

Phonetics of Southern Welsh Stress

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Abstract

This study is concerned with the phonetic manifestations of primary and secondary stress in Southern Welsh. The study found effects of primary stress on duration and F2 in the language. Specifically, vowels with primary stressed had longer duration and horizontally expanded vowel space when compared to unstressed vowels. Although there was significant difference in F0 between primary stressed vowels and their unstressed counterparts, F0 trajectory suggested no effect directly associated with stress. No significant effects of secondary stress were found in the present study. Due to the position shift of primary stress from the ultima to the penultimate (around the eleventh century) (Williams & Ball, 2001), vowels that occupy the ultima syllables were also included in the investigation. No clear stress related phonetic prominence was found for ultima vowels, except for word-final lengthening.

Keywords: stress, prosody, Welsh, Celtic

1 Introduction

Lexical stress is a suprasegmental linguistic phenomenon, which can provide rhythmic structure in a fixed-stress language such as in Turkish Kabardian and Polish (Gordon & Applebaum, 2010; Hayes, 2009). It can also encode lexical information in a language with phonemic stress, as in English and Spanish (Hayes, 2009). Earlier denotations on word level stress emphasised the strength of articulation during production of the stress bearing syllable, more specifically on ‘force’ and ‘loudness’ (Jones, 1949; Bloomfield, 1933; Bloch & Trager, 1942; Fry, 1958; Kingdon, 1958; Morton & Jassem, 1965).

This paper aims to examine which phonetic measures correlate with word stress in Welsh spoken in the southern region of Wales (primary and secondary). Not much research on stress has been done in the Celtic language family. Therefore, it is of interest to determine which cross linguistic features of stress extend into a language such as Welsh, and what its language-specific stress related characteristics are. There has been little experimental work done on word stress in Welsh and its sister languages – Breton and Cornish. Williams conducted her experimental study on Welsh stress for a PhD thesis in 1983. However, due to experimental designs, Williams’s study had several confounds and no consistent control group for the evaluation of acoustic properties in stressed vowels (see section 1 for details).

Earliest experimental study on the acoustic correlates of linguistic stress goes back to Fry’s work in English. Fry explored two phonetic manifestations of stress in English - duration and intensity (Fry, 1955). The experimental material consists of English words that change from a noun to a verb triggered by a change of stress location, such as in ‘object, digest and permit’ (Fry, 1955, P.765). Results of measurements and perceptual tests showed that both duration and intensity cue perception of stress, with duration having a more salient effect (Fry, 1955). Later in

1958, Fry extended his investigation into other acoustic cues including fundamental frequency, and confirmed its positive effect on stress perception; furthermore, he proposed the explicability of vowel quality (vowel space reduction) as a physical correlate to word stress (Fry, 1958). Since then, experimental work on word stress has mostly focused on the four acoustic correlates mentioned above cross linguistically – duration, F0, intensity and vowel quality.

In general, stressed vowels are related to phonetic correlates such as raised pitch, amplified intensity, longer duration, change in vowel quality and reduction in unstressed vowels (Gordon & Applebaum, 2010). Suggested by a great volume of research in stress hitherto, longer duration is said to be a constant cue to stress across languages (Ortega-Llebaria & Prieto, 2010). Consequently, supported by the ‘Hyper- and Hyperarticulation’ theory, when a vowel is unstressed, it is reasonable to suppose that shorter articulation time would lead to phonetic undershoot – centralisation of unstressed vowels (Lindblom, 1990 ; Garellek & White, 2015, p.26). Thus, a reduction in vowel space for unstressed vowels may be a phonetic characteristic in stress languages. However, typological differences across languages and other factors such as accentual conditions on the suprasegmentally level have resulted in varied conclusions on which correlates signal stress in different languages. For example, Ortega-Llebaria and Prieto (2010)’s work on Castilian Spanish and Central Catalan showed that stress correlates perform differently according to the focus status of the word. They found that duration serves as a strong cue to stress under both conditions in both languages, but not intensity, fundamental frequency or spectral-tilt (Ortega-Llebaria & Prieto, 2010). However, research done in Dutch, Polish, Macedonian, American English and Bulgarian suggest that change in vowel quality functions as a robust correlate to word stress (Sluijter & van Heuven, 1996a; Sluijter, 1995; Ortega-Llebaria & Prieto, 2010; Crosswhite, 2003; Ortega-Llebaria & Prieto, 2010; Plag, Kunter & Schramm, 2011).

Typological differences in stress manifestation may be due to phonological properties of the language under investigation (Gordon & Applebaum, 2010; Garellek & White, 2015). For example, pitch may not be used to signal stress in a language that has lexical tones, which is supported by results of Everett (1988) in Pirahã and Gandour, Harper & Potisuk (1996) in Thai, where tones are phonemic in both languages (Everett, 1988; Gandour, Harper & Potisuk, 1996; Gordon & Applebaum, 2010). According to Gordon & Applebaum (2010)’s paper on Turkish Kabardian, pitch and duration have a positive correlation with stress and intensity has minor effect on the production of stress. Notably, Turkish Kabardian employs a ‘vertical three-vowel system’, where only the vowel height is contrastive. There are many allophones of these vowels in the language due to its phonological rules of assimilation, such as labialisation, velarisation and fronting, depending on the succeeding consonant (Gordon & Applebaum, 2010, p.36).

Thus, according to Gordon and Applebaum, the inconsistent results of vowel reduction as a function of stress may be resultant of Turkish Kabardian’s assimilation rules that signal surrounding consonants, which leaves less room for vowel reduction (Gordon & Applebaum, 2010). In the Garellek and White (2015) paper on stress in Tongan, a reduction or expansion in vowel space was not found, but an upward shift – lowering of the first formant. Motivation behind the shift in vowel space in Tongan may also be due to the fact that there are few phonemes in the language’s vowel inventory, and a reduction in vowel space could harm perceptual distinctiveness (Garellek and White, 2015). Therefore, it is of interest to inspect whether there exists

an interaction between vowel space and stress conditions in Welsh, and if so, how such effect manifests according to the language's typological features.

This study will investigate acoustic correlates of stress and secondary stress in Southern Welsh, specifically regarding the six short vowels. Due to the Old Welsh Accent Shift (shift of stress position from word ultima to the penult), a compelling amount of literature suggests that the new penultimate stress in Welsh only serves as a rhythmic function, and the language's phonetic salience, such as F₀, had remained in the ultima (Williams, 1983; Jones, 1949; Thomas, 1984; Watkins, 1993). Williams's study also suggests certain acoustic salience of the ultima syllable (Williams, 1983). Therefore, due to Welsh's language-specific characteristics, in addition to the primary and secondary stressed syllable, the ultima syllable will be included in the study.

This paper has the following structure: firstly, the paper will introduce some typological properties of Welsh and review previous research done on Welsh stress. Then, an overview of language background will be given, which include information on Welsh's phonemic inventory, stress pattern and the Old Welsh Accent Shift. Thirdly, experimental methods and material will be explained, followed by reporting of the study's results. Finally, discussion of outcomes, their implications for research in acoustic properties of stress and a conclusion of this study will be drawn.

1.1 Typological features and previous research of Welsh stress

Southern Welsh has eleven monophthongs, specifically six short vowels and their long counterparts, except for the short mid central schwa. Similar to the Williams paper, the five long vowels will not be examined for the purpose of this study, since they only occur in stressed positions and mostly in monosyllabic words (Williams, 1999). Since there exists distinction between long and short vowels in Welsh, duration may not serve as a strong cue to stress for the sake of greater perceptual distinctiveness. Stress is non-contrastive in Welsh, primary stress mainly falls on the penultimate syllable; secondary stress is alternating and falls on the second to the last stressed syllable from the right edge of the word. Recall that Gordon and Applebaum (2010) noted in their paper that the limited effect of stress on vowel reduction in Turkish Kabardian may be due to the non-phonemic status of stress in the language. This could also be the case in Southern Welsh.

Williams' research consists of four main parts – preliminary measurements of stressed vowels based on listener judgements; further measurements of actual stressed vowels in spontaneous speech; measurements of stressed and unstressed consonants, followed by perceptual tests with artificially manipulated stimuli (modifying coda consonant /m/) (Williams, 1983). In the preliminary study, materials were recordings of one male Southern Welsh speaker producing 12 regularly stressed polysyllabic words in a carrier sentence. The carrier sentence used was 'Dydi hi ddim yn ddigon i YSGRIFENNU ___' ('It's not enough to WRITE ___'); transcribed in IPA as /dɨdɨ hi ðɨm ən ðɨgən ɪ sgrɨvənɨ ___/ (Williams, 1983, p.28). Therefore, Williams's results regarding duration and pitch could have been confounded by the utterance final position of target words, namely under the effects of utterance/phrase final lengthening and boundary tones (Xu & Wang, 2009).

Twelve acoustic parameters were used to compare target syllables (syllables **judged** as stressed in the preliminary study and stressed syllables in the second study) to other syllables **within** the same word. These parameters include 'shorter duration', 'lower estimated amplitude integral', 'F₀ change (within vowel) of less than 15 Hz',

‘higher F0 at start of vowel’, ‘greater mean amplitude’, ‘greater peak amplitude’ and their conversed counterparts (Williams, 1983, p.30).

Two monolingual English speakers judged syllables that correspond to the following properties to be stressed - ‘longer duration’, ‘greater estimated amplitude integral of vowel’, ‘F0 change greater than 15Hz’ and ‘greater peak amplitude’ (Williams, 1983, p.31). The Welsh speaker showed an opposite trend in judgement results. According to such results, monolingual English speakers judged the position of stress according to acoustic cues in their native language. Since stress is predictable in Welsh, the native Welsh speaker’s judgement reflects the actual trend of acoustic properties of stressed syllables in the data (compared to other syllables within the word).

However, as noted previously, such results are likely to be due to comparison of the stressed syllables to other syllables in the word, especially to the word initial and final syllables. Moreover, position of the target word in the carrier sentence may have further confounded the data trend as a result of sentence/phrase final lengthening. According to Williams, the conclusion that stressed syllables have shorter duration may also be due to the fact that the phonologically short schwa is permitted in the ultima position in Welsh (Williams & Ball, 2001).

The second part of Williams’ research measured stressed syllables produced during spontaneous speech. Results of this part of her study exhibited a parallel trend in acoustic properties with the Welsh speaker’s judgement from the preliminary study. Influence of sentential position may be smaller for the second part of the study, yet the same confounds were present regarding Williams’ choice of control group or the lack thereof. In addition, effects of word initial and final lengthening were not taken into account. Research done in Mandarin Chinese (Xu & Wang, 2009) and English (Nakatani, Aston & O’Connor, 1981) both support the effects of word-edge lengthening. All in all, Williams concluded that stress in Welsh is marked by **shorter** duration, **lower** amplitude and **lack** of pitch raise (Williams, 1983).

Since the schwa does not appear in word ultima position in Welsh, Williams later conducted research in which the schwa was omitted, in order to control for its effects on duration results. However, it is still difficult to disentangle effects of word/phrase-final lengthening in the results. Interestingly, this research shows that stressed penultimate vowels are slightly longer than unstressed antepenultimate vowels. In this study, mean durations for unstressed and primary stressed vowels were 71ms and 75ms respectively. However, sample sizes used were significantly asymmetrical (349 cases for primary stress and 97 for unstressed) (Williams & Ball, 2001, p.180).

In the third part of Williams’ study, 176 consonants’ durations were measured by stress categories –syllable onset and coda positions when stressed and unstressed. Williams found significant post-vocalic lengthening effect when the syllable bears stress (Williams, 1999, p.3). Furthermore, Williams’s final perceptual study found that longer duration of stressed coda consonant cues stress even in stimuli with a superimposed flat F0 contour, and that F0 does **not** affect listeners’ stress perception (Williams & Ball, 2001; Williams, 1999). Such findings of consonant strengthening by stress may suggest overall lengthening of the stressed syllable in Welsh. This prominence induced consonantal lengthening effect has also been found in early studies of Dutch, which uses duration to encode stressedness of vowels. It was observed that stressed consonants had longer duration in both syllable onset and coda positions. (Nootboom, 1972).

Contradictory results have been reported regarding Williams (1983)'s conclusion on the lack of F0 change in stressed vowels. Later research showed that stressed penult has higher pitch compare to unstressed syllables by around 17 Hz. However, similar to Williams's updated study mentioned above, sample sizes are highly uneven, and thus it is hard to determine the correlation between stress and F0 from the data. Therefore, it is necessary for a study with new experimental designs to be conducted, in order to gain a more comprehensive understanding of the phonetics of Welsh stress. More specifically, using word and phrase medial unstressed vowels as the control group.

1.2 Background on the Welsh language (Southern dialect)

Table 1 Southern Welsh vowel (top) and consonant (bottom) inventory

	Front		Central		Back	
	short	long	short	long	short	long
Close	ɪ	i:			ʊ	u:
Mid	ɛ	e:	ə		ɔ	o:
Open			a	a:		

	Bilabial	Labial -dental	Dental	Alveolar	Post- alveolar	Velar	Uvular	Glottal
Plosives	p b			t d		k g		
Nasal	m̥ m			n̥ n		ŋ		
Trill				r̥ r				
Fricative		f v	θ ð	s	ʃ		χ	h
Lateral- fricative				ɬ				
Lateral- approximan t				l				

1.2.1 Vowel inventory

As table 1 demonstrates, Modern Southern Welsh has six phonological short vowels and five long vowels. However, vowel length is only contrastive in monosyllabic words (see example 1 below for minimal and near minimal pairs).

- (1) [ˈme:l] mêl ‘honey’ [ˈmɛlm] melin ‘mill’
 [ˈto:n] tôn ‘tune’ [ˈtɔn] ton ‘wave’
 [ˈkʰu:n] cŵn ‘dogs’ [ˈkʰɔn] cwm ‘valley’

(adopted from Hannahs, 2013, p.24)

Long vowels only appear in stressed syllables and is sometimes marked by a circumflex such as ‘mêl’ and ‘tôn’ in example (1) above. Table 1 reflects vowel inventory of the southern variety of Welsh. In addition, Northern Welsh has a high central vowel /i/ and its long counterpart /i:/. The present study focuses on the southern dialect.

1.2.2 Language background and the Old Welsh Accent Shift

The Welsh language emerged from its mother language Common Brittonic (belonging to the Celtic family in the Indo-European language, also referred to as British) around the fifth century, then was recognised as an independent language by the mid-sixth century (Willis, 2009; Williams, 1999). There was little to no written documentation of the language (Old Welsh) until the mid-eighth century.

Literature that makes use of manuscripts from the ninth to eleventh centuries dates the Old Welsh Accent Shift to the thirteenth century, although this is still controversial (Griffen, 1991&1992; Williams & Ball, 2001; Hannahs, 2013). Despite controversy of the specific dating, large amount of documentation suggests a clear shift of stress location in the language. Welsh's parent language Brittonic had stress on the penultimate syllable, while the ultima position was occupied by inflectional endings (Williams, 1983; Hannahs, 2013). The loss of inflectional ending around the sixth century marked the transition from Brittonic to Old Welsh (Williams, 1999). Due to deletion of the last syllable, Old Welsh was then stressed on the ultima, the Old Welsh Accent Shift refers to when stress relocated to the penultimate syllable around the late eleventh century (Williams & Ball, 2001; Williams, 1999).

1.2.3 Stress patterns

In Modern Welsh, regular primary stress falls on the penultimate syllable in polysyllable words and the ultima in monosyllabic content words (see example 2a); monosyllabic function words do not bear stress (Czerniak, 2015; Williams, 1983). Secondary stress appears in words with four syllables or more and sometimes on the first syllable of trisyllabic words with irregular main stress on the ultima. Secondary stress is alternating and falls on the second syllable to the last stressed syllable (see example 2b). (Williams & Ball, 2001).

Irregular primary stress can fall on the ultima or antepenultimate. These cases mainly occur in loanwords (see example 2c) or stress reassignment triggered by morphological context (see example 2d).

- (2) a. ['ta:d] tad 'father'
 ['tada] tatau 'fathers'
 [blə'nəðɔ:ð] blynyddoedd 'years'
- b. [ˌbɛndɪ'gɛdɪg] bendigedig 'blessed'
 [ˌkaniə'ta:d] caniatâd 'permission'
- c. ['paragraf] paragraff 'paragraph'
 ['tɛstament] testament 'testament'
- d. [əm'la:ð] ymlâdd 'to be concerned'
 [əs'to:l] ystôl 'stool'
- (adapted from Czerniak, 2015, p.133 and Williams & Ball, 2001, p.166)

1.2.4 Schwa distribution

A final matter worth noting is the distribution of the schwa in Welsh. As mentioned previously, the schwa in Welsh is permitted in the ultima position. Yet, unlike other languages such as English and Russian, it can freely occupy the stressed penult

(Hannahs, 2013, p.24). Furthermore, it lacks a long counterpart unlike other vowels in the inventory. This may be due to the language specific rule that long vowels only occur in monosyllabic words and the schwa could not occupy that position in Welsh (Hannahs, 2013).

3 Methodology

3.1 Participants

Four female native Welsh speakers of the southern dialect living in London participated in this study. They were all aged between 20 and 45 years old and are originally from areas around Cardiff (on the Southern coast of Wales). All participants have lived in London for at least 3 years, however they stated that they communicate with friends and families in Welsh daily. Participants all received a compensation of seven pounds and fifty pence per hour for their involvement.

3.2 Stimuli

There were in total ninety-four words used in the study. Mainly four-syllable words ($(\text{CVCV}'\text{CVCV})$) were used for primary stressed, ultima and unstressed vowels. Words with irregular stress (i.e. certain loanwords and morphologically complex words) were not used in this study. Regularity of stress location for all stimuli was confirmed by a native Welsh language informant who did not participate in later recordings. There were nine three-syllable words used for primary stressed vowels and vowels at the ultima position; this was due to difficulties finding four-syllable words that fit the local environment criteria of the required vowel (such as /a/ and /ɔ/ at the ultima position and /ɪ/ at the penultimate position). There were also difficulties in finding /ɛ/ and /ʊ/ in an open syllable at word final position. In this case, $\text{CVCV}'\text{CVCVC}$ words were used instead.

For secondary stress, five-syllable words ($\text{CV}'\text{CVCV}'\text{CVCV}$) were used, most of them had plural or derivational suffixes added to four-syllable words. This is to avoid word-initial boundary effects on the secondary stressed syllable in four-syllable words. Note that there are two ways to pronounce the plural suffix '-au' - /ai/ in formal register, and /ɛ/ in informal register. In order to maintain consistency, speakers were informed to pronounce the plural suffix in the colloquial way (/ɛ/).

For the control group - unstressed vowels, antepenultimate syllables in four-syllable words were used, also to minimise effects of word boundaries in three-syllable words. In order to control local environment to minimise effects of coarticulation, surrounding consonants were kept constant to a few natural classes. Most neighbouring consonants were fricatives, in conjunction with some nasals, the liquid /l/ or the trill /r/.

See Appendix for full word list.

3.3 Procedure

The stimuli were presented as a wordlist written in Welsh on A4 papers, and were read out loud by the participants. A carrier sentence was used to embed every word – '*Dywedwch y gair ____ i fi.*' ([dəu'ɛduχ ə 'gai ____ ɪ 'vi]), '*Say the word ____ for me*'. There were three repetitions for each word, five words per stress level (word position) and per vowel, which produced 115 tokens per repetition, same set of tokens for

unstressed vowels were later used as the control group for comparison. There were 345 tokens from each speaker, yielding 1380 tokens in total. For the repetitions, the original word list was randomised in excel to avoid any priming effects. All recordings were done at the UCL Phonetics lab, in a sound-proof booth, and with a RØDENT1-A microphone. Recordings were made using Audacity, at a sampling rate of 44.1 kHz, then saved as .wav files. Tokens were then labelled manually in PRAAT using textgrid (Boersma & Weenink, 2009). Segment boundaries were determined according to clear onset and offset of the second formant (F2). The labelled files were analysed in VoiceSauce (Shue et al, 2011). Six acoustic parameters were chosen for measurements of F0, duration, energy (intensity), formant heights and voice quality (see table 2 below for details).

Table 2. Acoustic measurements

Measurements	Description	Parameters used in VoiceSauce
Fundamental Frequency	Pitch – in Hertz (Hz)	STRIGHT algorithm (Kawahara, Masuda-Katsuse & de Cheveigné, 1999)
Duration	Duration of vowels – in milliseconds (ms)	Running Duration
Intensity/Loudness	RMS energy	Energy
First Formant (F1)	Height of F1 – in Hz	Snack SoundToolkit(sjölander, 2004)
Second Formant (F2)	Height of F2 – in Hz	Snack SoundToolkit(sjölander, 2004)
Voice Quality	H1*-H2* and CPP	CPP – algorithm by Hillenbrand, Cleveland & Erickson (1994)

(adapted from Garellek & White, 2015, p.16&17)

Mean values of measurements for the whole vowel were computed by VoiceSauce and output as a text file. For voice quality, H1*-H2* measures the amplitude (dB) difference between the first and second harmonics (Garellek & White, 2015). Typically, spectral structures of breathy voice include higher amplitude of the first harmonic (higher spectral tilt); on the other hand, creaky voice has a lower first harmonic but higher second, third or fourth harmonic in amplitude (Hillenbrand, Cleveland & Erickson, 1994). Thus, in comparison to values of modal voice, lower values usually correspond to creaky voice and higher values to breathy voice (Bickley 1982; Garellek & White, 2015). Central peak prominence (CPP) measures the distance from the cepstral peak to the cepstrum regression line, and cepstral peak is usually less prominent for breathy voice (Hillenbrand, Cleveland & Erickson, 1994). Noise in the voice such as aspiration or irregular voicing in creaky voice are both associated with lower CPP values (Garellek & Keating, 2011).

3.4 Confounds and exclusions.

Due to choice of carrier sentence in this study, following segment of the target word is the vowel (/ɪ/), which may lead to glottalisation of the vowel in word-final open

syllables. Thus, results of CPP and H1*-H2* for vowels at the ultima position may be influenced.

Out of 1380 tokens, ten were excluded during labelling. For speaker two, this include two secondarily stressed /ʊ/ and one secondarily stressed /ɛ/ (mispronunciation). For speaker four, three unstressed /ʊ/, three secondarily stressed /ʊ/ and one primarily stressed /ʊ/ were excluded. All exclusions of /ʊ/ were due to severe reduction of the vowel around liquid consonants or possibly shortened duration for unstressed instances. The aforementioned cases all had reduction to the point of unidentifiable or missing segments (of target vowels).

During data analysis, any values more than three standard deviations from the mean were removed before statistical testing.

4 Results

4.1 Linear mixed effects model

This part of the study was concerned with determining which acoustic parameters are used to cue stress in Southern Welsh, and if word final vowels differ phonetically from unstressed vowels. Significant difference between unstressed and stressed/ultima vowels will be reported. Results of each acoustic measurement (see table 2) are analysed with linear mix effects models using the *lmer()* function provided in the *lme4* package. The aim of the analysis was to investigate the relationships between the acoustic values and stress/Welsh ultima effects. All statistical analysis was done in the software - *R* (R Development Core Team, 2008). Analysis procedure followed the instructions in Baayen (2008a) Chapter 7.

Three models were constructed for comparisons between stressed (primary and secondary) and unstressed vowels, and unstressed and ultimate vowels. The models used all included maximal random effects/slopes structures, such approach attests to better retain analytical power compared to conventional ANOVA analysis (Barr et al, 2013). These models each had a fixed effect for vowel (six short vowels, see table 1) and stress (word position for comparison between ultima and unstressed vowels). Note that the schwa was excluded for comparison between ultima and unstressed vowels. Three random effects were also included in the models – speaker, word and order (order of word production during recording). These random intercepts should account for uncontrollable variables such as speaking rate, speaker and word differences. By-speaker and by-order random slopes for the effects of stress/ultima effect were also included in the models. By including random slopes, model fit was significantly improved, according to likelihood ratio tests performed with the function *anova()* in *R* (Baayen, 2008a). Random slopes should account for the variability in stress/word position's effectiveness on speakers and order of production.

For analysis of the effects of stress in general (for all vowels), comparison using *anova()* was made, between models including fixed effects for stress and vowel and null models with one fixed effect (vowel). *p*-values and X^2 -values provided in the likelihood ratio tests output will be reported. Where there is a significant effect according to the likelihood ratio test, *t*-value in the model output will be reported. Analysis of effects of the ultima follows the above procedure, by replacing stress as fixed effect with word position (the ultima) in the models.

For individual vowels, a vowel by stress interaction will be added to the general model, to determine if the interaction significantly improves model fit. If significant effects for vowel by stress interaction are observed, additional models will be fitted

for each individual vowel by sub-setting the data. The models for within vowel comparisons had a fixed effect of stress, (no fixed effect for vowel), and random intercept and slopes for speaker only. Random intercepts and slopes for word and order had to be excluded due to convergence problem (possibly due to not enough within vowel observations for the model to estimate the effects of word and order) (Barr et al, 2014).

4.2 Fundamental frequency (F0)

Table 3 Mean F0 (Hz) for vowels with primary stress and no stress, t -values taken from linear mix effect model output, X^2 values and p -values adapted from likelihood ratio tests output (for standard deviation see parenthesis).

Vowels	Primary stress	No stress	t -value	χ^2 -values	p -values
/ɪ/	207.17(17.44)	217.14(21.09)	-1.53	$X^2(1) = 2.31$	0.13
/ɛ/	195.70(16.60)	215.25(23.00)	-3.51	$X^2(1) = 6.51$	<0.01*
/a/	194.52(16.44)	209.89(22.83)	-2.83	$X^2(1) = 5.19$	<0.02*
/ɔ/	193.85(19.46)	214.86(21.25)	-3.39	$X^2(1) = 6.20$	<0.01*
/ʊ/	202.78(19.45)	207.20(20.87)	-1.20	$X^2(1) = 1.52$	0.22
/ə/	203.81(16.73)	215.55(18.21)	-3.88	$X^2(1) = 7.18$	<0.007**
Overall	199.64(18.34)	213.32(21.41)	-3.03	$X^2(1) = 5.64$	<0.02*

Figure 1: Mean F0 (Hz) bar plot for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N – no stressed; P - primary stress; S- secondary stress).

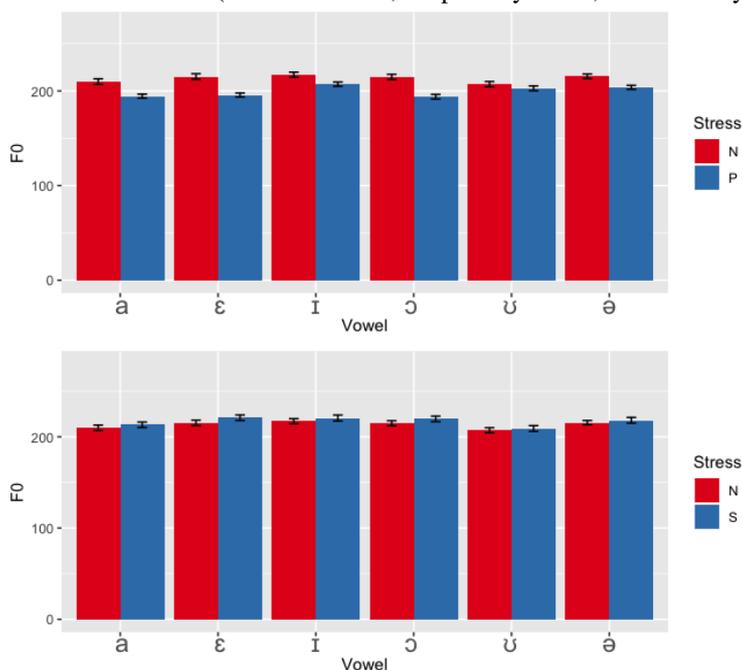


Figure 2: Mean F0 (Hz) bar plot by vowel for ultima vowels and unstressed vowels. Error bars indicate standard error of the mean. (N - no stress; U – ultima).

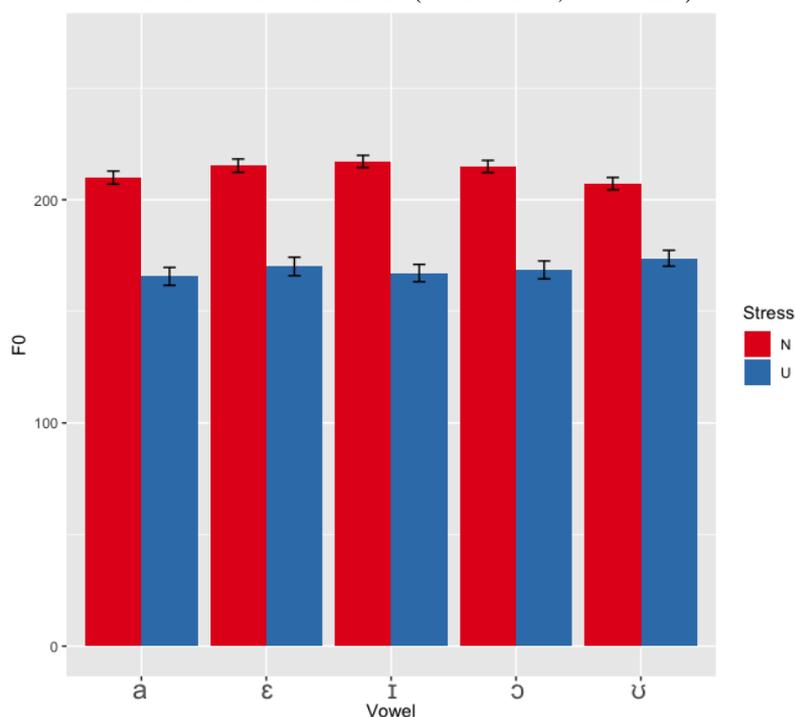


Figure 1 illustrates the means of fundamental frequency for each vowel under stressed (primary and secondary) and unstressed conditions. It is shown that vowels with main stress have significantly lower F0 values (overall by 13.68Hz) ($X^2(1) = 5.64$, $p < 0.02^*$), and this effect is least significant with the vowel /ʊ/. By adding a vowel by stress interaction in the model, likelihood ratio tests showed significant improvement of model fit ($X^2(5) = 19.46$, $p < 0.002^{**}$). Therefore, additional models were fitted for individual vowels for the effect of primary stress, in order to locate the variabilities. Results show that for /ɪ/ and /ʊ/, effect of primary stress on F0 is insignificant while the rest remained significant (see table 3).

Contrarily, secondary stressed vowels showed a positive effect on F0 values (see lower panel in figure 1). However, comparison between models with and without secondary stress as fixed effect did not have a significant result ($X^2(1) = 1.51$, $p = 0.22$).

Figure 2 shows that all vowels in ultima positions have lower pitch than unstressed syllables. Likelihood ratio tests shown significant results for such effect ($t = -4.85$, $X^2(1) = 8.802$, $p < 0.003^{**}$). No significance was found by adding interaction in the model for vowel by stress ($X^2(4) = 8.90$, $p = 0.06$). This indicates that the observation of overall pitch lowering in this case are similar across vowels.

4.3 Duration

Table 4 Mean duration (ms) for vowels with primary and no stress, t -values taken from linear mix effect model output, X^2 values and p -values adapted from likelihood ratio tests output (for standard deviation see parenthesis).

Vowels	Primary stress	No stress	t -values	χ^2 -values	p -values
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/ɪ/	87.58(28.79)	58.75(23.27)	7.52	$X^2(1) = 13.69$	<0.0002***
/ɛ/	125.77(33.88)	65.68(27.32)	5.54	$X^2(1) = 9.58$	<0.002**
/a/	129.99(30.07)	77.98(21.50)	5.38	$X^2(1) = 9.46$	<0.002**
/ɔ/	106.73(35.77)	60.34(21.68)	4.66	$X^2(1) = 8.76$	<0.003**
/ʊ/	73.36(36.18)	37.80(21.84)	6.37	$X^2(1) = 13.63$	<0.0002***
/ə/	61.06(21.03)	51.80(17.76)	1.16	$X^2(1) = 1.48$	0.22
Overall	97.52(40.38)	58.90(25.39)	5.93	$X^2(1) = 10.89$	<0.001**

Figure 3: Mean duration (ms) bar plot by vowel for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N - no stress; P - primary stress; S - secondary stress).

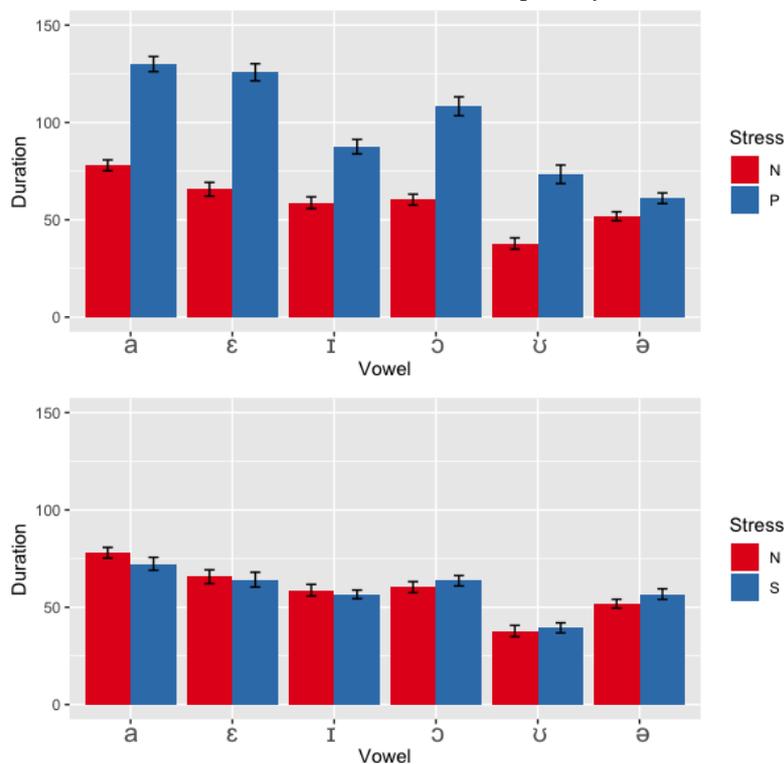


Table 5 Mean duration (ms) for ultima vowels and unstressed vowels, t -values taken from linear mix effect model output, X^2 values and p -values adapted from likelihood ratio tests output (for standard deviation see parenthesis).

Vowels	Ultima	No stress	t -values	χ^2 -values	p -values
/ɪ/	128.99(39.62)	58.75(23.27)	5.99	$X^2(1) = 10.24$	<0.001**
/ɛ/	128.98(40.97)	65.68(27.32)	5.31	$X^2(1) = 9.27$	<0.002**
/a/	128.89(42.95)	77.98(21.50)	3.35	$X^2(1) = 6.19$	<0.01*
/ɔ/	138.08(46.61)	60.34(21.68)	4.83	$X^2(1) = 8.69$	<0.003**

/ʊ/	103.43(43.73)	37.80(21.84)	3.67	$X^2(1) = 6.10$	<0.008**
Overall	125.74(44.07)	60.34(26.46)	4.58	$X^2(1) = 8.90$	<0.003**

Figure 4: Mean duration (ms) bar plot by vowel for ultima and unstressed vowels. Error bars indicate standard error of the mean (N - no stress; U – ultima).

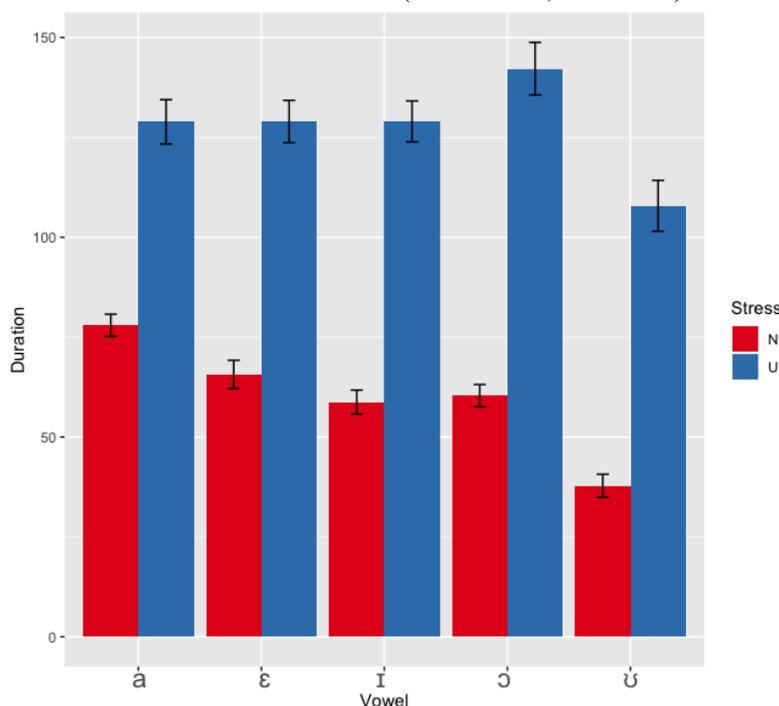


Figure 3 shows mean vowel duration values under the effect of stress (primary and secondary) and without. For primary stress, there is a significant effect of stress except for the vowel /ə/ ($X^2(1) = 10.891$, $p < 0.001$ **). Overall, vowels with main stress has a longer mean duration of 38.62ms (see table 4). By adding a vowel by stress interaction, likelihood ratio tests showed significant improvement of model fit ($X^2(5) = 33.001$, $p < 0.0001$ ***). Thus, within vowel models were fitted for evaluations of primary stress's effect on duration for each vowel. Each likelihood ratio test results suggests significance effect of primary stress on duration, apart from the vowel /ə/ (see table 4). Figure 3 also demonstrates mean durations of secondary stressed and unstressed vowels. Figure 3 (lower panel) shows inconsistent results of the effect of secondary stress, likelihood ratio tests also indicated that no significant effect on duration was found for secondary stress ($X^2(1) = 0.643$, $p = 0.42$).

Figure 4 shows that vowels at word ultima position all have longer durations compared to when unstressed, overall by 65.40ms (see table 5). Likelihood ratio tests without vowel by stress interaction showed significant result ($X^2(1) = 8.902$, $p < 0.003$ **). Tests with vowel by stress interaction also indicated significance of the effect on duration by word final position ($X^2(4) = 26.484$, $p < 0.0001$ ***). Therefore, further likelihood ratio tests were performed with additional models, accordingly to each vowel. The further tests demonstrate that there exists significance of duration difference for every vowel (see table 5). However, such results do not directly suggest any (Welsh) language internal word final lengthening effect. In other words, residual stress related effects from the Old Welsh Accent Shift. It is difficult to disentangle

cross linguistic effect of word/phrase edge lengthening from the significance seen here. Further evaluations will be made in the discussion section subsequently (see section 5.1).

4.4 RMS energy

Figure 5: Mean RMS energy bar plot by vowel for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N - no stress; P - primary stress; S - secondary stress).

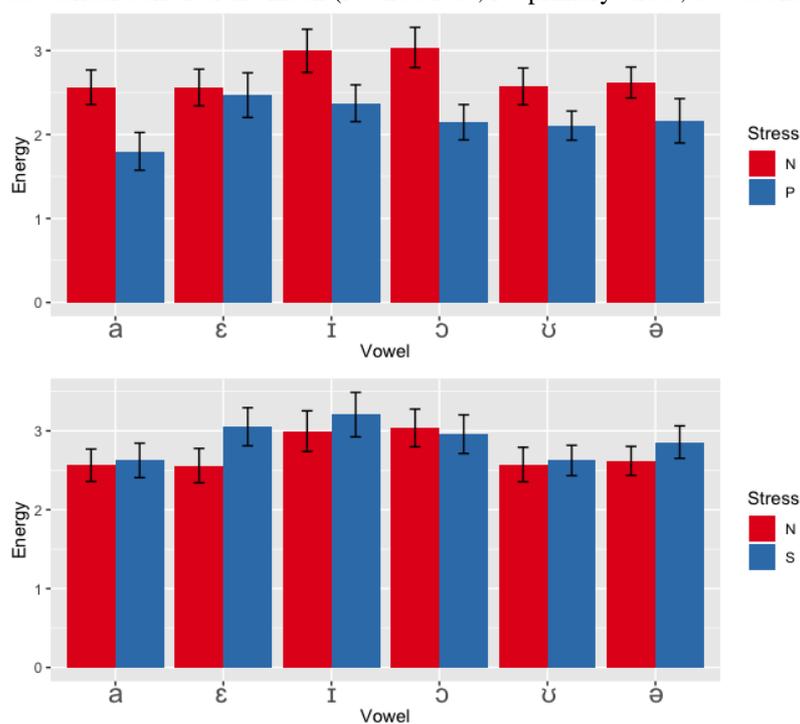


Figure 6: Mean RMS energy bar plot by vowel for ultima and unstressed vowels. Error bars indicate standard error of the mean (N - no stress; U - ultima).

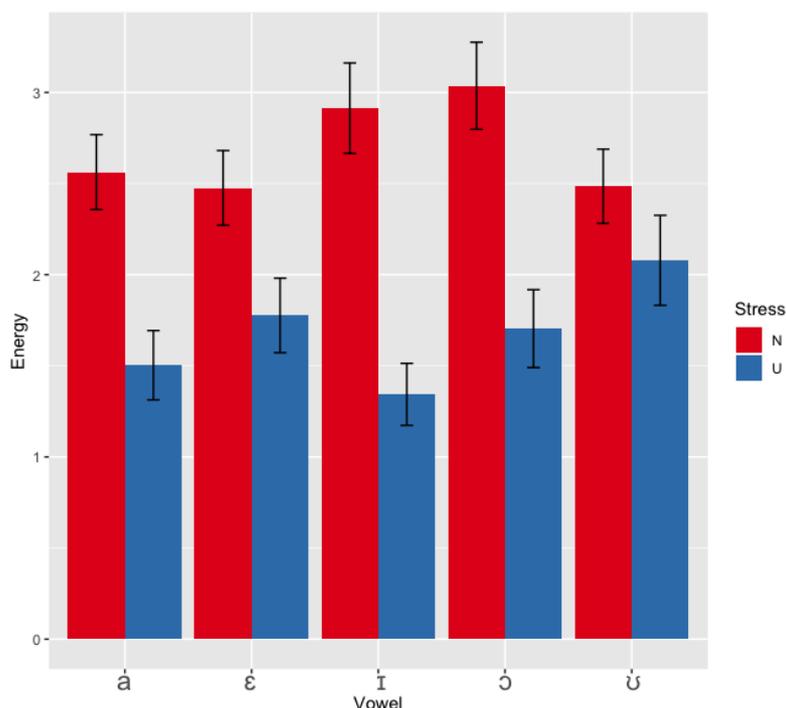


Table 6 Mean RMS energy for ultima vowels and unstressed vowels, *t*-values taken from linear mix effect model output, χ^2 values and *p*-values adapted from likelihood ratio tests output (for standard deviation see parenthesis).

Vowels	Ultima	No stress	<i>t</i> -values	χ^2 -values	<i>p</i> -values
/ɪ/	1.34(1.32)	2.91(1.86)	-2.51	$\chi^2(1) = 4.54$	<0.03*
/ε/	1.78(1.58)	2.48(1.56)	-3.61	$\chi^2(1) = 6.70$	<0.01**
/a/	1.50(1.45)	2.56(1.58)	-3.00	$\chi^2(1) = 5.55$	<0.02*
/ɔ/	1.70(1.64)	3.04(1.84)	-4.07	$\chi^2(1) = 7.50$	<0.006**
/ʊ/	2.08(1.91)	2.49(1.52)	-0.62	$\chi^2(1) = 0.47$	0.49
Overall	1.68(1.60)	2.70(1.68)	-2.89	$\chi^2(1) = 5.39$	<0.02*

Figure 5 demonstrates the mean RMS energy values of stressed (primary and secondary) and unstressed vowels. There was no significant effect for both primary and secondary stress found ($\chi^2(1) = 2.379$, $p = 0.12$, for primary stress) ($\chi^2(1) = 0.880$, $p = 0.35$, for secondary stress). Furthermore, figure 5 suggests contradictory effect between primary and secondary stress on RMS energy.

Figure 6 shows significant results when comparing unstressed and word ultima RMS energy across vowels ($\chi^2(1) = 5.389$, $p < 0.02^*$). A likelihood ratio test of this effect showed significant results with a vowel by word position interaction in the model ($\chi^2(4) = 19.184$, $p < 0.0007^{***}$) (see table 6). Likelihood ratio test for each vowel gave significant result, except for the vowel /ʊ/.

4.5 Formant heights (first and second formants)

Figure 7: Mean F1 (Hz) bar plot by vowel for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N - no stress; P - primary stress; S - secondary stress).

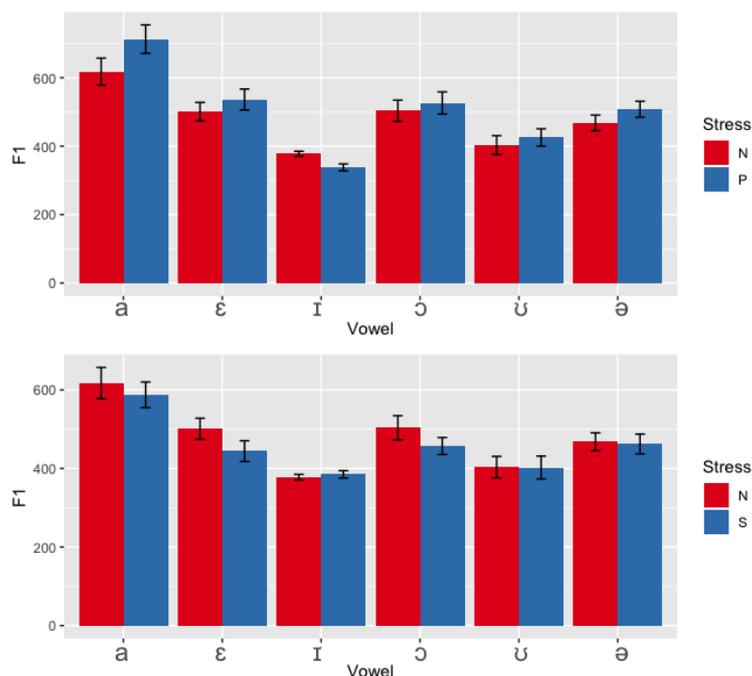


Figure 8: Mean F1 (Hz) bar plot by vowel for ultima and unstressed vowels. Error bars indicate standard error of the mean (N - no stress; U - ultima).

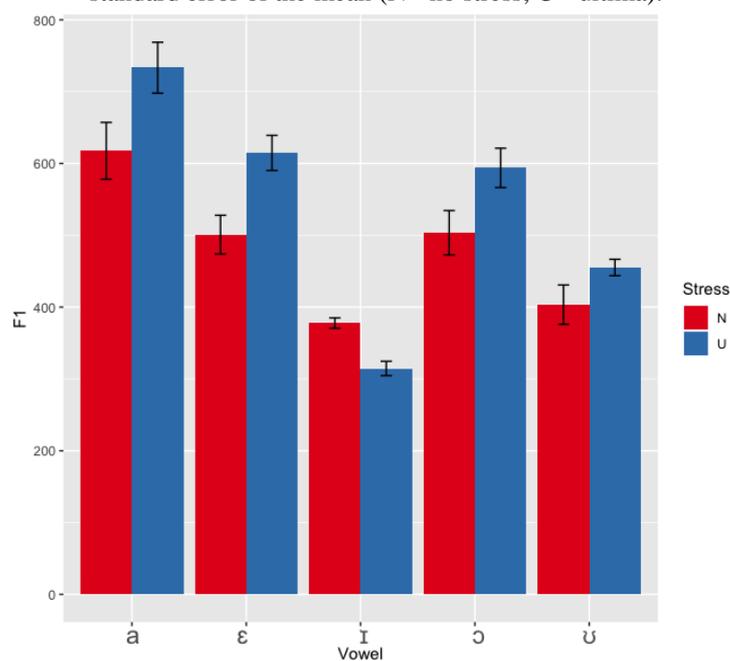


Figure 7 shows mean F1 (Hz) for the effect of stress between stressed and unstressed vowels. Overall, primary stressed vowels have higher F1 values in comparison to unstressed, and secondary stressed vowels have lower F1 values for stressed vowels. Vowel /i/ showed opposite effect within different stress levels. However, likelihood ratio tests did not indicate significance for effect of stress for both stress levels in either direction ($X^2(1) = 0.67$, $p = 0.41$, for primary stress), ($X^2(1) = 0.44$, $p = 0.51$, for secondary stress). Moreover, models fitted with vowel by stress interactions did not improve model fit for both stress conditions ($X^2(5) = 4.34$, $p = 0.50$, for primary stress), ($X^2(5) = 1.70$, $p = 0.89$, for secondary stress).

Vowels at word ultima positions have overall higher F1 values than unstressed (similar tendency with primary stress, see figure 7 and 8). No significant improvement of model fit was achieved for potential effect of ultima position on F1 ($X^2(1) = 2.06, p = 0.15$).

Figure 9: Mean F2 (Hz) bar plot by vowel for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N - no stress; P - primary stress; S - secondary stress).

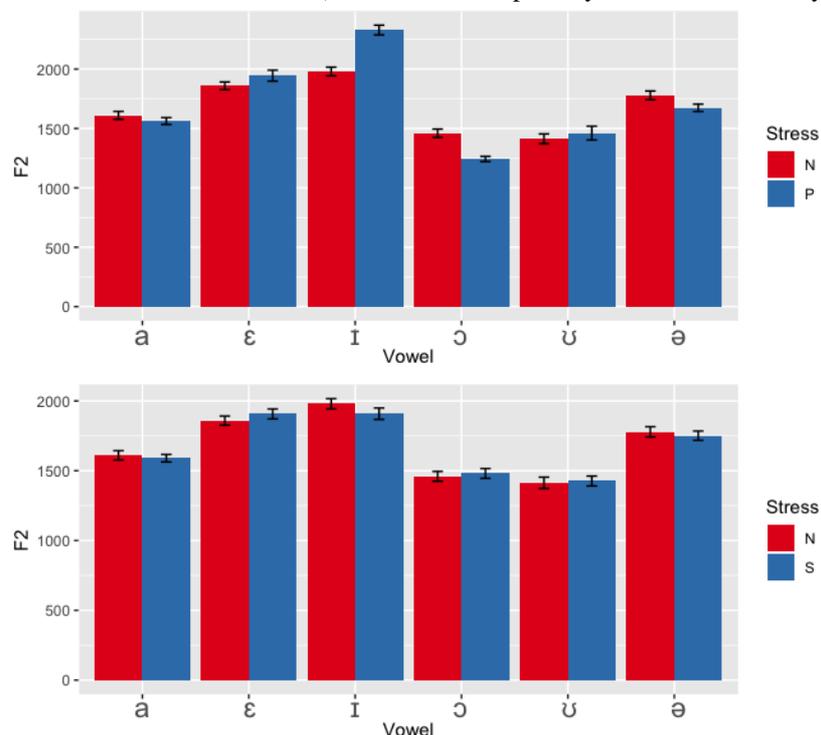


Figure 9 depicts mean F2 values for stressed and unstressed vowels. A likelihood ratio test did not find overall significance for the effect of stress for both primary and secondary stress ($X^2(1) = 0.004, p = 0.95$, for primary stress), ($X^2(1) = 0.12, p = 0.74$, for secondary stress). However, likelihood ratio test with vowel by stress interaction for primary stress significantly improved model fit, which suggests that there exists significant effect of stress on F2 for some vowel(s) ($X^2(5) = 25.46, p < 0.0001^{***}$). Therefore, within vowel comparisons were made for each vowel (see table 7). Contrarily, there was no significance by adding vowel by stress interaction for secondary stress ($X^2(5) = 1.28, p = 0.94$).

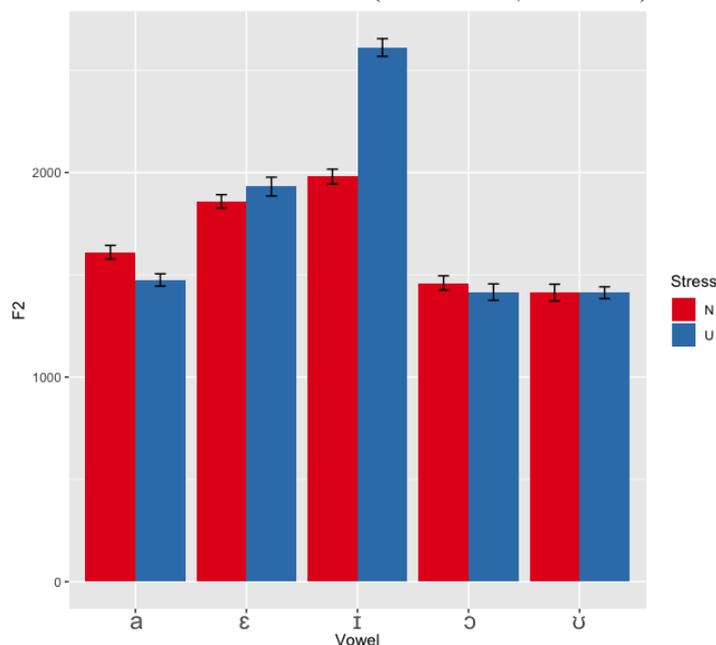
Table 7 Mean F2 (Hz) for vowels with primary and no stress, *t*-values taken from linear mix effect model output, X^2 values and *p*-values adapted from likelihood ratio tests output (for standard deviation see parenthesis).

Vowels	Primary stress	No stress	<i>t</i> -values	χ^2 -values	<i>p</i> -values
/I/	2329.02(317.84)	1979.75(283.85)	4.79	$X^2(1) = 8.63$	<0.003**
/ε/	1944.88(357.96)	1858.92(252.80)	1.27	$X^2(1) = 1.60$	0.21
/a/	1562.46(225.07)	1610.32(259.49)	-1.04	$X^2(1) = 1.12$	0.29
/ɔ/	1243.05(170.24)	1459.86(271.94)	-5.27	$X^2(1) = 9.16$	<0.002**
/ʊ/	1460.96(441.89)	1413.04(309.15)	0.51	$X^2(1) = 0.31$	0.58

/ə/	1674.13(240.60)	1778.69(285.82)	-2.26	$X^2(1) = 4.49$	<0.03*
Overall	1703.77(464.77)	1685.70(344.21)	-0.08	$X^2(1) = 0.004$	0.95

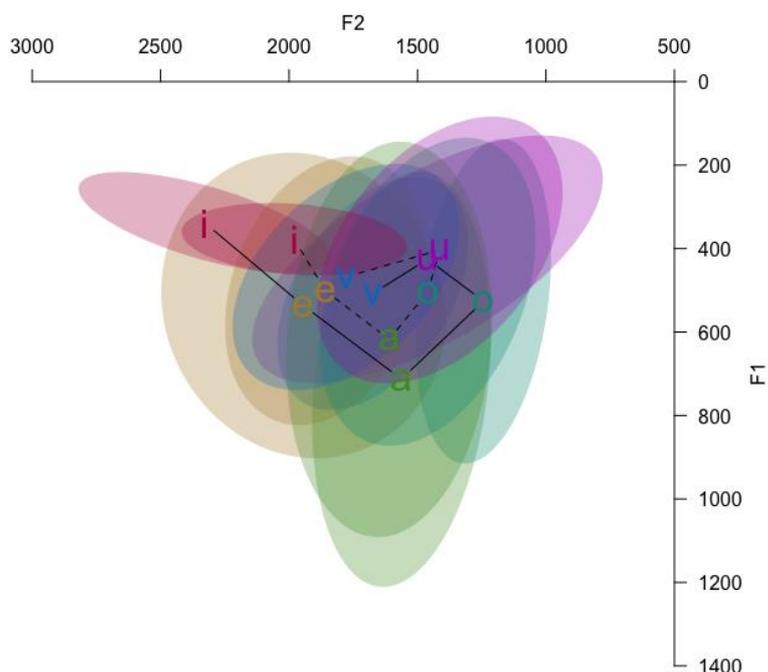
Within vowel comparison indicates when vowel /ɪ/ is primary stressed, its F2 is significantly higher; where vowel /ɔ/ and /ə/ showed significant lowering of F2 when primary stressed (see table 7).

Figure 10: Mean F2 (Hz) bar plot by vowel for ultima and unstressed vowels. Error bars indicate standard error of the mean (N - no stress; U - ultima).



Likelihood ratio test did not show improvement of model fit by effect of word ultima position on F2 ($X^2(1) = 3.07, p= 0.08$).

Figure 11: Vowel plot for primary and unstressed vowels (i- /ɪ/, e- /ɛ/, o- /ɔ/, u- /ʊ/, v- /ə/; Primary stress – solid line; Unstressed – dotted line).



Although there was only statistical significance for primary stress's effect on F2 for three vowels, figure 11 shows an overall consistent pattern of centralisation in vowel space for unstressed vowels (except for the vowel /ʊ/). Note that centralisation is most effective on more peripheral vowels according to figure 11, such as the vowels /i/, /ɔ/ and /a/. A more comprehensive review of this centralising effect will be given in the discussion section (see section 5.5).

4.6 Voice quality (CPP and H1*-H2*)

Figure 12: Mean CPP bar plot by vowel for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N - no stress; P - primary stress; S - secondary stress).

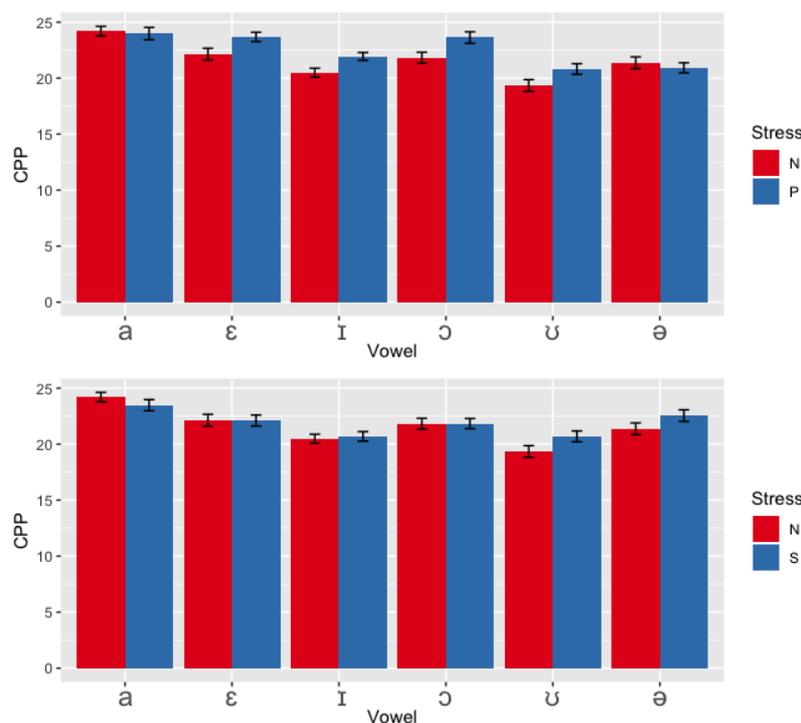


Figure 12 shows inconsistent effect of stress on CPP values. For primary stress, CPP values are higher for front and back vowels (/ɛ/, /ɪ/, /ɔ/ and /ʊ/) but not central vowels such as /a/ and /ə/ (see upper panel in figure 12). This indicates that vowels that bear primary stress are slightly noisier than when unstressed. No significance was found in the likelihood ratio test for stress as a fixed effect for primary stress ($X^2(1) = 2.98, p = 0.08$). Secondary stress showed less variations in CPP values between stressed and unstressed vowels, likelihood ratio test indicated no significance for the effect of stress ($X^2(1) = 3.53, p = 0.06$). Furthermore, adding a vowel by stress interaction in the model did not improve model fit for both stress levels ($X^2(5) = 7.45, p = 0.19$ for primary stress), ($X^2(5) = 3.12, p = 0.68$ for secondary stress). Figure 13 shows similar inconsistency for the effect of word position on CPP values, and likelihood ratio test indicated no significance for the effect of word ultima position on CPP measurements ($X^2(1) = 0.32, p = 0.57$).

Figure 13: Mean CPP bar plot by vowel for ultima and unstressed vowels. Error bars indicate standard error of the mean (N - no stress; U - ultima).

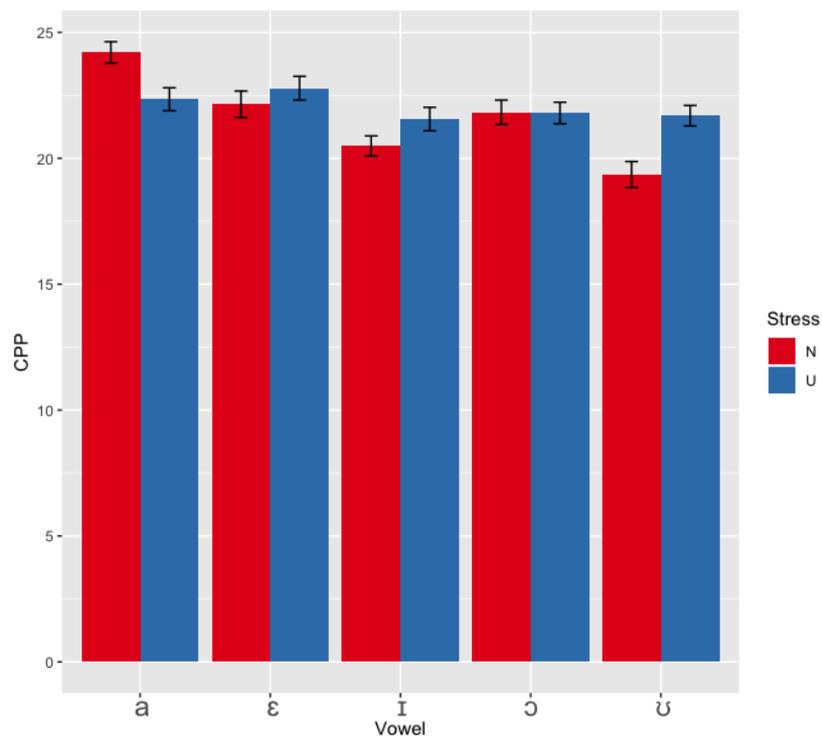


Figure 14: Mean H1*-H2* (dB) bar plot by vowel for primary (upper) and secondary (lower) stress. Error bars indicate standard error of the mean (N - no stress; P - primary stress; S - secondary stress).

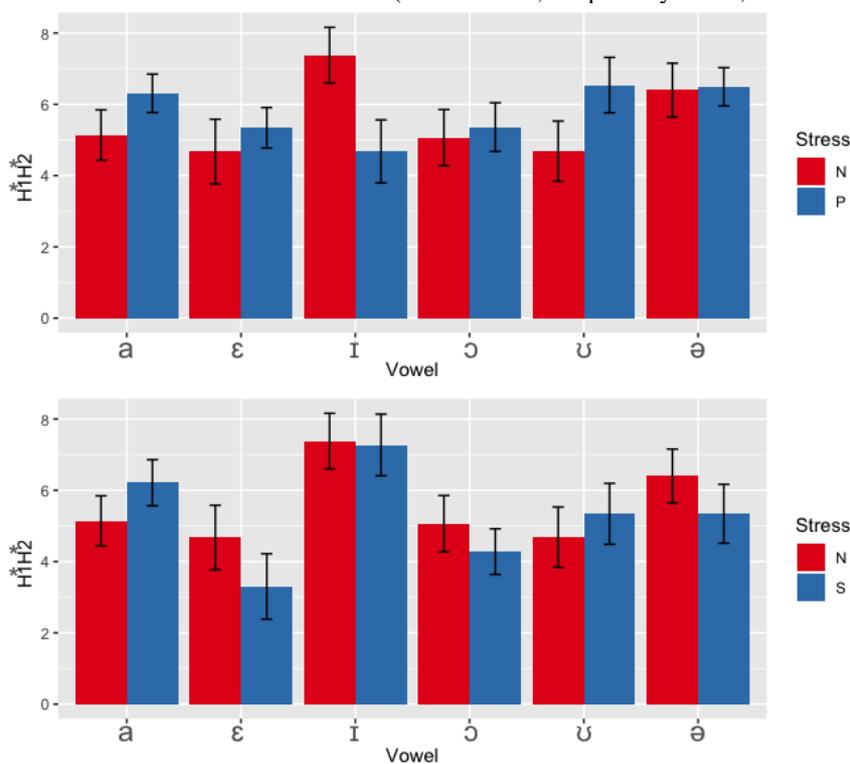


Figure 15: Mean H1*-H2* (dB) bar plot by vowel for ultima and unstressed vowels. Error bars indicate standard error of the mean (N - no stress; U - ultima).

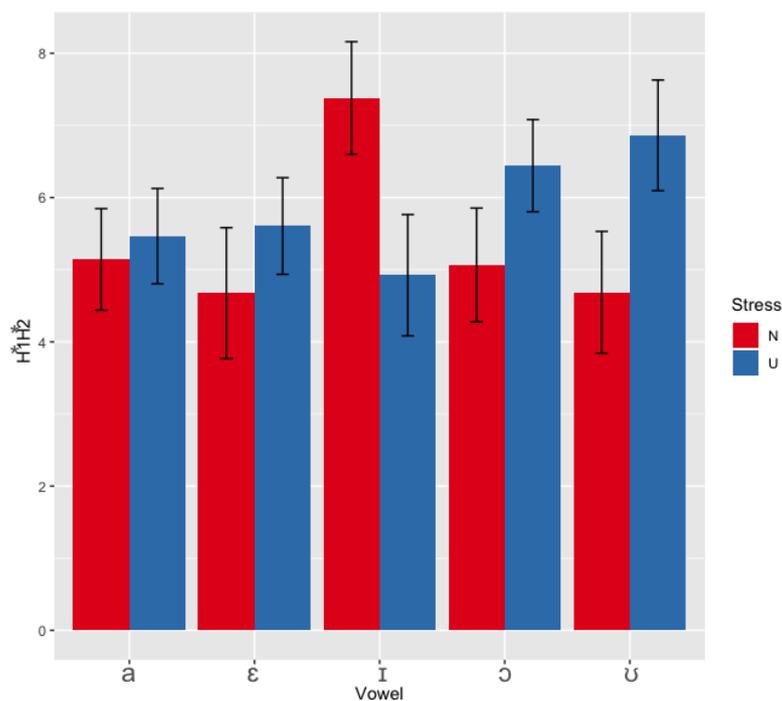


Figure 14 depicts mean values of $H1^*-H2^*$ for each vowel under different stress conditions. There is more regular positive effect of stress on $H1^*-H2^*$ values for primary stress (excluding the vowel /ɪ/) compare to secondary stress. However, no statistical significance was found for either stress level ($X^2(1) = 0.33$, $p = 0.57$ for primary stress), ($X^2(1) = 0.07$, $p = 0.78$ for secondary stress). Figure 15 shows mean values of $H1^*-H2^*$ between word-final vowels and unstressed vowels. A parallel observation can be made between primary stress and ultima by looking at figure 14 and 15. Similarly, the function of word-final position did not have a significant effect on $H1^*-H2^*$ measurements according to a likelihood ratio test ($X^2(1) = 0.17$, $p = 0.0.68$).

The relatively large standard errors for $H1^*-H2^*$ in this case may be due to considerable variations between speakers' voice quality, and complications from the carrier sentence chosen for this study (the later account for ultima only). There was noticeable difference in voice quality among speakers, which was observed in the spectrogram during labelling. Specifically, spectrogram of the raw data suggests that speaker two's voice quality was creakier overall, and speaker three's voice quality was categorically breathier.

5 Discussion

5.1 Duration as main effect of word stress in Southern Welsh

The present study investigates which acoustic parameters are used to encode word-level stress in Southern Welsh, as well as the acoustic characteristic of the ultima vowel in the interest of the Old Welsh Accent Shift. Results showed that duration serves as the most robust cue to primary stress in Southern Welsh. Such finding is consistent with most studies done on word stress cross linguistically, in that duration serves as a cue to stress. Extensive research shows that duration is used to signal stress in languages such as English (Fry, 1955), Dutch (Sluijter & van Heuven, 1996b), German (Aronov & Schweitzer, 2016), Tongan (Garellek & White, 2015),

Turkish Kabardian (Gordon & Applebaum, 2010), Spanish (Ortega-Llebaria & Prieto, 2010), Persian (Sadeghi, 2017), Catalan (Ortega-Llebaria & Prieto, 2010), and Uyghur (Yakup & Sereno, 2016). This effect was not significant for the vowel schwa, which corroborates with the findings of later research by Williams, it seems that duration of the schwa in Welsh does not vary significantly according to stress (Williams, 1999).

Interestingly, this result contradicts that of Williams's study on Welsh stress, in which she concluded that stressed penultimate vowels are marked by shorter duration (Williams, 1983). As discussed in earlier section, Williams compared stressed syllables to other syllables. Therefore, this observation most likely came from comparison of stressed vowels to vowels at word-edge positions. Indeed, when compared to unstressed vowels, primary stressed vowels are longer overall by around 39 ms and ultima vowels by 65 ms (see section 4.3). Since this study used the same data set for unstressed vowels for both comparisons, ultima vowels are longer than primary stressed vowels by about 26 ms.

However, longer duration in the ultima vowel is not unique to Welsh, final lengthening effects have been confirmed by a wide array of research such as Cambier-Langeveld (1997) for Dutch; Xu & Wang (2009) for Mandarin, Crystal & House (1988), Cooper, Paccia & Sorensen (1977), Byrd (2000), Cho (2006) and Nakatani, Aston & O'Connor (1981) for American English. Thus, longer duration in the ultima position in Welsh is most likely to be due to the effect of word-final lengthening.

A final note is that although there exists a length contrast in Welsh's vowel inventory, they are only contrastive in monosyllabic words (for details see section 2.1). This indicates that perceptual distinctiveness between long and short vowels is required only when they both bear primary stress. Thus, the use of duration to signal stress would not degrade perceptual distinctiveness, since there is no interaction between long and short vowels in stressed and unstressed conditions (i.e. instances where a short vowel is stressed, and a long vowel is unstressed).

5.2 F0 and stress in Southern Welsh

Surprisingly, fundamental frequency seems to show the opposite effect of stress when compared with research done on other languages – primary stressed vowels have significantly lower F0 overall when compared to unstressed vowels. Most literature and research suggest enlarged F0 excursions for stressed syllable, in other words, raising of pitch. Such languages include Indonesian (Adisasmito- Smith & Cohn 1996), Dutch (Sluijter & van Heuven 1996a), Turkish Kabardian (Gordon & Applebaum, 2010), Persian (Sadeghi, 2017), Tashlhiyt Berber (Gordon & Nafi, 2012) and English (Fry, 1958).

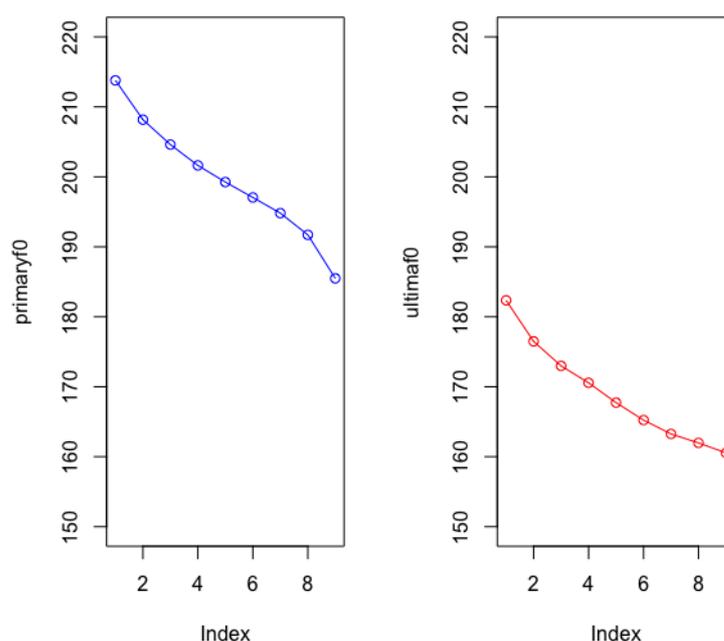
Unlike duration, cross linguistic research shows that correlation between F0 and stress is more inconsistent. Studies done in some languages suggest that F0 does not correlate with stress, or at least not strongly. For example, pitch does not seem to cue stress in British and Irish English (Kochanski, Grabe, Coleman & Rosner, 2005), Israeli Hebrew (Silber-Varod, Sagi & Amir, 2016), Kuot (Lindström & Remijsen, 2005), Uyghur (Yakup & Sereno, 2016) and Pirahã (Everett 1998). For Chickasaw, it was found that pitch is used to distinguish stress status between long vowels but not short vowels (Gordon, 2004). Moreover, change in F0 of the stressed syllable manifests differently according to sentential position (accented and unaccented). It is suggested that raising of pitch in stressed syllables is strongly associated with the on-focus word in a sentence. Huss (1978)'s study suggests that in English, significant

difference in pitch between syllables without and without stress only exists in words that are on focus. More recent research in Northern American English also found that F0 has a weak correlation with stress when unaccented (Plag, Kunter & Schramm, 2011).

The present study used words that are in nuclear position in the carrier sentence. Therefore, it is plausible that the overall lower F0 in stressed vowels may indicate a F0 lowering effect of stress in Welsh. Such finding is not contradictory to Williams's results – lack of F0 raise in stressed syllables (Williams, 1983). Lowering effect of pitch in stressed vowels would not be unique to Southern Welsh. Similar results have been found in Czech, where stressed syllables have lower pitch than unstressed, and are accompanied by a 'post-stress rise (L*-H)' (Volín, 2008; Volín & Weingartová, 2014, p.181).

This study also shows that mean F0 of ultima vowels is significantly lower than unstressed vowels, more so than their stressed counterparts. A vast array of literature on Welsh and Williams's research argue that the ultima in Welsh is accompanied by higher F0 (Williams & Ball, 2001).

Figure 16: F0 plot with each mean 1/9 measurements of the primary stressed vowels (left panel), and vowels at ultima positions (right panel).



To determine whether there exists a stress induced pitch lowering effect in the language, F0 contours of the vowel integral of the stressed penult and the ultima were plotted (see figure 16). Figure 16 shows consistent lowering of pitch from the onset of the stressed penultimate vowel to offset of the ultima vowel. Note that there are no visible peaks or valleys in the F0 trajectory for the stressed or ultima vowel. Thus, this study's finding indicates that perhaps there is little or no correlation between stress and F0 in Southern Welsh, and the ultima vowel does not seem to bear pitch prominence. In fact, such finding corresponds with results from Williams's research, in regard to F0 for primary stress. Specifically, it was found that a superimposed flat

F0 contour on the stressed nasal coda did not affect stress perception (Williams, 1983).

An alternative explanation to the later might be due to the carrier phrase used in this study - [dəu'ɛdʊχ ə 'gɑi ____ ɪ 'vi]. Recall that in order to avoid coda consonants' influence on the target vowels, target vowels were mostly in open syllables (except for the vowel /ɛ/ and /ʊ/ for ultima vowels). Consequently, around 60% of data reflects F0 in ultima vowels that directly precede the function word 'i' (IPA: /i/) ('for' in English), and are subject to glottal epenthesis. Glottal epenthesis here refers to when a glottal stop/glottalisation is introduced between two successive vowels, which has been observed in English (Hayes, 2009). Studies found that with glottalisation, a drop of F0 is commonly present, as perturbation of pitch can efficiently signal glottalisation (Dilley, Shattuck-Hufnagel & Ostendorf, 1996; see figure 17).

Figure 17: lowering of f0 accompanied by glottalisation

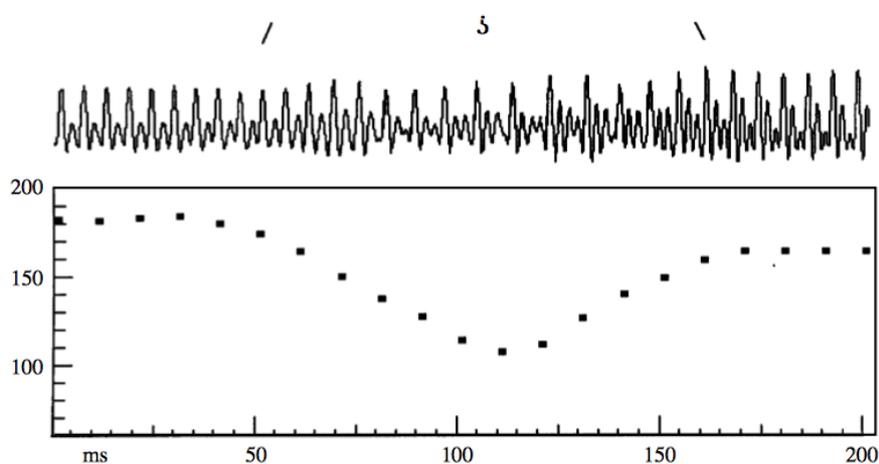


Figure 3. Dip in f_0 between two vowels results in perception of glottalization. Shown here is a portion of policy 3 *is*, where “3” indicates glottalization.

(Dilley, Shattuck-Hufnagel & Ostendorf, 1996, p.429)

5.3 Acoustic measures of secondary stress with linear discriminant analysis (LDA)

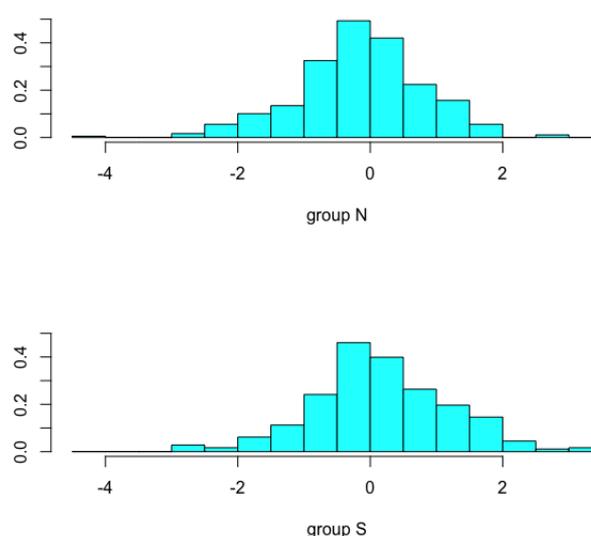
In this study, no statistical significance was reached in the measurements used for secondary stress. Therefore, in order to determine which acoustic measure best distinguishes secondary stressed and unstressed vowels, a linear discriminant analysis (LDA) was performed. As table 8 shows, although RMS energy has the highest value in comparison to other acoustic parameters, Figure 18 shows major overlapping of values for discriminant functions (acoustic measurements) between the secondary stress and no stress groups. Thus, it is possible that there is little to no phonetic signal for secondary stress in Southern Welsh. Similar discoveries were found for Turkish Kabardian (Gordon & Applebaum, 2010). Research in Indonesian also revealed varied phonetic manifestations in secondary stress across speakers (Adisasmito-Smith & Cohn, 1996).

Table 8 LDA output - coefficients of measurements as discriminant functions.

	Secondary stress
Duration	-0.008

F0	0.039
RMS energy	0.367
F1	-0.002
F2	-0.0004
CPP	0.100
H1*-H2*	0.037

Figure 18: Stacked histogram of LDA output between no stress (group N) and secondary stress (group S).



5.4 Welsh stress and intensity

It has been shown from previous research that intensity is often used to signal stress in many languages – such as Chickasaw (Gordon, 2004), English (Fry, 1955 & 1958; Plag, Kunter & Schramm, 2011), Turkish Kabardian (Gordon & Applebaum, 2010), Indonesian (Adisasmito-Smith & Cohn, 1996) and Castilian Spanish (Ortega-Llebaria & Prieto, 2010). The absence of RMS energy as a function of primary stress seems unexpected at first (see section 4.4). Since research for the five languages mentioned above all indicate a positive correlation between stress and intensity. However, such findings may be related to how F0 is related/unrelated to stress in Southern Welsh. Particularly, Southern Welsh does not use F0 to encode stress, and pitch is consistently lower in primary stressed vowels than unstressed vowels (see section 4.2).

Alku, Vintturi & Vilkmán (2002) investigated the relationship between raising of F0 and intensity in human speech. They found a positive linear relationship between pitch and intensity, specifically, speakers raise F0 while trying to increase loudness. This is because speakers enhance acoustic energy by increasing their subglottal pressure, which influences ‘individual glottal pulse’ (amplitude) and ‘the rate of repetition of consecutive glottal pulses’ (F0) (Alku, Vintturi & Vilkmán, 2002,

p.322). Indeed, stress induced pitch raise and increased energy are commonly observed in tandem, such as in the aforementioned languages.

Volín & Weingartová (2014) suggested that Dutch speakers tend to produce stress in a L2 with pre-existence acoustic cues in their native language. They measured sound pressure level (SPL) in Dutch speaker's production of stressed syllables in English and found that there was little difference of SPL values between stressed and unstressed vowels. Recall that in Dutch, F0 of the stressed syllables is decreased in primary stressed vowels (Volín, 2008). The same rationale can be applied to why ultima vowels also have significantly lower energy values compared to unstressed vowels, more so than primary stressed vowels. Recall that F0 in ultima vowels are lower than that in primary stressed penult. Note also that although pitch and intensity are lower in stressed vowels for both Southern Welsh and Dutch, such observation is related to stress in Dutch and not in Welsh. Therefore, data in this study suggests that lower RMS energy values of primary stressed vowels may be a result of the irrelevance between F0 and stress in the language.

5.5 Centralisation of vowel space in Southern Welsh

Results in this study show that vowel space for unstressed vowels is subject to reduction in comparison to primary stressed vowels, especially regarding F2. Vowel reduction in unstressed syllables is a common phonological process in many languages (Crosswhite, 2001). Yet, if a language does not have a formal vowel reduction process phonologically, such as in Southern Welsh, a phonetic realisation of centralisation in unstressed vowels can still be expected (Flemming, 2005; Garellek & White, 2015). Such phenomenon is associated with what is called 'phonetic undershoot' (Garellek & White, 2015, p.26). There are many related theories which can explain the reason behind 'undershoot'. For example, the 'Hyper-and Hypoarticulation' theory mentioned previously, the 'Articulatory Phonology framework' and the 'Parallel encoding and target approximation model (PENTA)' (Garellek & White, 2015, p.26; Xu, 2005).

All three theories associate 'undershoot' of unstressed vowels with the decrease in duration of unstressed vowels. Duration of unstressed vowels in Southern Welsh is evidently shorter than primary stressed vowels (see section 4.3 and 5.1). It is believed that when duration is shortened, articulatory targets may not be entirely realised (Garellek & White, 2015). One of the crucial mechanisms in speech according to the PENTA model is temporal alignment of the articulation process with syllables as units, or in other words 'syllable-synchronised target approximation' (Xu, Prom-on & Liu, 2015, p.4). Therefore, when articulatory targets are assigned (in this case-formant heights), shorter duration would lead to premature termination of the target approximation process (Xu, Prom-on & Liu, 2015) – such as phonetic undershoot in the vowel space for unstressed vowels.

Figure 11: (i- /ɪ/, e- /ɛ/, o- /ɔ/, u- /ʊ/, v- /ə/; Primary stress – solid line; Unstressed – dotted line).

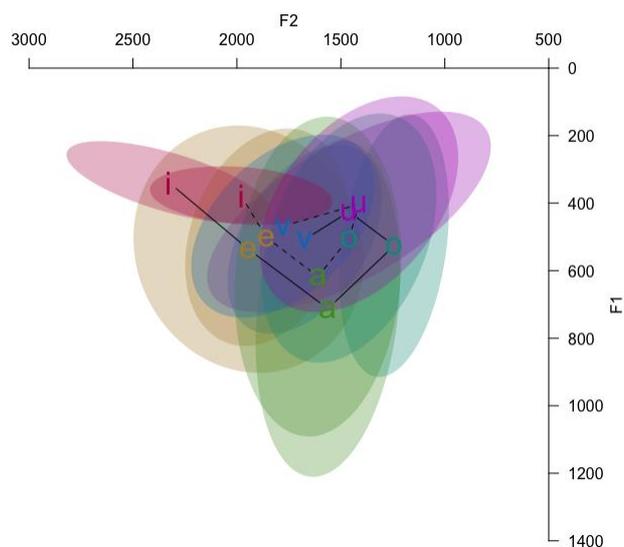


Figure 11 depicts the overall vowel space for all speakers under primary stressed and unstressed conditions (repeated here for convenience). Statistical analysis and visual inspection of figure 11 suggest a stronger horizontal reduction pattern than vertical (centralising for the second formant). Therefore, vowel reduction for unstressed vowels in Southern Welsh appears to merge contrasts in terms of frontness and backness. As section 1.1 shows, there is an additional contrast of roundness between front and back vowels in Welsh, which further lowers F2 values of the back vowels and enhances distinctiveness. This additional feature aids vowel dispersion in terms of back and front vowels. Such language specific typological characteristics could explain the reduction pattern at hand in Southern Welsh.

On the other hand, if the tongue height contrast of front and back vowels is reduced in unstressed vowels, perceptual distinctiveness may be compromised. Note that the unstressed vowel /a/ has been shifted upwards (in F1) more than other vowels in the language. Such observation further corroborates the rationale above, as there exists no open-mid vowels in Welsh's phonemic inventory. Therefore, raising in F1 for unstressed /a/ is less detrimental in regard to perceptual distinctiveness. Overall, in Southern Welsh, effect of vowel reduction as a function of stress is consistent with findings in other languages such as German (Mooshammer & Geng, 2008), Dutch (Bergem, 1993), Greek (Lengeris, 2012) and English (Crosswhite, 2001). However, such effect is not as potent as vowel reduction found in other languages. For example, Mooshammer and Geng (2008) found substantial reduction in vowel space (F1 and F2) for unstressed vowels (lax and tense) in German, although vowel inventory in Welsh is similar to that in German. This could be due to the fact that stress is non-contrastive in Welsh, and there is less incentive for an extensive reduction in vowel space to cue stress, similar of that for Turkish Kabardian (Gordon & Applebaum, 2010). Note that German also has non-contrastive stress. However, length (or lax and tense) contrasts serve as a distinctive feature not just in monosyllabic words, unlike in Welsh. This additional feature aids vowel dispersion, which may compensate for vowel reduction in the language.

5.6 Spectral-tilt and stress in Southern Welsh

According to Garellek & White (2015)'s paper on Tongan stress, CPP values can help interpret H1*-H2* results. If a higher H1*-H2* value is observed in conjunction with a high CPP value, a more modal voice quality can be presumed; if a high H1*-H2* value is observed with low CPP values, a breathier voice can be assumed. Additionally, low H1*-H2* values are typically associated with creaky voice.

Although Figure 12 and 14 show that primary stressed vowels have slightly higher values in CPP and H1*-H2* (except for vowel /ɪ/ and /ə/), no statistical significance was found for measurements of voice quality in this study. The use of spectral tilt to signal stress is controversial cross linguistically. In languages such as Persian (Sadeghi, 2017), British English (Kochanski et al, 2005), Swedish (Heldner, 2003), Spanish and Catalan (Ortega-Llebaria & Prieto, 2010), spectral tilt is said to be correlated with sentential accent instead of stress. Therefore, further research with different measurement method under different accentual conditions may help clarify the relationship between spectral balance and stress in Southern Welsh – such as comparing high and low frequency bands in the spectrum between stressed and unstressed vowels (used in Sluijter & van Heuven, 1996a for Dutch).

6 Conclusion

The aim of this study was to investigate which acoustic cues are used in the production of stressed vowels in Southern Welsh. In addition, this study attempted to verify some of the conventional beliefs with regard to vowels at the ultima position. The results suggest that primary stressed vowels in the language have longer duration, lower F0, lower energy and expanded vowel space when compared to unstressed vowels. However, the present study indicates that decrease in pitch and energy is not directly correlated with stress in Southern Welsh. For vowel reduction in unstressed vowels as a function of stress, there is a more significant horizontal reduction than vertical. The effect of F0 lowering is absent for secondary stressed vowels, which might have contributed to the finding of slightly higher energy in secondary stressed vowels. No significant effects of stress were observed for secondary stress. Perhaps there exists little phonetic evidence for secondary stress in the language.

Regarding ultima vowels, current results contradict with some previous research. Specifically, vowels at word final positions have lower F0 and energy. However, findings regarding the relationship between F0 and stress are consistent with results in the Williams (1983) study – little correlation between F0 and stress in the Welsh language. Although ultima vowels do have longer duration as earlier research indicates, it is difficult to determine whether it is due to language internal reasons or the cross linguistic phenomenon of word-edge/final lengthening.

Results in measurements for spectral tilt showed inconsistent patterns. Therefore, further research is needed to clarify the effect of stress on voice quality in the language. Moreover, this study focused on stress manifestation for sentential accented words. To better understand how stress is encoded in Welsh, further research is called for in order to disentangle acoustic effects associated with stress induced prominence with accent induced prominence.

Appendix: complete word list used for the experiment with IPA transcription

Primary	Gloss	Secondary	Gloss
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/a/		/a/	
[.kara'vʌnav]	to rail	[ar,ðʌŋo'siðo]	demonstrable
[.di've'θadɔi]	Condemned to death	[ɛs.gʌla'diɾɔn]	escalator
[.gɔɛ'ðʌberθ]	feast	[a,rʌto'ladɔg]	foreign
[.ɛsga'ladir]	escalator	[pɛn,dramo'nɔglɔg]	headlong
[.kədo'lado]	international	[əm,ðʌŋo'siade]	appearance
/ɛ/		/ɛ/	
[.gɔɔ'neðɔχ]	glory	[pɛr,χɛno'gaiθɛ]	ownerships
[.təŋed'veno]	fateful	[prɛ,sɛno'l'dɛbɛ]	attendances
[.əsgrɪ'venið]	secretary	[kə,frɛdi'nɔldɛb]	generality
[.kəvan'hɛðɔχ]	friendship	[ha,nɛdi'varɪs]	unrelenting
[.əmar'veɛð]	practice	[bɛ,nɛði'gɛsɛ]	ladies
/ɪ/		/ɪ/	
[.dadan'hɪðo]	to uncover	[am,ðɪfə'nɛdiɔg]	protected
[kla'sɪɾo]	classical	[χor,liɔ'ganɔd]	Merry-go-round
[kə'sɪlav]	advise	[kəv,rɪvɔ'l'dɛbɛ]	responsibility
[.pɛnta'fɪlɔn]	creeping cinquefoil	[əs,grɪvɛ'nɛdiɔg]	written
[.bɛnɛ'ðɪɛs]	lady	[əs,grɪvɛ'nəðɛs]	female secretary
/ɔ/		/ɔ/	
[.kəvan'sɔði]	to compose	[an,vɔnɛ'dɪɾɔn]	missionary
[.pɛrχɛ'nɔgi]	to own	[ə,mɔsɔ'diade]	attacks
[.arðə'vɔdo]	future	[a,lɔra'ðɔliad]	alter-worship
[.pəθɛv'nɔsɔ]	fortnightly	[gɔ,sɔdɛ'dɪɔgɔ]	enacted
[.arða'ŋɔsɔɾ]	demonstrator	[prɛ,fɔdo'laiθɛ]	predictions
/ʊ/		/ʊ/	
[kas'ɪʊχor]	Loughor	[kə,dɔla'dɔldɛb]	internationalism
[.χorli'gɔgan]	Merry-go-round	[a,mɔrɛ'gɛsɛ]	griddles
[.ara'ɪʊlad]	alien	[gɔ,rɔrɛ'gɛsɛ]	bracing-griddles
[pɛn,dramo'nɔgɔ]	head-over-heels	[ɾə,ŋɔla'dɔlav]	to internationalise
[ka'rɔriaiθ]	friendship	[ə,mɔrɛ'gɛsɪ]	to dress oneself
/ə/		/ə/	
[ə,mɔrɛ'gɛsɪ]	to dress oneself	[an,rɔdɛ'ðɪsɔ]	honourable
[.lɔvrɛ'ɪəðɔ]	pertaining to a library	[gɔ,lɔŋɛ'dɪɔgaiθ]	discharging
[lɔŋ'ðɾɔliad]	shipwreck	[prɪv,lɔθə'renɛ]	capital letters
[.prɪvlə'θɛrɛn]	capital letter	[tɛ,lɔno'rɛsɛ]	female harpists
[.pɛndɛr'venɔ]	determined	[a,mənɛð'garɔχ]	patience

Ultima	Gloss	Unstressed	Gloss
/a/		/a/	
[.əsgrɪ'venva]	desk	[.hanva'nɛgɔ]	unexpressed
[.əmða'ŋɔsva]	to honour	[.əmða'ŋɔsiad]	appearance
[.gɔrθrə'velɔ]	to rebel	[.gramə'dɛgɔ]	grammatical
[a'lɔrvə]	alter	[.arða'ŋɔsɔɾ]	demonstrator
[gɔ'sɔdvə]	station	[.arə'ɪʊlad]	alien
/ɛ/		/ɛ/	
[.arda'ləðɛs]	marchioness	[.hɛrɛ'nɔrsav]	lamp station
[.əmar'veɛð]	practice	[.prɛsɛ'nɔldɛb]	attendance
[.ɛkɔ'nɔmɛg]	economics	[.sɛrɛ'mɔni]	ceremony
[.prɪvlə'θɛrɛn]	capital letter	[.pɛrχɛ'nɔgi]	to own
[.bɛnɛ'ðɪɛs]	lady	[.bɛnɛ'ðɪɛs]	lady
/ɪ/		/ɪ/	
[.anrə'dɛðɪ]	to honour	[.amðɪ'fənva]	sanctuary

[.gəgə'neðɪ]	magnify	[.kəvrɪ'vɔldeb]	responsibility
[.pənder'vəni]	conclude	[.əsgrɪ'vedɪg]	written
[.sɛrɛ'mɔni]	ceremony	[.χɔrlɪ'gʊgən]	merry-go-round
[.kəvən'sɔðɪ]	to compose	[.əsgrɪ'venið]	secretary
/ə/		/ə/	
[.dadan'hɪðɔ]	to uncover	[.ənvɔ'vedɪg]	missionary
[gɔr'fuiɔ]	be mad	[.əmɔ'sɔdiəd]	attack
[.arðə'mɪnɔ]	desire	[.gɔsɔ'vedɪg]	set
[tak'li:sɔ]	make neat	[.prəfɔ'dɔlaiθ]	prediction
[.kədtɔ'ladɔ]	international	[.əmɔ'vedɪg]	subjunctive
/ʊ/		/ʊ/	
[.gəgə'neðʊχ]	glory	[.əmʊ'regɪs]	griddle
[.arðə'ŋɔsʊr]	demonstrator	[.kədtɔ'ladɔ]	international
[.ənʔə'deðʊr]	honourer	[.gɔrʊ'regɪs]	bracing-griddle
[.kəvən'hɛðʊχ]	friendship	[.ŋəŋʊ'ladɔ]	international
[mɑ.θəmə'tegʊr]	mathematician	[a.rəʃʊ'ladɔg]	foreign
		/ə/	
		[.ənʔə'deðɪs]	honourable
		[.gɔlə'ŋedɪg]	released
		[.telə'nɔres]	female harpist
		[.ənʔə'deðʊr]	honourer
		[.prɪvlə'thɛrən]	capital letter

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