Interaction between the Scottish English System of Prominence and Vowel Length

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Abstract

This study looks into interaction between the quasi-phonemic vowel length contrast in Scottish English and its word-prosodic system. We show that under the same phrasal accent the phonetically short vowels of the morphologically conditioned quasi-phonological contrast are produced with significantly more laryngeal effort (spectral balance) than the long ones, while the vowels do not differ in quality, overall intensity or fundamental frequency. This difference is explained by employing the concept of "functional load". Duration must be kept short to mark the short vowel length, while both word-stress and phrasal accent require lengthening. Therefore, the additional laryngeal effort in the short vowels serves a prominence-enhancing function. This finding supports the hypothesis proposed by Beckman that phonological categories of word-prosodic systems featuring "stress-accent" are not necessarily phonetically uniform language-internally.

1. Introduction

According to the "stress-accent hypothesis" [1] phonological categories of accentual systems are not necessarily phonetically uniform language-internally. There is some suggestive evidence that the stress-accent languages featuring vowel length may differentially employ intensity-related cues within the word-prosodic system. In such languages, duration may be "overloaded" due to its double functioning as a primary cue to vowel length and word-stress. Therefore, the other cues can be dynamically employed to achieve sufficient prominence.

For example, Fónagy [2] for Hungarian and Berinstein [3] for K'ekchi both noted that vowel peak intensity was a secondary acoustic correlate of short and long vowels in words with the same structure and prominence: i.e. in both languages the short vowels had up to 1-2 dB higher overall intensities than the long counterparts. The differences in overall intensity in both studies were systematic but small, and, thus, could be due to chance. Alternatively, the studies could report on less relevant correlates in the absence of more relevant measurements at that time.

We have reasons to believe that the latter alternative might indeed be true. More recent empirical studies on the acoustic correlates of stress and prominence in stress-accent languages have addressed the contribution of the laryngeal level in conveying stress and prominence in both speech production and perception [4-6]. "Spectral balance" (also termed as "spectral tilt" or "emphasis" for methodological reasons) is a relative measure of the intensity in spectral frequencies above low frequencies (>0.5kHz); and is a primary perceptual cue to Dutch and English word-stress close in strength to duration [4;5;7]. Besides, when duration becomes unavailable as a cue (e.g. by introducing reverberating noise), spectral balance is the strongest perceptual cue to Dutch word-stress [5]. This shows that the strength of the acoustic correlates can be adjusted dynamically within a word-prosodic system depending on such environmental conditions.

The acoustic measure of "spectral balance" reflects a relative asymmetry of the glottal pulse resulting from the greater laryngeal effort bearing a compound effect from the pulmonic and/or laryngeal levels [8]. A relative increase in the adduction force during the closing phase compared to the glottal opening [8;9] corresponds to an increase of sound pressure level (SPL) above low frequencies of the radiated spectrum, while the overall intensity may or may not be increased depending on variable factors (such as recording and speaking volumes, sound-to-noise-ratio, distance from the microphone, etc). Therefore, an acoustic measure reflecting glottal asymmetry might be a better candidate to explain the systematic but small overall intensity differences between short and long vowels found in [2;3], given that the two studies stringently controlled for the recording settings.

In this study, we look into interaction between the Scottish English vowel length and its word-prosodic system. More specifically, we address the system-internal dynamics of the intensity-related correlates of the Scottish English word-prosodic system by measuring the spectral balance differences between the short/long vowels under phrasal accent requiring lengthening. We also consider the effects of overall intensity, F0 and segmental structure (formants), since these correlates of vocal effort are known to co-vary with spectral balance [10].

2. The Scottish Vowel Length Rule and Spectral Balance

Like other English varieties, Scottish Standard English (SSE) features stress-accent [1]: i.e. it employs the acoustic parameters other than F0 (which mainly cues the intonational events) to encode prominence. It uses duration and spectral balance as primary cues word-stress [4-6]. Besides, it uses duration (accentual lengthening) as a secondary cue to phrasal accent [11].

SSE also features the "Scottish Vowel Length Rule" (SVLR) [12;13]. The SVLR involves a highly systematic distribution of vowel duration conditioned by the postvocalic consonantal voicing and manner of articulation. It applies to the vowels /i/, /ʉ/ and /ɑe/, and is conditioned by either: (1) the right consonantal context, whereby voiced fricatives and /r/ condition long duration of the vowel, while other consonants condition short duration; (2) the morphological context after the vowels: i.e. the vowels are long in word-final open syllables (as in "brew") and before the morpheme "_ed" in "brewed" [14].

The long monophthongs are about twice as long than the short ones [13;15].

The acoustic duration of vowels in SSE serves, thus, several (sometimes conflicting) functions. For example, the short vowel cannot be infinitely lengthened without interfering with the systemic shortness required by the SVLR, yet has to undergo lengthening both under word-stress and phrasal accent. It is possible that this durational "load" from the SVLR on prominence is resolved by employing other important acoustic correlates of the word-prosodic system.

In a cross-linguistic study of vocal effort involving four Scottish and four Russian adults, Gordeeva et al. [16] showed that in Scottish English the application of rule (1) in the vowel /i/ differentially affected the spectral balance of short and long vowels under phrasal accent, whereby the short vowels were produced with about 4 dB greater midfrequency RMS-power compared to the long ones. The speakers spent more laryngeal effort in producing the short accented vowel compared to the long one. However, in the study there was a confounding effect of the variable consonantal context (as in "sheep" versus "cheese").

In SSE, the differences between the application of the above Rules (1) and (2) also create a quasi-phonemic length contrast in a number of words such as "brood" /brʉd/ and "brewed" /brʉːd/ [14]. This allows comparing short and long vowels in the same consonantal contexts. We can predict significant differences in spectral balance of the short and long vowels under phrasal accent, whereby the short vowels should be produced with greater laryngeal effort (spectral balance).

3. Materials

Data were gathered from two female (Speaker 1 and 2) and one male speaker (Speaker 3) of Scottish Standard English. The recordings were made in a soundproof booth using ATM10a omnidirectional condenser microphone. The materials consisted of the minimal pair "rude" [rʉd] versus "rued" [rʉːd] embedded in the carrier sentence "I can say ___ again". The carrier words were pronounced with a nuclear pitch accent. The subjects were instructed to maintain similar prominence across utterances. There were a total of 102 instances of both carrier words for all speakers, with about 18 instances of each word per speaker.

4. Acoustic Measurements

The data was digitised at a sampling rate of 11050 Hz and 16-bit quantisation. Vowel duration was labelled using PRAAT [17]. Spectral balance was automatically measured from the annotated vowel duration (Dur, ms). We used the methodology described in more detail in [16;18].

The spectral level (dB, SPL) was calculated in 600Hz-bands around F2 and F3 from the short term Discrete Time Fourier Transform (DTFT). A Hamming window of 46 ms was used to extract the speech signal samples. The spectral level is defined as 20 times the base-10 logarithm of the measured root-mean-square (RMS) value in a frequency band, relative to the maximum RMS value allowed by 16-bit quantisation. The spectral bands did not overlap. The mean RMS-power values (dB) were extracted for each band over the steady part of the vowel. The steady part was defined as 25% of the total vowel duration from the onset, and 40% to the offset, the minimum allowed duration of the steady part was set to 25 ms. The overall intensity (OI, dB) was measured the same way as in the spectral bands, with the difference that the RMS-power measurements covered all spectrum frequencies.

The raw RMS-power measurements in spectral bands around F2 and F3 were then corrected for the intra- and inter-speaker variability in overall intensity by subtracting the OI value of the token from its RMS-power around F2 and F3. We also corrected for the supralaryngeal effects due to formant shifts using [4;9]. This resulted in two normalised RMS-power measurements (dB): i.e. A2* for F2 and A3* for F3.

Additionally, we used F2 (Hz) and F3 (Hz) to control for any RMS-power differences due to differences in formant structure. We also used F0 (Hz) of the central frame of the vowel steady-state to control for potential influence of F0 on the intensity measurements.

5. Statistical Analysis

We investigated the main effect of the vowel length on the acoustic correlates of vocal effort in prominent syllables, and whether this effect was speaker-dependent. Therefore, we ran a multivariate analysis of variance ($\alpha = .05$) with DUR, OI, A2*, A3*, F2, F3, F0 as dependent variables and with "length" and "subject" as fixed factors.

6. Results

The results are summarised in Table 1. The results showed a highly significant main effect of the factor "length" for the dependent variables DUR, A2* and A3*, and no significant main effect for the variables OI, F2, F3 and F0.

Table 1 *The results of the multivariate ANOVA.*

	Main effects				Interaction	
	Length (df=1,96)		Speaker (df=2,96)		(df=2,96)	
Variable	F	p	F	p	F	p
Dur, ms	320.3	<.001	25.6	<.001	17.2	<.001
A2*, dB	11.3	<.001	112.4	<.001	0.7	ns
A3*, dB	38.8	<.001	258.9	<.001	2.1	ns
OI, dB	0.5	ns	34.8	<.001	3.3	<.05
F2, Hz	1.9	ns	80.3	<.001	3.4	<.05
F3, Hz	2.6	ns	31	<.001	2.5	ns
F0, Hz	0.9	ns	1474	<.001	0.5	ns

This result confirms our prediction that the quasi-phonemic Scottish English vowel length triggers a differential employment of laryngeal effort (A2* and A3*) under phrasal accent. The acoustic duration is differentiated as a function of the length contrast. Other correlates of vocal effort (OI, F2, F3 and F0) are not significantly affected under these circumstances.

There is also a highly significant main affect of the factor "speaker" on all the dependent variables. This could be expected, since the three speakers had very different F0 means (see Table 2), and also varied in absolute formant values due to differences in vocal tract size. Furthermore, individual speaking volumes inevitably varied across the speakers, affecting all intensity-related parameters. Vowel duration differed reflecting the individual variation in producing the short and long vowels.

However, there were no significant "length*speaker" interaction for the variables A2* and A3* that could affect our prediction. There was a significant interaction involving OI that is explained by the fact that Speaker 2 had on average lower OI on the long vowels than on the short ones, while the other speakers produced it the other way around (see Table 2).

Importantly, despite this speaker-dependent variability in overall intensity, the direction of the short/long differences in A2* and A3* remained systematically the same for all three speakers. The direction of the acoustic difference in A2* between the short and long vowels for each of the speakers is represented in Figure 1. The figure illustrates that the subjects produced the short SSE vowel on average with a 3.3 dB greater RMS-power levels around F2 (A2*) compared to the long one. For A3*, the difference was in the same direction for all speakers, and the mean magnitude of the RMS-power difference was 5.3 dB.

Table 2 *Subject means for the seven acoustic variables in the short and long vowel length condition.*

	Speaker					
	1		2		3	
Variable	short	long	short	long	short	long
Dur, ms	84	124	91	187	88	175
A2*, dB	-27	-30	-19	-22	-35	-39
A3*, dB	-34	-40	-17	-20	-35	-42
OI, dB	-23	-22	-20	-21	-24	-23
F2, Hz	1582	1477	1853	1848	1644	1667
F3, Hz	2656	2682	2407	2387	2314	2466
F0, Hz	198	196	202	200	126	127

Figure 1 *Speaker means for the RMS-power around F2 for the short and long Scottish English vowel [ʉ].*

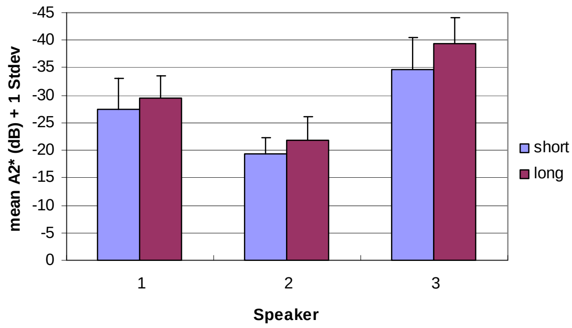

Figure 2 *Long-term average spectrum of all short (blue plain line) and all long (red dashed line) tokens of [ʉ] produced by Speaker 3 (male).*

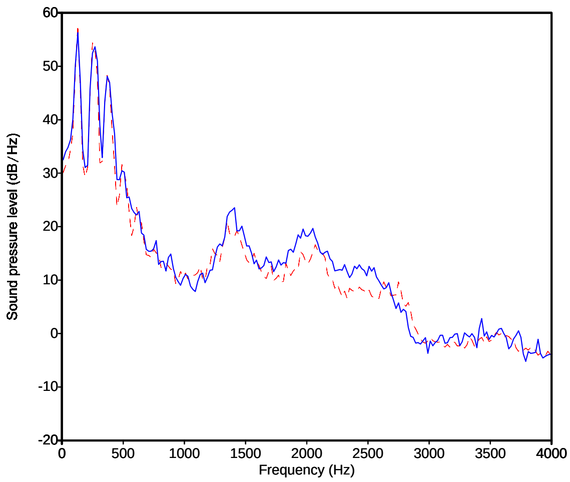

Figure 3 *Correlation between the measure A3* (dB) and the duration of /ʉ/ (ms) for the three SSE speakers.*

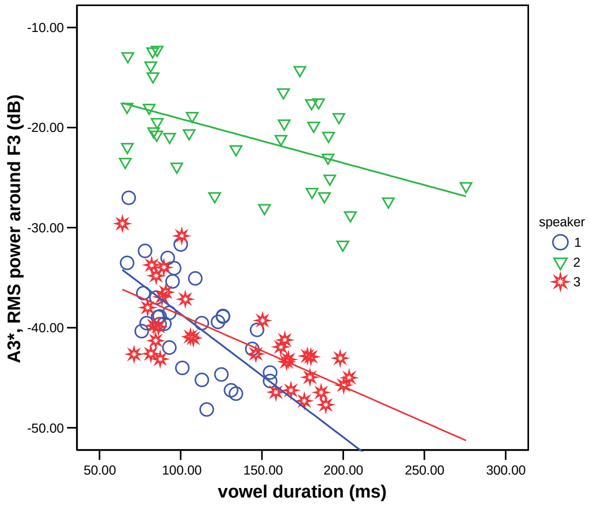

Figure 2 shows this effect on the long-term average spectrum of all "rude" and "rued" tokens produced by the Subject 3. It is clear that the two vowels (short and long) do not substantially differ in formant frequencies; yet the RMS-power levels of the short vowel (blue plain line) are higher in F2 and F3 and higher than those of the long one (red dashed line).

Additionally, Figure 3 shows the systematic negative correlation between the measure A3* (dB) and vowel duration (ms) for each of the three speakers. This supports the idea that the laryngeal effort and vowel duration are interdependent correlates under phrasal accent.

The direction of the higher frequency RMS-power differences confirms our hypothesis that the SSE short prominent vowels are systematically produced with greater laryngeal effort than the long ones.

7. Discussion and Conclusions

The aim of this study was to look into the dynamics of interaction between the quasi-phonemic vowel length in Scottish English and its word-prosodic system. We tested the hypothesis that Scottish English may differentially employ intensity-related correlates, such as spectral balance (A2* and A3*), within its word-prosodic system, since the acoustic correlate "duration" serves several (at times conflicting) functions. For example, such a "conflicting" situation as to duration arises when the short SVLR vowel has to undergo lengthening both under word-stress and phrasal accent.

The higher frequency (> 0.5kHz) intensity measures in this study reflect the asymmetry of the glottal pulse with the higher values of A2* and A3* corresponding to greater laryngeal effort. The results show that under phrasal accent the short vowels (in items "rude" [ˈrʉd]) are systematically produced with 3 to 5 dB higher A2* and A3* than the long ones (in "rued" [ˈrʉːd]). This effect is manifested in the absence of the confounding influence of the surrounding consonants; and it appears that the extent and the direction of the differences is very similar to those already observed in the post-vocalic consonantal conditioning of short/long SSE vowels [16].

The effect is not accompanied by any significant differences between tokens [ˈrʉd] and [ˈrʉːd] in vowel quality, F0 or overall intensity. The absence of the significant effects in OI suggests that the differences in spectral balance have the origin in the employment of laryngeal structures rather than of the pulmonic ones, as OI is proportional to subglottal pressure.

Under phrasal accent, the short vowels have systemic limits from the SVLR "shortness" conflicting with the accentual lengthening. The laryngeal effort is a good candidate to compensate for this durational conflict under phrasal accent, since the laryngeal level is not lexically contrastive, and because in this context the other acoustic parameters already encode intonational meaning (F0) and segmental contrasts (vowel quality, formants).

The minor differences in overall intensity between short/long vowels in Fónagy [2] for Hungarian and Berinstein [3] for K'ekchi, were in the same direction as the significant spectral balance differences in this study. Therefore, it is very likely that for these languages the underlying differences in mid- and high frequency intensities are more substantial than OI. Different stress-accent languages featuring vowel length may employ language-specific means to deal with the functional overlap in duration, and have different solutions to compensate for the load. For example, languages like Dutch [19] and Finnish [20] use differentiated temporal pitch alignment with the accented syllables for the phonologically short and long vowels. It is, thus, an open question whether such primary (as to phrasal accent) F0-alignment differences in short/long prominent vowels are also accompanied by the secondary laryngeal effort differences, or not. Recall, though, that there are no significant F0 differences between the short/long SSE vowels in this study that would suggest the opposite: i.e. a pitch-alignment difference in the SSE short and long /ʉ/.

The finding of differentiated laryngeal effort in SSE vowel length is a good example of a dynamic nature of word prosodic systems [1]. The strength of the acoustic correlates to prominence can be adjusted depending on the environmental factors such as ambient noise [5] or the language-internal load on the word-prosodic correlates from the phonological system itself, such as the case with the Scottish Vowel Length Rule in this study.

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9. References

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