WORD CLASS AND FREQUENCY EFFECTS IN HAWAIIAN STRESSED VOWEL CLUSTERS

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ABSTRACT

Lexical factors like grammatical class and usage frequency condition phonetic variation. Previous research has found that sounds in more frequent words and function words tend to be shorter and hypo-articulated compared with less frequent words and content words. However, these patterns have been explored in a limited range of languages. This study investigates vowel reduction based on word class and frequency in Hawaiian. Durations and F1/F2 were measured for word-final, primary stressed clusters /ai, au, ei, ou/ (n=1046) in natural speech.

/ai/ is centralized in non-content words, with less diphthongal and shorter reflexes in higher-frequency words; /au/ is centralized, less diphthongal, and shorter in non-content words; and /ou/ is shorter in non-content and more frequent words. This finding that vowel clusters in non-content and higher-frequency words tend to be phonetically reduced in Hawaiian is relevant to phonological theories which remain to be tested in a wide typological range of languages.

Keywords: Hawaiian, vowels, reduction, word frequency, grammatical class

1. BACKGROUND ON HAWAIIAN

ʻŌlelo Hawaiʻi (Hawaiian) is the Indigenous Austronesian language of the Hawaiian Islands. After a steep decline, Hawaiian had only a few hundred speakers in the 1970s and 1980s, when bans on the language were lifted and community leaders spearheaded innovative revitalization programs. *Ka Leo Hawaiʻi* (KLH), a radio show which regularly broadcast interviews with native speakers beginning in 1972, was an early catalyst in the Hawaiian renaissance [1, 2]. The digitized KLH archives are widely used today in educational contexts.

Despite the availability of extensive audio archives, the phonetics and phonology of Hawaiian remain understudied. The present study investigates three aspects of variation – trajectory position, trajectory length, and duration – in a subset of primary stressed vowel clusters, probing the effects of wordform frequency and word class. The data analyzed here come from KLH interviews recorded in 1972-1974 with eight elderly native speakers. The results have implications not only for descriptions of Hawaiian, but also for language-independent theories of phonological representation and phonetic performance that are seldom tested on Austronesian languages.

2. FREQUENCY AND WORD CLASS

Reduction, the shortening and/or less full articulation of words or phones under certain conditions, is typically associated with unstressed environments [3, 4], but variation in hyper- and hypo-articulated outputs can also be observed within syllables bearing lexical stress. Higher **frequency** words have been found to have shorter acoustic durations than low frequency words in English [5], Dutch [6], and Chinese [7] and have been found to be centralized in the vowel space in English [8] and French [9] (though see [10] for conflicting observations in German).

Most psycholinguistic theories of speech assume separate processes for function and content word production (e.g. [11]). **Grammatical word class** thus also plays a role in vowel variation, with the phones in function words and pronouns typically reduced compared to content/lexical words. Such word class variation has been noted in English [12], Dutch [13], French [9], Icelandic [14], Scottish Gaelic [15], Vietnamese [16], and Japanese [17].

Observations of vowel reduction in higher-frequency and non-content words – words that tend to be most predictable [18] – are often taken as evidence for theories like the Smooth Signal Redundancy Hypothesis (SSRH): In order to balance articulatory ease with communicative success, speakers exhibit an inverse relationship between language redundancy and articulatory effort [19], resulting in undershoot of full durational and quality targets in reduced environments [20, 21]. When studies find an effect of word class even after accounting for prosodic effects predicted by the SSRH, their findings are taken to support a phonological model with independent lexical representations for homophonous words of different classes [22, 23]. Though these models of linguistic storage and performance are language-independent, the range of languages on which their predictions have been tested remains limited and typologically skewed toward Indo-European lects.

3. HAWAIIAN PHONOLOGY

In its native lexicon, Hawaiian has the vowel phonemes /i e a o u/ and /iː eː aː oː uː/, as well as the consonants /ʔ, h, l~r, m, n, p, k~t, v~w/ [24, 25]. The short diphthongs /ae ai ao au ei eu iu oi ou/ and the long diphthongs /aːe aːi aːo aːu eːi oːu/ are under most analyses not unitary phonemes, and are referred to herein as tautosyllabic clusters comprised of two separate vowel phonemes [25, 26, 27].

Syllable structure in Hawaiian is highly constrained, with no codas and no complex onsets in the native lexicon. Primary lexical stress is assigned to the syllable containing the penultimate mora of the word; stress is thus final in words ending in a tautosyllabic cluster or long vowel, and penultimate in words ending in a singleton short vowel [28, 29].

Kettig [27] detailed the acoustic profile of the Hawaiian vowel system based on F1/F2 measurements of the eight-speaker KLH dataset also used in the present study. He observed that the trajectories of /ai/ and /au/ in pronouns and directional particles exhibit trajectory reduction compared to their content word equivalents, though he did not investigate durations or report on word frequency. Previously, Parker Jones [25] reported qualitative reduction in Hawaiian /a/ in function words based on a small single-speaker sample.

4. RESEARCH QUESTIONS AND DATA

The present study probes two main research questions regarding whether Hawaiian fits reduction patterns previously described in unrelated languages:

- Does higher word frequency correlate with reduced vowel durations and trajectories?
- Do non-content words like pronouns and directionals have reduced vowel durations and trajectories compared with content words?

The data here comprise recordings of radio interviews from the 1970s, and thus represent an unscripted speech style in a studio environment. The eight speakers are one male and one female elder, each from the islands of Kauaʻi, Oʻahu, Maui, and Hawaiʻi [30]. Their interviews were transcribed and force-aligned using the Montreal Forced Aligner [31], with overlapping speech data discarded and all phone and word boundaries manually checked for accuracy. Durations and F1/F2 measurements at nine points in each token were extracted using the Fast Track plugin [32] in Praat [33], with re-measurements and outlier exclusion workflows outlined in [27]. Vowels were normalized using the ANAE log-diff method [34, 35].

Word frequency measures were obtained from Brockway [36] and are based on word counts in the first 40 transcripts of KLH episodes, which contained 4,826 word types and 315,785 tokens.

The clusters /ai, au, ei, ou/ were selected for analysis because the lexicon of Hawaiian contains both content and non-content words (specifically pronouns, pluralization/directional/verbal particles, and a question word) with each of these clusters bearing primary lexical stress. Table 1 provides examples of words analyzed as well as token counts after exclusions; word type counts are also provided in parentheses.

	Content word	Non-content word
/ai/	/ʔ**ai/** eat n=141 (23)	/m**ai/** hither n=237 (2)
/au/	/p**au/** finished n=175 (25)	/v**au/** 1SG n=159 (3)
/ei/	/l**ei/** garland n=12 (6)	/n**ei/** PROX n=61 (1)
/ou/	/h**ou/** new n=17 (2)	/ˌkaː.ˈk**ou/** 1PL.IN n=244 (5)

Table 1: Examples of words containing each of the clusters with word-final primary lexical stress; n=token counts (word type counts in parentheses).

Several exclusions were made to control for and anticipate some possible effects outside the scope of the present investigation: (1) Tokens immediately preceded or followed by a vowel without an intervening consonant (e.g. *...lei o ka...*) were excluded due to difficulty determining phone boundaries. (2) Only word-final primary stressed clusters are analyzed. Though primary stress can fall on either the final or penultimate syllable in Hawaiian, only one non-content word contains one of these primary stressed clusters in a penultimate syllable (/m**ai**.la/ 'hither'). In content words, token counts were also higher for clusters in final position. (3) Tokens immediately followed by a pause were excluded. The present dataset is not parsed for phrase boundary types, nor have the pauses been tagged for which indicate true phrase finality and which arise due to disfluencies or speaker overlap; it would therefore be difficult to disentangle the various types of utterance- and phrase-final lengthening observed cross-linguistically and noted previously in Hawaiian [25]. (4) Two tokens of greater than 500 ms were excluded, as inspection of these outliers showed that they were due to hesitation and listing prosody.

5. ANALYSIS AND RESULTS

5.1. Constructing Linear Mixed Effects Models

The following sections report the results of a series of linear mixed effects models using the R package *lmerTest* [37] which were constructed to measure the effects of word class and frequency on trajectory centralization, trajectory length, and duration. Each of these models contained the same structure: Fixed effects were binary content word status (content/non-content) and word frequency (operationalized by the log normalized frequency), with a by-speaker random intercept in each model. Due to a high co-linearity between word class and frequency (with content words tending to have lower frequencies than non-content words), testing interactions in these models caused convergence issues, though future work on an expanded dataset should investigate this possible confound.

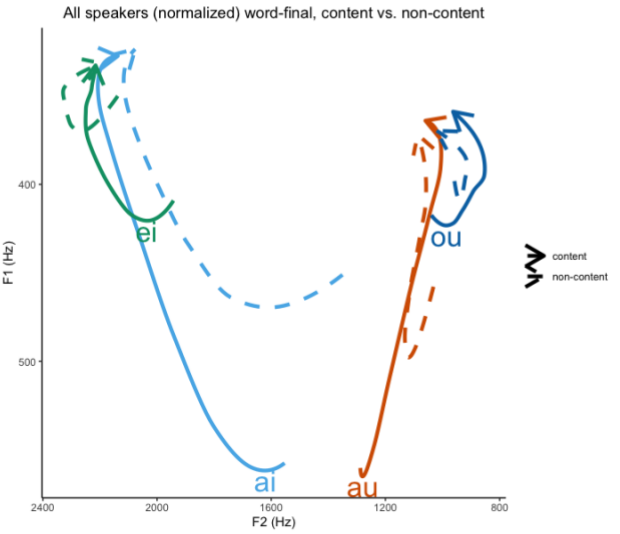

Figure 1: Mean trajectories of word-final, non-pre-pausal, primary stressed vowel clusters in content words (solid) and non-content words (dotted).

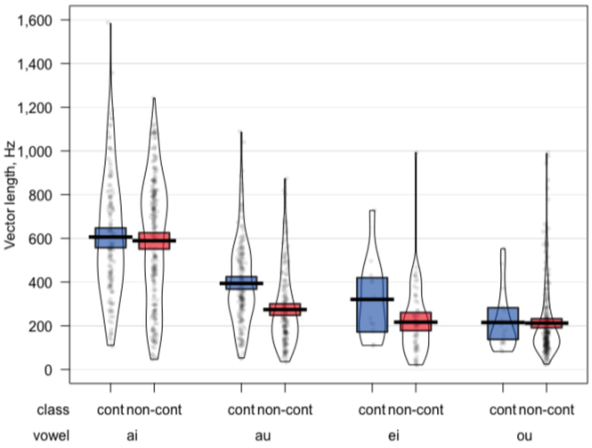

Figure 2: Trajectory length (vector length between F1 max and min) in content and non-content words.

5.2. Trajectory position

Fig. 1 plots the trajectories of /ai/, /au/, /ei/, and /ou/, split by whether they appear in tokens of content or non-content words. The lowest points of the /ai/ and /au/ trajectories appear to be centralized in non-content words compared to content words; /ei/ and /ou/ also appear to be more monophthongal in non-content words than content words.

To statistically test the centralization of the initial element /a/, two models were constructed, one for /ai/ and one for /au/; the predicted variable was the maximum F1 measurement within each token – that is, the lowest point in its trajectory. For /ai/, F1 was found to be significantly reduced (higher in the vowel space) in non-content tokens compared to content tokens (β=-95.8, SE=21.0, t=-4.6, p<.001). For /au/, F1 was significantly reduced in non-content tokens (β=-103.2, SE=15.2, t=-6.8, p<.001). In these models, word frequency did not significantly predict either /ai/ nor /au/ F1 maximum.

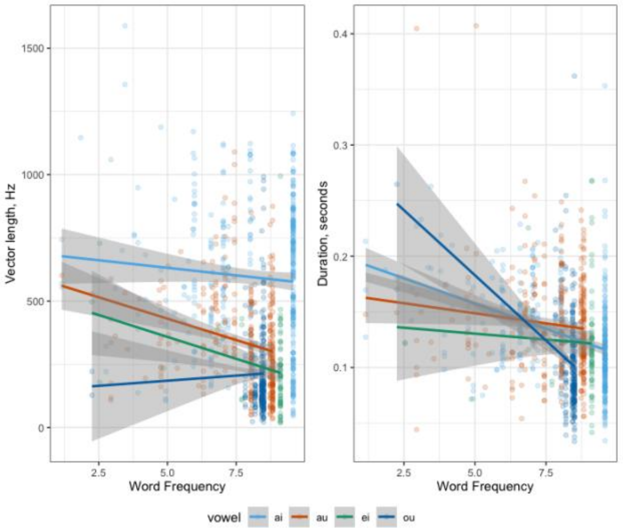

Figure 3: Trajectory length (left) and duration (right) by word frequency. Shaded standard error ranges.

5.3. Trajectory Length

To investigate whether word class or frequency predicted the length of trajectories – reflective of how monophthongal or diphthongal a given token was – four models were constructed, one for each cluster. Trajectory vector length was operationalized by calculating the F1/F2 Euclidean distance between the point of maximum F1 and the point of minimum F1 for each token (a modification of vector length calculations described by e.g. [38, 39]). A singular fit error was encountered for the /ei/ cluster model due the presence of only one non-content word type, so statistical test results are not reported for this cluster.

As illustrated in Fig. 2, a vector length difference between word classes was significant for /au/ (β=-132.9, SE=25.8, t=-5.2, p<.001), indicating that non-content words are pronounced with more monophthongal reflexes than content words. This was not a significant effect for /ai/ or /ou/. A vector length difference was predicted by word frequency for /ai/ (β=-31.9, SE=15.1, t=-2.1, p=.03), indicating that more frequent /ai/ words contain more monophthongal reflexes than less frequent ones. Though Fig. 3 (left) shows /au/ with a steeper negative slope than /ai/, frequency was not a significant predictor for /au/ or /ou/ in these models.

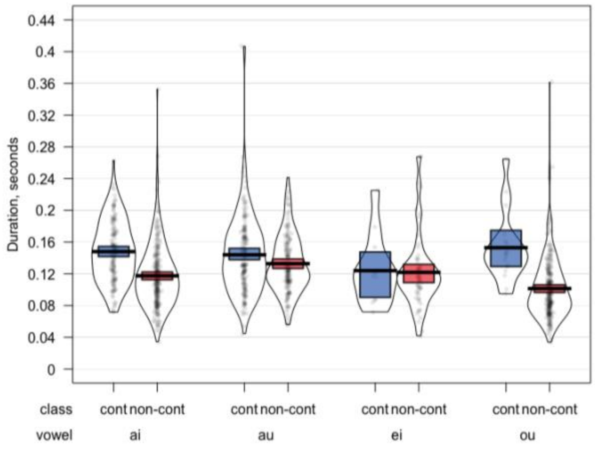

Figure 4: Cluster duration in content and non-content words.

5.4. Duration

Fig. 3 (right) shows token durations by word frequency and Fig. 4 illustrates duration differences between content and non-content words. Though it appears in Fig. 4 that /ai/ exhibits duration differences by word class, this effect was not significant; instead, frequency was found to significantly predict duration, with lower durations associated with higher frequencies (β=-0.008, SE=0.002, t=-3.9, p<.001). On the other hand, word class was a significant predictor for /au/ duration (β=-0.016, SE=0.006, t=-2.5, p=.012) while frequency was not. Neither class nor frequency were significant predictors for /ei/, while for /ou/, both word class (β=-0.036, SE=0.010, t=-3.6, p<.001) and frequency (β=-0.013, SE=0.002, t=-2.9, p=.004) were significant.

6. DISCUSSION

To summarize: /ai/ exhibits significant centralization in non-content words, as well as less diphthongal reflexes and reduced durations in higher-frequency words; /au/ has significant centralization, monophthongization, and durational reduction in non-content words; /ou/ has significant durational reduction based on word class and frequency; and /ei/ appears to be more monophthongal in non-content words, but statistical power in this sample was too low to obtain results. These findings of duration and trajectory variation in Hawaiian stressed vowel clusters are in line with Parker Jones' [25] previous observation for /a/ as well as cross-linguistic expectations, and may represent the first time these research questions have been tested on a substantial multi-speaker dataset in an Austronesian language.

Though a thorough discussion is outside the scope of the present paper, interspeaker variation was apparent in this sample. Inspection of individual speaker vowel plots showed that some of these elders exhibited large differences between content and non-content words, while others reduced very little across grammatical classes. Future work on this corpus should focus on factors that might condition variation in reduction rates, such as differing degrees of English/Hawaiian bilingual dominance or levels of comfort with the formal radio interview setting.

Future work should also address other factors that this study was not able to consider, particularly with regard to variation in vowel duration. For instance, accounting for within- and between-speaker speech rate differences may allow for clearer patterns in duration variation to emerge. While all tokens preceded or followed by vowels were excluded from consideration, the present study included tokens before or after /w/, /h/, and /ʔ/, for which segmentation was often difficult; excluding all such data would have massively reduced the number of words it was possible to analyze, but these tokens may have introduced inconsistencies (cf. [40]).

One challenge for researching phonetic variation in endangered and understudied languages like Hawaiian is that their phone-aligned datasets of spontaneous speech tend to be small, yielding a limited spread of words spoken per person and too few iterations per word to have statistical power. This investigation encountered such issues with statistical power in the /ei/ vowel, so future work should test the present observations on an expanded dataset. However, though the number of tokens analyzed here is several orders of magnitude smaller than those used to run similar tests in better-resourced languages, the results suggest that Hawaiian does exhibit the putative universal tendency for vowels in non-content and high-frequency words to be phonetically reduced in primary stressed position. The relative strength of the class and frequency effects may vary by vowel, and further research is necessary to disentangle the role of these two lexical factors.

As Hawaiian becomes better documented, with more thoroughly-tagged and larger phonetic datasets available, other predictors used to disentangle prosodic, grammatical, and frequency-based variation (such as lemma frequency, speech rate, position within word/utterance/phrase, etc.) will hopefully become available for improved statistical modeling. The continued documentation of such phonetic variation in not only Hawaiian, but also the world's thousands of other understudied languages, is crucial in order to test phonological theories against a set of empirical evidence reflective of the full range of human linguistic experience.

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