A PHONETIC AND PHONOLOGICAL APPROACH TO STRESS IN SINHALA VERBS

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1. INTRODUCTION.

1.1. REVIEW OF PHONETIC STRESS. According to Cutler (2005) research on stress and stress perception has primarily focused on the acoustic characteristics of stressed versus unstressed syllables, and how listeners make use of acoustic cues to make judgements as regards the occurrence of stress. Most phoneticians agree that the three acoustic dimensions involved in the realisation of stress are duration, fundamental frequency, and intensity. These acoustic properties correspond to the perceptual phenomena of length, pitch, and loudness, respectively. Some phoneticians also include vowel quality as an additional dimension (Laver 1994, Hayward 2000). In general, stress is described as the display of prominence by the exaggeration of one or more of the phonetic parameters on certain syllables when contrasted with others (Laver 1994). Hence, a syllable displaying such prominence can be said to have possibly longer duration, higher pitch, greater acoustic intensity, and more carefully articulated phones when in contrast with unstressed syllables (Hayward 2000). However, some linguists make more specific claims as to which parameters play a larger role in the realisation of stress. Ladefoged (2003) states it is likely to be some combination of pitch, length, and loudness, with the first two playing the greatest role.

To further complicate the phonetic description of stress, it appears that its phonetic manifestation varies from language to language (Laver 1994). Based on many studies conducted on English stress, Laver claims that English exploits all four parameters. However, studies conducted by Fry (1955) claim that English relies heavily on duration and intensity. In another study conducted by Mol and Uhlenbeck in 1965 in which the intensity relationship of stressed and unstressed syllable was reversed, it shows that intensity did not affect the perception of stress (Cutler 2005). On the other hand, Fujimura and Erickson (1997) state that stress is primarily manifested in the change of the fundamental frequency. In summary, Cutler asserts that the least controversial findings as of today are (1) syllables are perceived to be stressed if they exhibit fundamental frequency excursion and (2) greater syllable duration is likewise associated with perceived stress. The more controversial finding is that intensity manipulations only weakly affect stress perception, such as the findings shown by Mol and Uhlenbeck.

As for the muscular activities involved in the production of stress, Hayward (2000) says that stressed syllables display raised subglottal pressure when compared with unstressed syllables. This increase in pressure can be accomplished by respiratory activity, by laryngeal activity, or a combination of both. Another possibility is that respiratory and laryngeal muscles are involved in the production of stress (Hayward 2000, Ladefoged 2001). Ladefoged (2001) claims that more air is pushed out of the lungs in the production of stressed syllables. Succinctly, it can be stated that a stressed syllable may have greater respiratory energy than neighbouring unstressed syllables.

Although acoustic parameters and muscular activities have been identified, it is still a difficult task to objectively measure stress. Ladefoged offers a highly impressionistic approach to identifying stressed syllables. He suggests that the best way to decide whether a syllable is stressed is to try to tap out the beat as a word is being produced. The claim is that it is easier to produce an increased tap exactly in time with an existing increase of respiratory or laryngeal activity (Ladefoged 2001). Here Ladefoged is again correlating increased muscular activity with stressed syllables. This is apparent in his hypothesis which states that listeners perceive stress by putting together all of the cues available in order to deduce the motor activity a speaker would use to produce the same stresses. In general, stress has proven to be both the most straightforward to analyse impressionistically and the most difficult to define in purely phonetic terms (Hayward 2000).

1.2. REVIEW OF PHONOLOGICAL STRESS. Regarding stress from a phonological perspective, stress makes up part of the metrical organisation of speech. According to Kager (1999), there are conflicting forces at work in lexical stress: rhythm, quantity-sensitivity, and edge-marking. Rhythm is the pressure toward a regularly alternating distribution of weak (unstressed) and strong (stressed) syllables. Quantity-sensitivity is the pressure to match syllable weight to prominence. Edge-marking is the pressure to mark the edges of morphemes. Languages that make linguistic use of stress can be divided into two categories: fixed lexical and variable lexical stress. Laver (1994), citing Hyman's typological analysis of stress, states that the majority of fixed lexical stress languages demonstrate a preference for stress toward the initial or final syllable of a word, which points to an edge-marking, or demarcative, function. Variable lexical stress languages all demonstrate a range of different locations of lexical stress. This pattern is commonly found in languages where lexical stress makes a contrast in meaning. Hyman also reported that there were a few languages with stress that is governed by syllable weight (Laver 1994). From a phonological standpoint, stress can be regarded as a binary distinction. A two-way distinction can be drawn (i.e. stressed and unstressed) (Laver 1994). This differs from a phonetic analysis of stress, which is regarded as a gradient phenomenon. The phonetic realisation of any syllable can be said to show a greater or lesser degree of stress relative to the manifestation of some other syllable. However, some linguists make more distinctions in the levels of stress in their phonological analyses, which poses additional difficulties. As Ladefoged (2001) points out these linguists, in actuality, are conflating stress and tonic accent into 'levels of stress'.

1.3. OVERVIEW OF THIS PAPER. This paper will focus on stress in Sinhala verbs. Sinhala is an Indo-Aryan language and is spoken predominantly in the island nation of Sri Lanka. For a majority of present day Indo-Aryan languages, stress is not contrastive (Masica 1991). There are a few exceptional cases; Assamese has phonemically contrastive stress, and Siraiki has a few cases of lexically contrastive stress (Masica 1991). For a significant number of Indo-Aryan languages, stress is predicted by using a complicated set of rules, usually involving the number of syllables, whether they are open or closed, and the nature of their vowels (Masica 1991). Sinhala and Nepali, according to Masica, demonstrate a tendency for a weak word-initial stress. Letterman's 1997 dissertation on Sinhala, based on impressionistic analysis, makes five observations as regards Sinhala stress: (1) syllable weight has a role in determining stress, (2) primary stress tends to fall on the initial or peninitial syllable, whichever is heavier, (3) parsing appears to be left to right, (4) word-final stress is found when read as a list due to final glottal stop or phonetic lengthening, (5) some heavy syllables carry secondary and not primary stress. Although Letterman's findings are somewhat similar to those presented this paper, she does not attempt to systematically verify her findings using objective measurements or native speaker intuition. The reader is left to judge her phonological account of Sinhala stress solely based on unsystematic observations.

Using instrumental analysis, this paper will attempt to derive an objective measure of stress in Sinhala verbs (Section 2). The measure and its predictions will be checked against native speaker intuition. It will be shown that higher intensity and longer duration, combined, have a high degree of correlation with stressed syllables. Once an objective measure has been developed, the verbs will be analysed for any display of predictable stress (Section 3). In this section, it will be shown that Sinhala does have a preference for stress word-initially (if the initial syllable has an onset) and on heavy syllables. This pattern will then be accounted for using an Optimality Theory approach.

2. Acoustic Measurements.

2.1. Overview of Sinhala Consonants. Sinhala presents a few challenges regarding acoustic measurements. Before measuring syllables for acoustic correlates of stress, it is important to devise a consistent method of measuring phonetic segments. In an effort to highlight the problematic segments, a brief overview of Sinhala consonants. Table 1 presents the consonant inventory of Sinhala.

	Bilabial	Alveolar	Post-alveolar	Retroflex	Palatal	Velar	Glottal
Stop	p b	t d		ṭ ḍ		k g	
• breathy	bh	dh		ḍh		gh	
• prenasalised	m̆b	n̆d		n̆ḍ		ŋ̆g	
Nasal	m	n			ñ	ŋ	
Trill		r					
Fricative		s	š				h
Affricate			c j				
Approximant	w			y			
Lateral Approximant		l					

Table 1. Consonant inventory of Sinhala.

Of the consonants shown in Table 1, prenasalised stops and their status as a single unit need to be addressed. There is morphophonological evidence for the treatment of prenasalised stops as a single unit. In a subset of nouns, the plural form appears to be derived from the singular form by deleting the final schwa. For example, consider *li.n̆də* ‘well.SG’, *a.ŋ̆gə* ‘horn.SG’, and *hu.lə.ŋ̆gə* ‘wind.SG’. The plural forms for these nouns are *liŋ* ‘well.PL’, *aŋ* ‘horn.PL’, and *hu.laŋ* ‘wind.PL’. The alternation observed here between prenasalised stops and velar nasal is similar to other nasal/velar nasal alternations seen in other nouns, such as *ta.na/taŋ* ‘breast/breasts’, *ha.ma/haŋ* ‘skin/skins’, and *ka.na/ kaŋ* ‘ear/ears’. Phonetic evidence is provided by the analysis of gemination. Certain verbs display gemination in the past tense, such as *a.din.nə* ‘to pull’ and *æd.da* ‘pull.PAST’. The verb *a.n̆din.nə* ‘to draw’ follows a similar pattern except that when it geminates, the nasal portion of the prenasalised stop migrates to the previous syllable and becomes a coda nasal, as in *æn.da* ‘draw.PAST’. Geminate affricates behave in a similar fashion, for example the noun *puc.can.nə* ‘child’ is phonetically [put.can.nə]. The observations above have implications as regards the distribution of prenasalised stops. It appears that prenasalised stops can only occur in onset position. Furthermore, it can be said that prenasalised stops only occur in word-medial position since there has been no evidence of word-initial prenasalised stops.

The overview of prenasalised stops brings up another challenge, that is the measurement of geminates. It is important to understand how geminates behave within the syllable. For the most part, through impressionistic and phonological analyses, it was determined that geminates are heterosyllabic. Further evidence is provided by analysing the occurrences of geminates in Sinhala. All instances of geminates so far encountered are intervocalic (e.g. *jiivatvennə* 'to live', *hiṭəgatta* 'stand.PAST', *bædde* 'fry.FOCUSED PAST'). Ladefoged and Maddieson (1996) state that geminate stops in many languages are limited to word-medial position where they usually close the preceding syllable, as well as serving as the onset of the following syllable. They also note that the vowel preceding the geminate is usually shortened to some degree. This pattern can be seen in Sinhala. For the particular consultant and tempo recorded in this study, the average length of a vowel in a non-final open syllable is 89.7 ms. The average length of a vowel preceding a geminate is about 55.6 ms. It has been well observed that coda consonants do affect the length of preceding vowels; therefore, one can conclude that a portion of the geminate is occupying the coda position of a syllable.

However, there still is the matter of proving that a portion of the geminate is the onset of the following syllable. A phonological analysis of Sinhala shows that the language does not contain complex codas. Therefore, on grounds of phonology, one is forced to split geminates across syllables. One can also demonstrate this based on phonetic evidence. Using observations from Ladefoged and Maddieson (1996), languages with a distinction of consonant length have only two distinctive lengths. Furthermore, they cite Lehiste (1966) and Eek (1984-5) whose analyses of Estonian show a third length is created by lengthening of long consonants in stressed syllables. Keeping these points in mind, the duration of stop closures in a subset of tokens were measured. It was readily noted that there were two slightly different lengths. The average length of an onset in a word-medial syllable is about 65.3 ms. However, the average length of an onset in word-initial position is approximately 102.5 ms. This difference is interesting considering that many researchers have observed some degree of stress on word-initial syllables. This 1:1.6 difference seems to be relevant to geminates as shown below in the analysis of geminate **dd**.

During the acoustic analysis of geminates, a peculiar pattern has been observed with geminate **dd**. In many of the intensity diagrams of geminate dd, there is a perturbation during the closure phase of the stop. A clear demonstration of this perturbation can be seen in Figure 1 below.

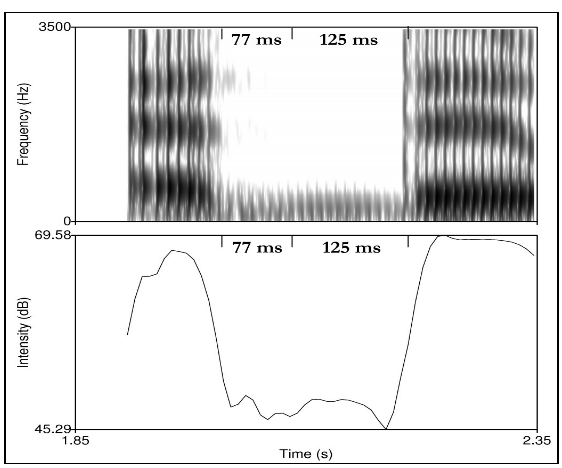

FIGURE 1. Spectrogram and intensity diagram demonstrating intensity perturbation in geminate dd.

The perturbation seen in the figure above is relatively simple compared to those seen in other tokens. In general, there is a sharp fall of intensity at the beginning of the geminate. Then there is a short rise of intensity slightly less than midway through the closure. The intensity falls again and then rises sharply during the release of the stop. At this stage of the investigation, it is uncertain as to the cause to the intensity perturbation; however, many of the intensity diagrams demonstrate this pattern. In Figure 1, the short rise of intensity begins 77 ms into the stop. The burst of the stop occurs 125 ms later. This is roughly a 1:1.6 difference, similar to the difference seen with the duration of stops in word-medial and word-initial positions.[1] If it is assumed that the syllable boundary occurs at the perturbation, then it follows that the onset is lengthened. This lengthened onset possibly corresponds to the judgements of a few observers who claim that the release of geminate stops seem to be 'stronger' or 'more prominent' than the release of single stops. As a result, based primarily on the measurements of single stops and secondarily on the observation of intensity perturbation in geminate **dd**, geminates will be split into codas and onsets with a ratio of 1:1.6.

2.2. EXPERIMENT I: MEASURING SYLLABLE INTENSITY AND PITCH. In the initial analysis of stress in Sinhala, many students in the field methods class described stressed syllables as sounding 'louder'. Therefore, the first experiment devised was to measure the intensity of each syllable and to compare the results to the judgement of the consultant and other researchers. First, a list of verbs with various syllable structures was compiled. The verbs were then recorded in frames on digital audio tape. The tapes were then converted into wave files for analysis. After converting the recording into tokens, the next step was to record native speaker judgement of stress in order to assess the degree of correlation for each experiment. In a one-hour elicitation session, the consultant was asked to listen to the sentences he had recorded one week earlier. He was then instructed to identify the verb and indicate which part of the verb sounded 'more prominent'. He was specifically instructed to identify stressed syllables in this manner so that he would not be influenced by words such as 'higher', 'louder', or 'longer' which could cause one to focus on a particular feature. He was also instructed that he may choose more than one syllable if he believes there is more than one syllable that are prominent. During the elicitation, it was noted that the consultant would bounce his index finger in the air while articulating the verbs. Ladefoged (2001) suggests tapping out the beat as the word is being produced as a useful test in determining stress. He claims that it is easier to produce an increased tap exactly in time with an existing increasing in activity (be it respiratory or laryngeal). During the elicitation session, the consultant assessed eighty verbs. The tables in this and the following sections show in bold print the syllables that he identified as being 'prominent'.

For each verb, the highest intensity for each syllable was recorded. Table 2, below, illustrates a few tokens with the highest intensity achieved for each syllable.

[1] A similar perturbation appears when observing other voiced continuant geminates such as /ll/ and /mm/; however, the ratio is nearer to 1: 1.4.

	Highest Intensity (in dB)					
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**
ka.ḍə.nə.wa	69.07	65.68	59.96	63.93		
kæ.ḍu.wa	64.71	58.48	65.39			
ka.ḍə.wə.nə.wa	62.88	64.01	59.72	57.36	57.73	
kæ.**ḍew**.wa	64.16	61.82	56.50			
a.**di**.nə.wa	60.83	59.95	56.68	61.65		
æd.**da**	56.09	58.17				
a.**din**.ne	57.23	56.56	54.94			
æd.**de**	57.65	55.18				
a.**dii**	59.00	57.19				
ad.**də**.wə.nə.wa	54.23	62.43	57.35	55.39	54.62	
i.ňdə.**gan**.na.nə.wa	65.64	67.14	71.70	64.03	62.96	65.19
i.ňdə.**gan**.nə.wai	61.29	66.28	68.87	64.93	65.67	
i.ňdə.**gan.nan.naŋ**	60.28	64.86	66.24	60.27	62.30	
i.**ňdə**.gæ.nə	59.74	70.19	66.03	64.81		

TABLE 2. Selection of results from intensity measurements.[a]

[a] Highest values are shaded in grey. Syllables in bold print were identified by the consultant as being prominent.

In Table 2, the syllables in bold correspond to syllables judged to be stressed by the consultant, and the values in the grey cells are the highest intensities measured. In some cases, the highest intensity levels correspond to the stressed syllables (e.g. ***ka**.ḍə.nə.wa*, *æd.**da***, *ad.**də**.wə.nə.wa,* and *i.**ňdə**.gæ.nə*). However, for the most part, intensity alone is not a very reliable indicator of stress. The fact that intensity alone is not a very good indicator of stress is noted in Ladefoged (2003). He states that stress is really not as simple as measuring intensity. It is likely to be a combination of pitch, length, and loudness, with the first two playing the greatest role. Ladefoged demonstrates his claim by showing three pitch and intensity diagrams of three identical sentences with contrastive stress appearing on a different word. From the pitch diagrams, it is clear that the words with contrastive stress have higher pitch and greater pitch movement. The intensity diagrams also show all words have nearly equal intensity. Ladefoged concludes that intensity as shown in decibels is usually not a very useful acoustic property to measure. To test this claim and its relevance to Sinhala, a follow-up experiment was conducted. Using the tokens recorded for the experiment above, the syllables were analysed for pitch. Table 3 contains the highest pitch values for each syllable in the tokens shown in Table 2.

	Highest Pitch (in Hz)				
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**
ka.ḍə.nə.wa	99.84	102.62	93.56	102.49	
kæ.ḍu.wa	103.03	107.95	99.82		
ka.ḍə.wə.nə.wa	100.11	101.94	99.43	96.59	98.55
kæ.**ḍew**.wa	99.75	101.30	95.89		
a.**di**.nə.wa	104.56	113.08	97.67	106.52	
æd.**da**	95.66	100.42			
a.**din**.ne	99.71	104.02	106.98		
æd.**de**	98.34	105.29			
a.**dii**	102.31	109.99			
ad.**də**.wə.nə.wa	96.74	108.00	98.05	94.23	101.05

	Highest Pitch (in Hz)				
i.ňdə.**gan**.na.nə.wa	114.92	102.18	106.88	102.21	97.96
i.ňdə.**gan**.nə.wai	103.19	100.34	107.35	105.32	101.12
i.ňdə.**gan.nan.naŋ**	108.39	100.79	102.06	97.88	102.51
i.**ňdə**.gæ.nə	106.44	109.07	113.13	113.42	

TABLE 3. Selection of results from pitch measurements.[a]

[a] Highest values are shaded in grey. Syllables in bold print were identified by the consultant as being prominent.

Surprisingly, the highest pitch was often found on the first or second syllable of each token. However, the highest value often does not fall on the stressed syllable. Perhaps a static measurement of pitch is not an excellent method for analysing stress. Cutler (2005) suggests that syllables are perceived to be stressed if they exhibit excursion of the fundamental frequency. It follows that the syllables should be examined for the amount of pitch movement. Figure 2 shows the pitch diagram for *kaḍəwai.*

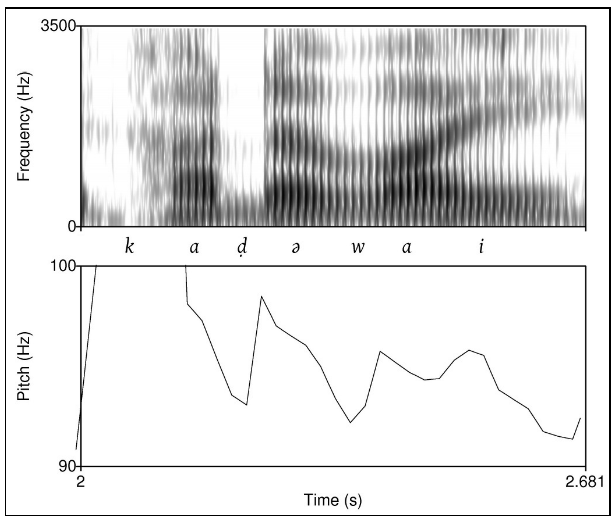

FIGURE 2. Spectrogram and pitch trace of the token *ka.ḍə.wai.*

It is important to note the high pitch values in the first syllable in the figure above. This is caused by extrapolation introduced by Praat. During the closure of the stop [k], there is no frequency information for the program to analyse. Still during the burst, there is no low frequency information (e.g. voicing). However, the burst itself contains a significant level of high frequency information. Therefore, the software extrapolates information between these two points creating a sharp rise. Once voicing begins for the vowel [a], the computer finds information corresponding to F_0. Again, the computer extrapolates information between the burst and the vowel creating a sharp fall. The same phenomenon can be seen with the stop [ḍ] (in the figure above). The only difference is that there is voicing information that is conflicting with the high energy burst, which keeps it from rising too sharply. Unfortunately, examining the pitch trace does not provide useful information in determining the stress *ka.ḍə.wai* which was found to be on the final syllable. The first syllable, if one were to ignore the extrapolation, demonstrates a movement of 5.4 Hz. The second syllable, also ignoring the extrapolation, has a movement of 4.2 Hz. The final syllable has a movement of only 4.5 Hz. Again, pitch does not immediately provide an insight to stress. The analysis of pitch will be abandoned for the remainder of this paper. The next experiment will analyse duration in hopes of finding a better correlate for stress.

2.3. EXPERIMENT II: MEASURING SYLLABLE DURATION. The previous experiment which examined intensity as a correlate for stress had mixed results. Furthermore, pitch appeared to play only a small role in realising lexical stress. Although this is contrary to results found in many previous studies, it is not necessarily conflicting information. As stated in the introduction, all languages containing stress can use any of the four correlates (and in any combination) in the realisation of stress. This section will analyse duration as a potential correlate.

Using the tokens collected for the first experiment, each syllable was measured for duration. The measurements for selected tokens are provided in Table 4.

	Duration of Syllable (in seconds)					
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**
i.ňdə.**gan**.nə.**wan**.ne	0.079	0.224	0.259	0.097	0.294	0.093
i.ňdə.**gan**.na.nə.wa	0.050	0.185	0.296	0.110	0.149	0.167
i.ňdə.**gan**.nə.**wai**	0.047	0.172	0.257	0.112	0.277	
i.ňdə.**gan.nan.naŋ**	0.065	0.172	0.289	0.281	0.260	
i.ňdə.**gan.naŋ**	0.043	0.224	0.311	0.239		
i.**ňdə**.gæ.nə	0.045	0.187	0.134	0.142		
i.ňdə.ga.**nii**	0.092	0.190	0.177	0.272		
i.ňdə.**gan**.nu.we	0.085	0.186	0.306	0.083	0.145	
i.ňdə.**gat**.ta	0.083	0.174	0.298	0.193		
i.ňdə.**gat**.te	0.112	0.167	0.274	0.162		
ad.**də**.wə.nə.wa	0.162	0.186	0.137	0.157	0.200	
æd.**dew**.wa	0.190	0.365	0.249			
æd.də.**wan**.ne	0.196	0.204	0.212	0.165		
æd.**dew**.we	0.218	0.353	0.215			

TABLE 4. Measurements of duration for selected tokens. [a]

[a] Highest values are shaded in grey. Syllables in bold print were identified by the consultant as being prominent.

It should be noted that the stressed syllables are mainly heavy syllables (i.e. those with codas, long vowels, or diphthongs). It follows that syllables with more segments will have longer durations. However, a few measurements seem problematic. Firstly, many of the syllables that occur in utterance-final position appear slightly longer than other syllables (e.g. *i.ňdə.gan.na.nə.wa* , *i.ňdə.gat.ta* , *æd.dew.wa,* and *æd.dew.we*). This lengthening appears to be an utterance-final phenomenon. Upon closer inspection, the duration of utterance-final CV syllables appear to be 1.2 times the length of word-medial CV syllables. If one were to take the duration of the final syllable in *ad.də.wə.nə.wa* and divide it by 1.2 to compensate for lengthening, it will have a value of 167 ms. This will then result in the second syllable being the longest and therefore corresponding to the syllable judged to be stressed.

	Duration of Syllable (in seconds)					
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**
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i.ňdə.**gan**.nə.**wai**	0.047	0.172	0.257	0.112	0.231	
i.ňdə.**gan.nan.naŋ**	0.065	0.172	0.289	0.281	0.217	

	Duration of Syllable (in seconds)					
i.ňdə.**gan**.**naŋ**	0.043	0.224	0.311	0.199		
i.**ňdə**.gæ.nə	0.045	0.187	0.134	0.142		
i.ňdə.ga.**nii**	0.092	0.190	0.177	0.227		
i.ňdə.**gan**.nu.we	0.085	0.186	0.306	0.083	0.145	
i.ňdə.**gat**.ta	0.083	0.174	0.298	0.161		
i.ňdə.**gat**.te	0.112	0.167	0.274	0.135		
ad.**də**.wə.nə.wa	0.162	0.186	0.137	0.157	0.167	
æd.**dew**.wa	0.190	0.365	0.208			
æd.də.**wan**.ne	0.196	0.204	0.212	0.138		
æd.**dew**.we	0.218	0.353	0.215			

TABLE 5. Tokens from Table 4 with modified utterance-final syllable measurements. [a]

[a] Highest values are shaded in grey. Syllables in bold print were identified by the consultant as being prominent.

A second issue to consider is that a few heavy syllables are significantly longer than others; yet, shorter syllables are still judged to be stressed. This problem can be seen by examining the values for *iňdəgannaŋ*. The duration of the final syllable (199 ms) is shorter than the duration of the second syllable (224 ms); yet, the final syllable is judged to be stressed. The last issue to examine is the relative closeness of some values. In the token *æd.də.wan.ne*, the peninitial and penultimate syllables only differ by 8 ms, and the initial and penultimate syllables by 16 ms. Why should such a small amount of time make such a huge difference in determining stress? Based on impressionistic analysis, the penultimate syllable seems to have a higher degree of stress than the peninitial syllable, and the first syllable does not seem to be stressed. This leads to the next experiment which derives a complex calculation involving intensity and duration in order to achieve a better characterisation of stress.

2.4. EXPERIMENT III: PRELIMINARY CALCULATIONS BASED ON INTENSITY AND DURATION. So far in this paper, it has been shown that intensity alone is not a reliable correlate of stress. Also, it has been demonstrated that measuring the highest pitch per syllable or interpreting pitch movement is not profitable. The last experiment has shown that greater duration is a good indicator of a stressed syllable. However, there are still a few issues that needed resolving. This section will combine intensity and duration measurements in order to devise a better measurement for stress.

Before proceeding forward, it should be pointed out that there have been studies conducted which attempted to link duration and intensity as physical correlates of stress. One such study is that of Fry (1955). In his study, Fry chose a group of English words in which a change of lexical category is commonly associated with a shift of stress from one syllable to another (e.g. initial stress on the noun ‘object’ and final stress on the verb ‘object’). Using spectrography, he measured the duration of all segments and the highest intensity achieved within the vowels for each target word. Since his target words were all two-syllable words, he was able to derive clean ratios which show that both duration and intensity are cues the judgement of stress. Furthermore, it was shown that vowels demonstrate the major differences in duration and intensity with a shift of stress. In the second part of his study, he manipulated vowel length and intensity levels for the target words. He then asked native English speakers to judge which syllable appeared to be stressed. The results show that duration was a more effective cue than intensity. In Section 2.2 and 2.3 of this paper, it was demonstrated that duration of the syllable was more closely correlated with stress than intensity. Thus, the findings here correspond with those of Fry's.

However, since the correlations of the duration and intensity with stress were not precise, it is worth pursuing some method of integrating the two cues in order create a better fit. The formula derived for this experiment is based on two hypothetical situations. In the first hypothetical situation where all the syllables of a word have exactly the same intensity levels, one would expect that the syllable with the longest duration is the stressed syllable. This is simply an alternate way of stating that heavy syllables are stressed, which was shown in the previous section. In the second hypothetical situation, if all syllables of a word were exactly the same length (e.g. CV.CV.CV.CV), then one would expect the syllable with greatest intensity level to be the stressed syllable. This is based on observations from the first experiment. Using these hypothetical situations, a simple formula used in the evaluation of stress can be derived simply by multiplying the intensity of a syllable by its duration, hence $s = xi$ where s is the result in units of decibel seconds (dB×s), x the duration in seconds, and i the intensity in decibels. For example, let us assume to have a two syllable word. The first syllable has a duration of x_1 and intensity value i_1, whereas the second syllable has a duration of x_2 and intensity value i_2. We can compare the two syllables as follows: x_1i_1 ? x_2i_2. If we take the first hypothetical situation and assume the intensities to be equal, i_1 and i_2 can be replaced with a single value, i, which falls out of the equation. This means the syllable with the greater duration will have a higher overall value and is realised as the stressed syllable. The same line of reasoning applies to the second hypothetical situation. The equation is essentially taking the area of a rectangular region of an intensity diagram. Therefore, the aim of this equation is to approximate the area under the intensity curve for each syllable. A straightforward method of approximating the area of the curve for a syllable is to simply use the highest intensity value and multiply it by its duration. However, using this method will result in excessively calculating area outside of the curve. This overestimation is shown in black in Figure 3(a). An alternative to this method is to multiply the average intensity value by its duration. This method, shown in Figure 3(b), calculates less area outside the curve. It is difficult to estimate which of these methods will produce better results, since this highly depends on the shape of each curve. Some curves are flatter and will have a lesser degree of overestimation using either of these techniques, whereas sharper curves will result in a higher degree of overestimation. This stage of the investigation will use the average intensity in the calculation of the energy of the syllable.

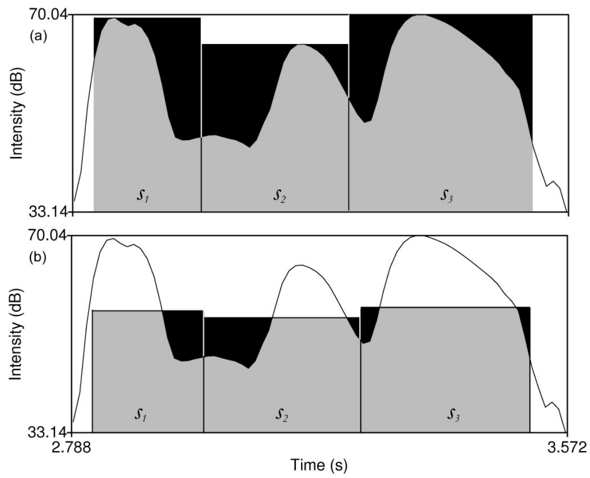

FIGURE 3. Simple methods for estimating the area under the intensity curve.[a]

[a] In (a) the highest intensity is used to define the upper boundary of each syllable. In (b) the average intensity is used to define the upper boundary. The black regions indicate the area outside of the curve that is included in the estimations.

For each syllable, the highest and lowest intensity values were recorded and then averaged. The average intensity was then multiplied by the duration of the syllable yielding a dB×sec value. This is reported below for selected conjugations of the verb *iňdəgannə* 'to sit'.

	Syllable (Average Intensity - Duration)					
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**
i.ňdə.**gan**.nə.**wan**.ne	4.88	13.84	16.21	6.14	18.09	5.40
i.ňdə.**gan**.na.nə.wa	3.01	11.18	18.81	6.57	8.80	9.66
i.ňdə.**gan**.nə.**wai**	2.67	9.85	15.92	6.79	16.54	
i.ňdə.**gan.nan.naŋ**	3.72	10.22	17.45	15.79	14.08	
i.ňdə.**gan.naŋ**	2.47	13.00	18.13	13.38		
i.**ňdə**.gæ.nə	2.71	11.38	8.30	8.77		
i.ňdə.ga.**nii**	5.59	10.94	10.63	14.99		
i.ňdə.**gan**.nu.we	4.86	10.84	17.28	4.69	8.41	
i.ňdə.**gat**.ta	5.06	10.51	14.87	9.38		
i.ňdə.**gat**.te	6.95	10.30	15.24	8.31		
æd.**da**	11.88	17.14				
æd.**de**	12.98	14.35				
ad.**də**.wə.nə.wa	9.11	10.51	7.79	8.68	9.14	
æd.**dew**.wa	10.89	21.09	15.29			
æd.də.**wan**.ne	11.37	11.88	13.98	10.00		
æd.**dew**.we	12.67	20.39	13.77			
æd.də.**wan.naŋ**	10.70	13.95	17.06	17.45		
æd.də.**wai**	10.34	12.84	14.95			

TABLE 6. dB×sec values for each syllable in selected conjugations of ***iňdəgannə*** and ***adinnə***.[a]

[a] Highest values are shaded in grey. Syllables in bold print were identified by the consultant as being prominent.

Using the measuring technique suggested above, the correlation to stressed syllables is slightly stronger. This is demonstrated by the comparing the values for *iňdəgannaŋ* in Table 6 with those in Table 5. Based on the result of this experiment, one might be able to get an even better fit by precisely measuring the area under the intensity curve for each syllable. The next experiment will do exactly that.

2.5. EXPERIMENT IV: CALCULATIONS BASED ON INTENSITY AND DURATION. The previous experiment derived a simple equation using both intensity and duration, in order to predict stress. The equation is basically an approximation of the area bounded by the intensity curve for a syllable. Syllables having a high dB×sec value corresponded with stressed syllables. The first part of this final experiment will precisely measure the intensity×time value for each syllable. The results will be compared to native speaker's intuition.

The method of measuring the area bounded by the intensity curve presented in an intensity diagram is to sample the intensity value at small, but regular, intervals. Hence, one is taking what appears to be a continuous curve and sampling the value at regular intervals throughout the syllable. This results in a set of discrete measurements. This is the basis of discrete theory, which is used in the digital reproduction of analogue signals. The measurements can be used to recreate the original curve by extrapolating information between two measurements. Hence, smaller intervals will result in a better representation of the original curve. To perform such measurements for this experiment, an acoustic analysis program developed for Matthew Gordon's research project on the perception of stress was used. Before conducting any measurements, some information regarding the analysis program is provided.

The acoustic analysis program used for this experiment was initially designed to model the perception of acoustic signals. The program takes standard RIFF .wav files of any sampling rate and creates spectra using 11 ms windows and performing a Fast Fourier Transform on each window. This is the initial process of creating a spectrogram. Each spectrum contains the values corresponding to the intensity of 128 frequency bins (i.e. each spectrum has 128 data points). The width of each bin is one-half the sampling rate (i.e. Nyquist frequency) divided by 128 (in this case, approximately 128 Hz). The values for each bin undergo a series of transformations based on psycho-acoustic research (e.g. attenuation of frequencies based on outer and inner ear properties, refractory effects, and frequency attenuation based on the intensity of neighbouring frequencies). After these transformations, the values from each spectrum are summed up resulting in a perceptual value. However, for this experiment, all of the psycho-acoustic models have been disabled, leaving the program to simply add the acoustic intensity values from each spectrum. Figure 4 demonstrates the summation process.

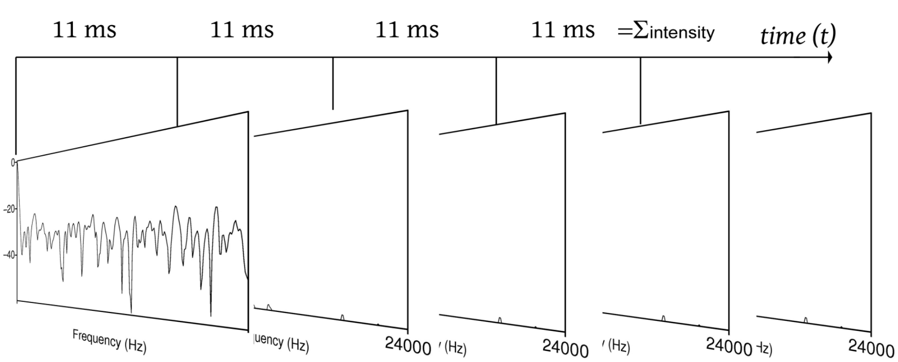

FIGURE 4. Demonstrating the summation process.

As the figure above suggests, the program moves along an audio file, in 11 ms steps, summing up the intensities. The results produced by the program are extremely large. Each spectrum provides 128 data intensity points and each syllable has a number of spectra between 4 and 30. Therefore, the results provided in this section will be linearly scaled in order to make it easier to compare values. Furthermore, since utterance-final lengthening has been regularly observed, syllables occurring utterance-finally will be scaled down to 83.3% (i.e. 1÷1.2, see Section 2.3) to compensate for lengthening.

It is important to emphasise that the values presented in this section should be interpreted relatively to each other. A syllable with an intensity-duration value of 17 is considered to have a higher degree of prominent than a syllable with a value of 10. At this stage of analysis, it is unclear how much difference is necessary in order for one syllable to be judged more stressed than the other.[2] The data provided below will be presented in three sub-sections: (1) analysis of open syllables, (2) analysis of closed syllables, and (3) analysis of syllables with long vowels. First, CV syllables will be analysed. Below are selected tokens composed of CV syllables.

	Intensity-Duration Value (Syllable)						
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**	**Syll. 7**
i.**ňdə**.gæ.nə	5.13	12.82	10.85	6.36			
ka.ḍə.nə.wa	12.81	8.26	11.15	8.76			
kæ.ḍu.we	12.27	11.65	8.32				
ka.**ḍə**.wə.nə.wa	13.08	8.10	8.10	9.14	9.06		
pe.nu.na	15.24	12.89	14.82				
pe.nu.ne	15.24	12.89	14.81				
a.**di**.nə.wa	11.25	12.03	9.51	15.14			

TABLE 7. Analysis of tokens with only open syllables.[a]

[a] Grey shading indicates syllables with the highest intensity value. Syllables in bold print were identified by the consultant as being prominent.

From the data presented in Table 7, it appears that prominence predominately occurs word-initially, with the exception of *iňdəgænə* and *adinəwa*. The difference between these two tokens and the others in the table is that their initial syllable does not contain an onset. It is possible that a word-initial syllable without an onset does not receive stress. The stress shifts over to the next syllable with an onset. This analysis can be supported by examining tokens that begin with a vowel as seen below.

[2] Further experimentation is needed to fully answer this question. When verifying the results of this experiment with native speaker intuition, sometimes a difference of 1.6 between the intensity-duration values of two syllables was sufficient for the consultant to indicate which syllable is stressed (see *æd.da* in Table 8). Also, there appeared to be a bias of selecting heavy syllables. Considering the token i.*ňdə.gan.nə.wan.ne* in TABLE 9, there is a 5.38 difference between the second and fourth syllables and a 6.79 difference between the second and last syllables. Since there are two other syllables with even higher values, the consultant readily identified the heavy syllables as being stressed.

	Intensity-Duration Value (Syllable)						
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**	**Syll. 7**
æd.**da**	14.57	16.12					
æd.**de**	15.17	17.64					
ad.**də**.wə.nə.wa	13.43	12.16	8.55	8.49	7.70		
ad.**də.wan**.ne	12.48	14.12	16.88	12.15			
ad.**də.wan.naŋ**	12.92	15.68	20.70	18.03			
ad.**də**.wai	12.78	13.07	15.06				
i.**ňdə**.ga.**nii**	6.00	11.81	11.56	15.51			
i.**ňdə.gan**.na.nə.wa	6.24	13.10	19.57	10.99	10.49	9.62	

TABLE 8. Analysis of words beginning with a vowel.[a]

[a] The grey shading indicates the higher of the two values occurring in the first two syllables. Syllables in bold print were identified by the consultant as being prominent.

When comparing only the first two syllables of the tokens in Table 8, the second syllables show slightly higher values than the first ones, with the exception of *addəwənəwa*. Furthermore, the first CV syllable, granted if only a V or VC syllable precedes it, typically has a higher intensity value when compared to other CV syllables within the same word (e.g. *addəwanne*). It can be generalised that the first syllable containing an onset will have some degree of stress.

The next two syllable types, closed syllables and those containing long vowels, are relatively straight-forward. Table 9 and Table 10 present tokens of these types along with their intensity values.

	Intensity-Duration Value (Syllable)						
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**	**Syll. 7**
i.ňdə.**gan**.nə.**wan**.ne	1.78	14.42	18.39	9.04	18.20	7.63	
i.**ňdə.gan**.na.nə.wa	6.24	13.10	19.57	10.99	10.49	9.62	
i.ňdə.**gan.nan.naŋ**	8.98	10.87	17.71	15.16	13.68		
i.ňdə.**gan**.nu.we	4.35	12.64	18.46	6.61	10.13		
i.**ňdə.gat**.ta	4.55	11.94	18.84	11.50			
i.**ňdə.gat**.te	6.42	12.48	18.09	9.18			
kæ.**ḍew**.wa	10.28	19.66	12.57				
kæ.**ḍew**.we	11.16	19.55	10.24				
ka.ḍə.wan.naŋ	11.20	7.04	18.23	15.00			
sud.də.kə.rə.nə.wa	17.83	10.34	14.29	10.09	12.82	12.63	
sud.də.ke.ruw.wa	14.95	10.11	15.66	19.08	11.36		
sud.də.kə.**ran**.ne	16.92	8.83	12.72	18.98	13.70		
sud.də.kə.**ran.naŋ**	16.38	11.10	11.74	16.93	15.26		
sud.də.kə.rə.wə.nə.wa	17.82	9.36	12.19	10.81	10.10	9.99	13.97
pen.nan.naŋ	18.85	22.22	18.30				
a.**din.naŋ**	7.39	17.36	15.68				
ad.**də.wan.naŋ**	12.92	15.68	20.70	18.03			

TABLE 9. Analysis of closed syllables.[a]

[a] Grey shading indicates closed syllables. Syllables in bold print were identified by the consultant as being prominent.

	Intensity-Duration Value (Syllable)						
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**	**Syll. 7**
i.ňdə.**gan**.nə.**wai**	6.11	14.22	16.51	9.53	17.43		
i.**ňdə**.ga.**nii**	6.00	11.81	11.56	15.51			
ka.**ḍai**	11.08	19.98					
ka.ḍə.wai	10.91	10.24	20.06				
sud.də.kə.**rai**	14.78	11.29	12.04	18.72			
sud.də.kə.rə.**wai**	14.30	8.52	10.49	10.65	16.58		
pee.nə.wa	26.83	10.95	11.12				
peen.ne	35.31	13.43					
pe.**nei**	14.09	22.96					
a.**dii**	9.17	19.25					
ad.**də**.wai	12.78	13.07	15.06				

Table 10. Analysis of syllables with long vowels.[a]

[a] Grey shading indicates syllables with long vowels or diphthongs. Syllables in bold print were identified by the consultant as being prominent.

In Table 9, closed syllables consistently had the highest intensity-duration values, while in Table 10, syllables with long vowels or diphthongs had the highest values. Table 11 compares the values gathered in this experiment with native speaker judgement. The number of grey cells in each row corresponds to the number of prominent syllables indicated by the consultant.

	Intensity Value (Syllable)						
Target	**Syll. 1**	**Syll. 2**	**Syll. 3**	**Syll. 4**	**Syll. 5**	**Syll. 6**	**Syll. 7**
i.ňdə.**gan**.nə.**wan**.ne	1.78	14.42	18.39	9.04	18.20	7.63	
i.**ňdə**.**gan**.na.nə.wa	6.24	13.10	19.57	10.99	10.49	9.62	
i.ňdə.**gan**.nə.**wai**	6.11	14.22	16.51	9.53	17.43		
i.ňdə.**gan**.**nan**.**naŋ**	8.98	10.87	17.71	15.16	13.68		
i.**ňdə**.**gan**.**naŋ**	3.97	14.32	19.27	12.20			
i.**ňdə**.gæ.nə	5.13	12.82	10.85	6.36			
i.**ňdə**.ga.**nii**	6.00	11.81	11.56	15.51			
i.ňdə.**gan**.nu.we	4.35	12.64	18.46	6.61	10.13		
i.**ňdə**.**gat**.ta	4.55	11.94	18.84	11.50			
i.**ňdə**.**gat**.te	6.42	12.48	18.09	9.18			
ka.ḍə.nə.wa	12.81	8.26	11.15	8.76			
kæ.ḍuw.wa	14.49	14.07	10.31				
ka.ḍan.ne	14.19	19.07	10.90				
kæ.ḍu.we	12.27	11.65	8.32				
ka.ḍan.**naŋ**	10.26	16.12	13.28				
ka.ḍai	11.08	19.98					
ka.**ḍə**.wə.nə.wa	13.08	8.10	8.10	9.14	9.06		
kæ.**ḍew**.wa	10.28	19.66	12.57				
kæ.**ḍew**.we	11.16	19.55	10.24				
ka.**ḍə**.wan.naŋ	11.20	7.04	18.23	15.00			
ka.ḍə.wai	10.91	10.24	20.06				
pee.nə.wa	26.83	10.95	11.12				
peen.ne	35.31	13.43					
pe.nu.ne	15.24	12.89	17.78				
pe.**nei**	14.09	22.96					

	Intensity Value (Syllable)						
pen.nan.ne	22.43	22.95	12.67				
pen.nu.we	20.92	15.08	12.67				
pen.nan.naŋ	18.85	22.22	18.30				
pen.**nai**	20.26	20.67					
a.**di**.nə.wa	11.25	12.03	9.51	15.14			
æd.**da**	14.57	16.12					
a.**din**.ne	7.48	18.78	13.28				
æd.**de**	15.17	17.64					
a.**din.naŋ**	7.39	17.36	15.68				
a.**dii**	9.17	19.25					
ad.**də**.wə.nə.wa	13.43	12.16	8.55	8.49	7.70		
æd.**dew**.wa	11.44	26.12	15.28				
ad.**də.wan**.ne	12.48	14.12	16.88	12.15			
æd.**dew**.we	14.28	28.82	13.40				
ad.**də.wan.naŋ**	12.92	15.68	20.70	18.03			
ad.**də.wai**	12.78	13.07	15.06				

TABLE 11. Sample tokens and measurements. [a]

[a] Syllables in bold print are judged to be stressed by the consultant. Values in grey are the higher values. The number of cells shaded for each word corresponds to the number of syllables selected by the consultant.

Of the 26 words which the consultant indicated as having one stressed syllable, 18 (69.2%) of the syllables corresponded the highest intensity value measured in the word. Of the 11 words where he chose two syllables (hence, 22 syllables), 19 (86.4%) of the syllables corresponded to the measurements. Of the 4 words where he indicated three stressed syllables (that is 12 syllables), all 12 (100%) corresponded to the measurements. A total of 60 syllables were identified by the consultant. Forty-nine (81.7%) of the syllables he identified were characterised by high intensity-duration measurements.

In summary, intensity and duration appear to be the key correlates in the realisation of stress in Sinhala. Native speaker intuition often correlates with the results yielded by the acoustic analysis conducted in this experiment. Based on this data, a generalisation can be made as regards stress sites. Firstly, heavy syllables are stressed. This is perhaps due to the number of segments, or moras in phonological perspective, within the syllable which in turn translates to longer duration. Secondly, the first syllable containing an onset is also stressed. At times, this initial stress appears to be weaker than the stress found in heavy syllables. If the initial syllable is CV, it will not be perceived as prominent as a CVV or CVC stressed syllable. However, if the initial syllable is CVV or CVC, then the syllable will be perceived as equally prominent as other heavy syllables. Using these generalisations, one is now able to account for stress sites in a phonological framework.

3. A PHONOLOGICAL ACCOUNT OF STRESS. From the experimental data presented in Section 2, one is able to derive a general pattern for locating stress in Sinhala verbs. This pattern can be formalised within a phonological framework. Choosing the appropriate framework is crucial. This section will commit to an Optimality Theory (OT) approach and show how OT accounts for the stress pattern observed.

Kager (1999) states that word stress patterns are typically governed by conflicting forces. The interaction of conflicting metrical constraints has been observed and reported in many pre-OT studies. The forces in conflict are rhythm, quantity-sensitivity, and edge marking. Rhythm is the pressure towards a regularly alternating distribution of weak and strong syllables. Quantity-sensitivity is the pressure to match syllable weight to prominence. Edge-marking is the pressure to mark the edges of morphemes. One can describe the pattern seen in the Sinhala verbs as a conflict of quantity-sensitivity with edge-marking (i.e. the realisation of stress on heavy syllables and the realisation of a weak stress word-initially). The central idea of Optimality Theory is that surface forms of a language reflect solutions to conflicts between competing demands. This makes OT the ideal framework to describe Sinhala stress. In order to derive the necessary constraints and rankings, one needs to compare the surface form and the suboptimal forms. This will be accomplished below.

Before deciding which constraints are needed to describe Sinhala verb stress, one first must recognise the fact that a foot-based approach is not appropriate. Firstly, there is a requirement that the head of every foot be the locus of stress. Furthermore, the foot is usually analysed as disyllabic or bimoraic. This assumption is used to describe the regular alternating distribution of weak and strong syllables. However, there is no evidence of this alternation in Sinhala. For example, the verb ***ka.**ḍə.wə.nə.wa* has been reported by the consultant as only having initial stress, where as *i.**ňdə.**gan.nan.naŋ* has a weak stress on the second syllable and heavy stress on the following three syllables. Therefore, one must not appeal to foot-based constraints. There are constraints that rely on the syllable. This is more appropriate for this task.

Having eliminated foot-based constraints, one can now begin with the analysis. The most straight-forward conflicting force to describe is syllable weight. As shown in the preceding section, heavy syllables are stressed. In this case, suboptimal candidates are defined as those with unstressed heavy syllables.

(1) i.ňdə.**gan.nan.naŋ** > i.ňdə.**gan.nan.**naŋ, i.ňdə.gan.**nan.naŋ** > i.ňdə.gan.**nan.**naŋ

The suboptimaility of the three rightmost forms in (1) is due to a constraint enforcing quantity-sensitivity. There is a close relation between syllable weight and the degree of prominence. Therefore, these forms are in violation of Weight-to-Stress-Principle (Kager 1999).

(2) **Weight-to-Stress-Principle (WSP)**
Heavy syllables are stressed.

WSP is violated anytime a heavy syllable is not stressed. It is important to note that this constraint could potentially be cumulative, in other words accrue multiple violations. For example, in (1) the right-most form would accrue two violations for having two unstressed heavy syllables.

The second conflicting force is the pressure for word-initial stress. However, there are two parts to this pattern: (1) a force pulling stress towards the left-edge of the word, and (2) the demand for an onset in the initial stressed syllable. Before defining the constraints behind these forces, we turn to current research on weight-sensitive stress for some insight as regards onset.

Gordon (forthcoming) notes that the vast majority of weight-sensitive stress systems ignore onsets in the calculation of syllable weight. Yet, it has been shown that some language do demonstrate clear cases of onset-sensitive stress. Gordon cites the work of Everett and Everett (1984) on Pirahã, an indigenous language spoken in Brazil. Pirahã has a five-way weight hierarchy in which both the onset and the rime play a role in syllable weight. The five-way hierarchy is as follows: KVV > GVV > VV > KV > GV where K stands for a voiceless consonant and G for a voiced consonant. He also cites Iowa-Oto which has stress on the first syllable unless it is onsetless, in which case stress is then on the second syllable. This is the case with Sinhala. Other languages containing this same onset-sensitive system are Lamalamic, Umbuykam, Parimankutinma, Banawá, and Arrernte. Gordon's article is an attempt to explain the basis for onset-sensitive stress and its rarity relative to rime-sensitive stress. He presents compelling evidence based on studies of the auditory system. For example, the auditory system is most sensitive to a stimulus at its onset before auditory sensitivity declines. This is typically referred to as *adaptation*. Once there is silence or a decrease of stimulation, the auditory system recovers.

In his phonological description of these systems, Gordon proposes a few important constraints, two of which will be used to describe Sinhala stress. First, notice in Section 2.5 that all but one of the syllables with an intensity-duration value has an onset. It can be stated that there is a demand for stress bearing syllables to have an onset. In the conjugations of the verb *iňdəganna* the initial syllable is never stressed.

(3) i.**ňdə.gat.**ta > **i.**ňdə.**gat.**ta, **i.**ňdə.gat.**ta**, **i.**ňdə.gat.ta,

This pattern is addressed by employing a prominence constraint that bans the occurrence of stress on onsetless syllables (Gordon forthcoming).

(4) ***PROM[∅[X]$_R$]$_\sigma$**
No syllable lacking an onset can carry prominence.

The second part of this conflicting force is the demand to align with the left edge of the word. Kager (1999) and Gordon (forthcoming) offer a set of alignment constraints that can be used to address this demand. In general, the alignment constraint is defined as in (5).

(5) **Generalised Alignment**
ALIGN (Cat_1, Edge_1, Cat_2, Edge_2) =
$\forall$ Cat_1 $\exists$ Cat_2, such that Edge_1 of Cat_1 and Edge_2 of Cat_2 coincide.

In order to use this constraint, the categories and edges must be defined. The claim is that a stressed syllable occurs word-initially. Therefore, the two categories are stressed syllable (σ́) and prosodic word (PrWd). The edges involved are the left edge of the stressed syllable and the left edge of the prosodic word. The definition of the specific align constraint is given in (6).

(6) **ALIGN (σ́, L, PrWd, L)**
For every stressed syllable there exists a prosodic word that the left edge of the stressed syllable matches the left edge of the prosodic word.

It is apparent from the data seen in Section 2.5 that not all stressed syllables occur at the left-edge of the prosodic word. Given the manner this constraint is defined, there is now a need to crucially rank the constraints in (4) and (6). Consider the ordering of WSP and the ALIGN constraint in the following tableau.

(7)

Input: /sud.də.ke.ruw.wa/	WSP	ALIGN (σ́, L, PrWd, L)
a. ☞ ˈ**sud**.də.ke.ˈ**ruw**.wa		***
b. ˈ**sud**.də.ke.ruw.wa	*!	

In (7), the winning candidate is the attested form is. This is due to the ranking of WSP above Align. If the order is reversed, the winning candidate will have only one stressed syllable which must occur at the left edge. This is demonstrated in (8).

(8)

Input: /sud.də.ke.ruw.wa/	Align (σ́, L, PrWd, L)	WSP
a. ˈ**sud**.də.ke.ˈ**ruw**.wa	*!**	
b. ☞ ˈ**sud**.də.ke.ruw.wa		*

Notice in (8a) the fourth syllable, which is behaving in accordance to the Weight-to-Stress Principle, accrues three violations of the Align constraint since it is three syllables removed from the left edge. The winning candidate in (8b) avoids this by violating the WSP constraint. Therefore, it has been established that WSP must be ranked above Align.

To determine the overall hierarchy, it must be shown how *Prom is ordered relative to the other two constraints. First, the ordering between *Prom and Align will be considered. The potential ordering for these two constraints can be shown by examining a verb in which the initial syllable is not stressed, as in (9).

(9)

Input: /ad.də.wan.ne/	*Prom$[\varnothing[X]_R]_\sigma$	Align (σ́, L, PrWd, L)
a. ☞ ad.**də.wan.**ne		*,**
b. **ad.**də.**wan.**ne	*!	**
c. **ad.**də.wan.ne	*!	

The tableau in (9) shows the winning candidate is the one that does not violate *Prom. Therefore *Prom must be ranked above Align. Now one must determine if there is a ranking between *Prom and WSP. This is demonstrated in (10).

(10)

Input: /ad.də.wan.ne/	*Prom$[\varnothing[X]_R]_\sigma$	WSP
a. ☞ ad.**də.wan.**ne		*
b. **ad.**də.**wan.**ne	*!	

When *Prom is ranked above WSP, candidate (10a) surfaces as the winning candidate. This is attested. Therefore, the overall ranking is *Prom$[\varnothing[X]_R]_\sigma$ >> WSP >> Align (σ́, L, PrWd, L). However, as it turns out there is one more constraint needed. Consider the following example of *iňdəganii* in (11).

(11)

Input: /i.ňdə.ga.**nii**/	*Prom$[\varnothing[X]_R]_\sigma$	WSP	Align (σ́, L, PrWd, L)
a. i.**ňdə**.ga.**nii**			*, ***!
b. ☞ i.ňdə.ga.**nii**			***

In (11b) the winning candidate violates the Align constraint one time fewer than the attested candidate. This undesired outcome is prevented by allowing at most one unstressed syllable to separate the leftmost stress from the left edge of the prosodic word (Gordon forthcoming). This constraint is called LAPSE LEFT.

(12) **LAPSE LEFT** (Gordon 2002)
A maximum of one unstressed syllable separates the leftmost stress from the left edge of a stress domain

LAPSE LEFT must be ranked above the ALIGN constraint in order prevent the outcome seen in (11). This is demonstrated in (13).

(13)

Input: /i.ňdə.ga.**nii**/	**LAPSE LEFT**	**ALIGN (σ́, L, PrWd, L)**
a. ☞ i.**ňdə**.ga.**nii**		*, ***
b. i.ňdə.ga.**nii**	*!	***

With LAPSE LEFT, the attested candidate is the winning one. Although it has been stated that the purpose of LAPSE LEFT is to prevent an excessive amount of unstressed syllables from appearing at the left edge of the prosodic word, it can also be thought of as a force that pulls a stressed syllable to the left. Initially, the ALIGN constraint was used to pull all stressed syllables towards the left edge. So, does it appear that the ALIGN constraint is redundant? The answer is no. It not only pulls all stressed syllables to the left, but it also restricts the number of stressed syllables appearing within the word. The following tableau demonstrates this phenomenon.

(14)

Input: /i.ňdə.ga.**nii**/	**LAPSE LEFT**	**ALIGN (σ́, L, PrWd, L)**
a. ☞ i.**ňdə**.ga.**nii**		*, ***
b. i.**ňdə.ga.nii**		*, **, **!*

So far there has been no restriction on the possibility of an open syllable being a stressed. In (14b) the open syllable is stressed; therefore, it accrues two more violations than the candidate in (14a).

The constraint hierarchy established prior to (11) was *PROM[∅[X]$_R$]$_σ$ >> WSP >> ALIGN (σ́, L, PrWd, L). In (14) it has been shown that LAPSE LEFT outranks ALIGN. This leads to the question of how does LAPSE LEFT relate to *PROM[∅[X]$_R$]$_σ$ and WSP. To determine its proper position within the hierarchy, LAPSE LEFT will be compared first to WSP. The two candidates in (15) differ only in respects to obeying LAPSE LEFT and WSP.

(15)

Input: /ad.də.wai/	**LAPSE LEFT**	**WSP**
a. ☞ ad.**də.wai**		*
b. ad.də.**wai**	*!	

As demonstrated above, in order to have the attested candidate in (15a) be the winning candidate, LAPSE LEFT must be ranked higher than WSP; otherwise the suboptimal candidate (15b) will surface. Now LAPSE LEFT will be compared to *PROM[∅[X]R]σ .

(16)

Input: /ad.də.wai/	*Prom$[\varnothing[X]_R]_\sigma$	Lapse Left
a. ☞ ad.**də.wai**		
b. **ad.**də.**wai**	*!	
c. ad.də.**wai**		*!

At first glance it appears that *Prom$[\varnothing[X]_R]_\sigma$ outranks in (18). However, notice that the attested candidate in (18a) does not violate either constraint, whereas candidates (18b) and (18c) violate one or the other. If one were to swap the ordering of these two constraints, the attested candidate would still be the winning candidate. This is demonstrated in (17).

(17)

Input: / ad.də.wai /	Lapse Left	*Prom$[\varnothing[X]_R]_\sigma$
a. ☞ ad.**də.wai**		
b. **ad.**də.**wai**		*!
c. ad.də.**wai**	*!	

Therefore, there is no crucial ranking between Lapse Left and *Prom$[\varnothing[X]_R]_\sigma$. The finalised constraint hierarchy is as follows: *Prom$[\varnothing[X]_R]_\sigma$, Lapse Left >> WSP >> Align (σ́, L, PrWd, L). To conclude the analysis of stress in Sinhala verbs, two tableaux with the full constraint rankings are presented in (18) and (19).

(18)

Input: /sud.də.kə.ran.naŋ/	*Prom$[\varnothing[X]_R]_\sigma$	Lapse Left	WSP	Align (σ́, L, PrWd, L)
a. ☞ **sud.**də.kə.**ran.naŋ**				***,****
b. sud.**də.**kə.**ran.naŋ**			*!	*,***,****
c. **sud.**də.kə.ran.**naŋ**			*!	****
d. **sud.**də.**kə.**ran.**naŋ**			*!	**,****
e. sud.də.kə.**ran.naŋ**		*!	*	***,****

(19)

Input: /ad.də.wan.ne/	*Prom$[\varnothing[X]_R]_\sigma$	Lapse Left	WSP	Align (σ́, L, PrWd, L)
a. ☞ ad.**də.wan.**ne			*	*,**
b. **ad.**də.**wan.**ne	*!			**
c. ad.də.**wan.**ne		*!	*	**
d. **ad.**də.wan.ne	*!		*	
e. ad.**də.wan.ne**			*	*,**,*!**

4. Conclusion. Section 2 examined the possibility of finding an objective procedure in the identification of phonetically stressed syllables. It was shown that intensity and duration appear to be the key parameters in the realisation of stress in Sinhala. Based on an equation which integrated the two parameters, a generalisation can be made regarding the stress pattern: (1) heavy syllables are stressed and (2) the first syllable containing an onset is also stressed. At times, the initial stress appears to be weaker than the stress found in heavy syllables. Section 3 focused on the development of a phonological account within an OT framework. Four conflict pressures were identified: (1) a ban on stress on onsetless syllables, (2) an allowance of an unstressed syllable word-initially, (3) matching prominence with syllable weights, and (4) a pull of stressed syllables to the left, which also governs the number of stressed syllables within the word.

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