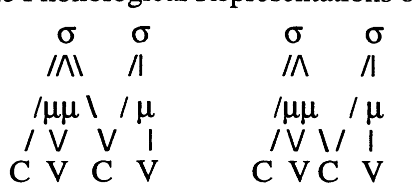
If a syllable containing a long vowel is closed by a geminate consonant as in (8a), it would be expected to contain three moras since the long vowel bears two moras underlyingly and the geminate bears one (following Hayes 1989). In addition, the phonological behavior of Sinhala indicates that non-geminate coda consonants also bear weight, given the observation that Sinhala lexical words seem to require a minimal weight (two moras) to which coda consonants contribute. Thus, Sinhala presumably has two means by which trimoraic syllables may arise: a syllable containing a long vowel may be closed by either a geminate (as in 8a) or non-geminate consonant (as in 8b).

If Sinhala did exhibit trimoraic shortening at some level, we would predict that the shortening would occur in the rhyme of the syllable (since only the rhyme bears weight, i.e. moras); two logical possibilities would be that either the vowel or the coda consonant would lose a mora and therefore shorten. Given our previous discussion, it is clear that the vowel does not undergo any significant shortening and so it is the coda consonant, if anything, which would demonstrate shortening.

In terms of phonetic output, we might expect either that a following onset consonant would not evidence any shortening at all, or that the difference between the shortening of an onset consonant following a long vowel, and the shortening of a coda consonant or geminate consonant in the same environment, should be statistically different. We have seen in Table 10 above that onset consonants following long vowels undergo significant shortening; thus, in order to maintain that there is phonetic evidence for trimoraic shortening in Sinhala, it would seem to be necessary that this effect differ significantly from the shortening of both a non-geminate consonant serving as a coda and a following geminate consonant[9], since both of these consonants bear moras in Sinhala. However, as is evidenced above, this is not the case. The shortening of an onset consonant following a long vowel as compared with the shortening of a non-geminate coda consonant following a long vowel is not statistically significant. The shortening is significant between the geminate versus non-geminate consonants: the geminate consonants shorten significantly more than do the non-geminate consonants following long as opposed to short vowels.

This has several implications, one of which is that there is a significant shortening occurring in a trimoraic syllable (although even when shortened, the geminate consonant is always significantly longer than its non-geminate counterpart). The first issue to address is how this shortening might be represented phonologically. One possibility would be to delink the mora of the geminate consonant and link the coda melody directly to the preceding syllable head as shown in (9a) below, leaving it still linked to the following syllable head as an onset. Another possibility would be to delink the geminate's mora and then link the geminate consonant to the preceding vowel's second mora, as shown in (9b). The prediction this would make, though, is that the vowel might shorten slightly since it is then sharing its mora with another segment (Hubbard 1993) and we know that the vowel does not shorten in these contexts. Thus, (9a) is the more likely structure for such a shortening.

(9) Possible Phonological Representations of Trimoraic Shortening in Sinhala



a) $CVVC_1C_1V$ b) $CVVC_1C_1V$

[9] If it could be shown that coda consonants in Sinhala syllables containing long vowels were not assigned a mora, only geminate codas should be significantly different.

The second issue to address is that if this is trimoraic shortening, why doesn't it equally effect the non-geminate coda consonant? One explanation for this could be that the single coda consonant does not always bear a mora, and thus it is not required to lose one. Assume for a moment that Sinhala does ban trimoraic structures. Since a single coda consonant is assigned a mora by Weight-by-Position rather than bearing one underlyingly like the geminate, it could be that if a syllable already contains a long vowel, then the Weight-by-Position Rule does not apply since it would then create a structure which violates this ban. The blocking of the assignment of Weight-by-Position in syllables with long vowels would then result in a structure like that in (10):

(10) Sinhala Syllable containing a long vowel and coda consonant

```
  σ       σ
 //\\     /|
/μμ \    / μ
/ V  \  /  |
C V   C C  V
```

$CVVC_1C_2V$

The shortening that a non-geminate coda consonant undergoes is statistically the same as the shortening that a following syllable's onset consonant undergoes; both of these shortenings could be assumed to arise from a factor other than trimoraic shortening, such as a timing relationship at a higher level of structure (e.g. the word, see Jongman and Sereno 1991; Port, Dalby & O'Dell 1987; etc.).

The foregoing experiment then has provided evidence that Sinhala long vowels do not undergo shortening in closed syllables and that consonants following long vowels do undergo significant shortening. In addition, I have argued that there is some potential phonetic evidence for trimoraic shortening, the basis of which relies on further phonological evidence that trimoraic shortening is occurring in the language. The continued systematic study of the relationship between phonological representation and phonetic timing is an issue for cross-linguistic analysis. It is hoped that the present study is both a contribution and an impetus toward this further research.

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Appendix

In the case of nonsense words, [k] was used for easy segmentation purposes, and schwa was used word finally since it is commonly found there in actual lexical items. Note that actual lexical items (drawn from Disanayaka 1991, Karunatillake 1990, and Moscrop and Mendis 1899) were preferred to nonsense words whenever possible; thus, variation in the quality of the second syllable vowel was permitted. While onsetless lexical items which fulfilled the disyllabic constraint and satisfied the segmental quality constraints were also sometimes possible, nonsense items with onsets were created in their place in order to make certain that the lack of an onset did not confound the duration of the rhyme in the initial syllable. Nonsense forms will have no following gloss; lexical words will be followed by a gloss. (Note that before running the experiment, a native speaker not participating in the experiment was consulted for alternative lexical suggestions in place of nonsense words.)

[i] Set:

[pipi] - 'opening, expanding'	[kiipə] - 'many, much'
[kibə]	[kiibə]
[titə] - 'dot'	[hiitə] - 'cold'
[kidə] - 'marsh, bog'	[kiidə]

[kid∂] - 'marsh, bog'	[kiid∂]
[piT∂] - 'back of body'	[piiT∂] - 'faculty, stage'
[piD∂] - 'space'	[kiiD∂]
[Tik∂] - 'little'	[kiik∂]
[dig∂] - 'long'	[diig∂] - 'patrilocal marriage'
[kipp∂]	[kiipp∂]
[tibb∂] - 'tortoise'	[kiibb∂]
[titt∂] - 'bitter'	[tiitt∂] - 'ink, paint'
[widda] - 'shot'	[kiidd∂]
[piTTu] - 'rice cereal'	[kiiTT∂]
[kiDD∂]	[kiiDD∂]
[kikk∂]	[kiikk∂]
[kigg∂]	[kiigg∂]
[kipm∂]	[kiipm∂]
[kibs∂]	[kiibs∂]
[sity∂]	[siity∂]
[kids∂]	[kiids∂]
[kiTn∂]	[kiiTn∂]
[kiDs∂]	[kiiDs∂]
[diks∂]	[diiks∂]
[kigs∂]	[kiigs∂]

[u] Set:

[kup∂] - 'stubborn/unruly'	[ruup∂] - 'pictures'
[kub∂]	[kuub∂]
[kut∂]	[kuut∂]
[pud∂] - 'worship/offering'	[kuude] - 'basket'
[puTu] - 'chairs'	[kuuT∂]
[kuD∂] - 'umbrellas'	[kuuDe] - 'in the basket'
[kuk∂]	[kuuk∂]
[kug∂]	[kuug∂]
[kupp∂]	[suuppu] - 'pacifiers'
[kubb∂]	[kuubb∂]
[puttu] - 'sons'	[puuttu] - 'joining'
[mudd∂] - 'ring'	[kuudd∂]

[kuTT∂]	[muuTTu] - 'joints'
[kuDD∂] - 'baskets'	[kuuDD∂]
[kukko] - 'pups'	[kuukk∂]
[kugg∂]	[kuugg∂]
[kupm∂]	[kuupm∂]
[kups∂]	[kuups∂]
[kubs∂]	[kuubs∂]
[suty∂]	[suuty∂]
[kuds∂]	[kuuds∂]
[kuTn∂]	[kuuTn∂]
[kuDs∂]	[kuuDs∂]
[duks∂]	[duuks∂]
[kugs∂]	[kuugs∂]

[a] Set:

[hap∂] - 'cuds'	[taap∂] - 'heat, sorrow'
[kab∂]	[kaab∂]
[hat∂] - 'seven'	[paat∂] - 'below'
[tad∂] - 'hard'	[kaad∂]
[kaT∂] - 'mouth'	[paaT∂] - 'color'
[kaD∂] - 'shops'	[kaaD∂] - 'cards'
[hak∂] - 'conch'	[kaak∂]
[vag∂] - 'news'	[baage] - 'half'
[happ∂] - 'strike against'	[taapp∂] - 'parapet wall'
[baabu] - 'babies'	[kaabb∂]
[sattu] - 'animals'	[taatta] - 'father'
[sadd∂] - 'noises'	[kaadd∂]
[kaTT∂] - 'shell'	[kaaTT∂]
[kaaDD∂]	[kaaDD∂]
[hakk∂] - 'jaw'	[laakk∂] - 'writing table'
[nagg∂] - 'climb' (caus.)	[laaggo] - 'fish'
[kaps∂]	[kaaps∂]
[kabs∂]	[kaabs∂]
[saty∂] - 'truth'	[saaty∂]
[kads∂]	[kaads∂]

[kaTn∂]	[kaaTn∂]
[kaDs∂]	[kaaDs∂]
[daks∂]	[daaks∂]
[kags∂]	[kaags∂]