Stress and contrastive length are distinctively cued in ʻōlelo Hawaiʻi vowels

THOMAS KETTIG, YORK UNIVERSITY

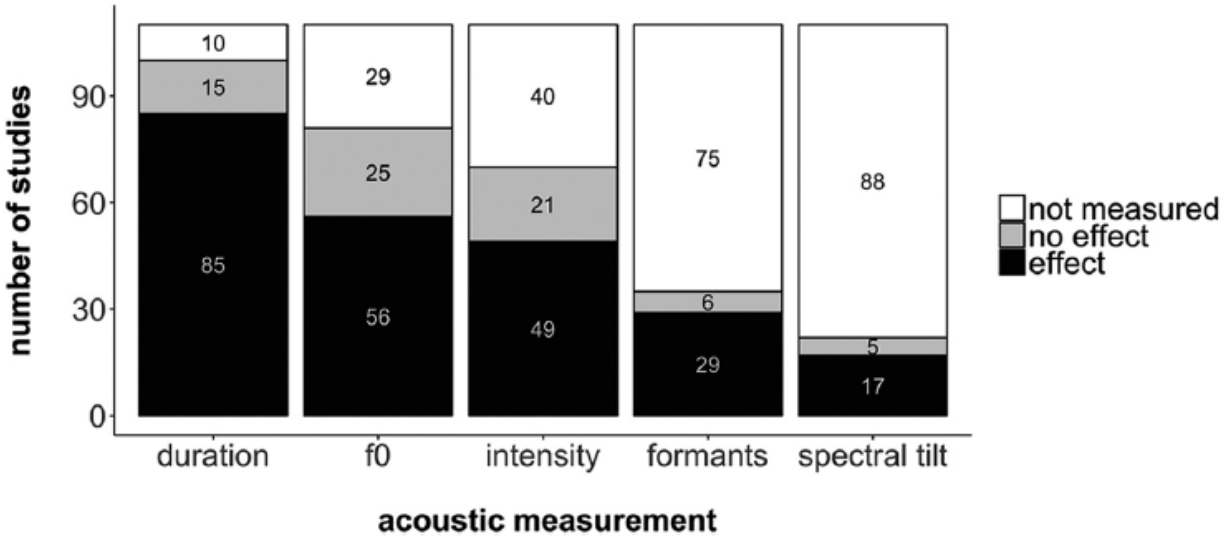
LISA DAVIDSON, NEW YORK UNIVERSITY

AFLA 2024, AMHERST

Acoustic correlates of stress across languages

According to a meta-analysis of acoustic correlates to word stress, 5 correlates have been investigated most often (in decreasing order) (Gordon & Roettger 2017)

- *Duration*
- *Fundamental Frequency (F0)*
- *Intensity*
- Formants
- Spectral Tilt



Stress: Duration, F0, Intensity

Duration: In 65/72 (90%) languages, stressed syllables were longer than unstressed ones (Gordon & Roettger 2017)

F0: In 46/63 (73%) languages, F0 distinguished stressed from unstressed syllables

Intensity: Studies using mean/peak/midpoint intensity found that it distinguished stress in 39/52 (75%) languages

Stress: Primary vs. secondary vs. unstressed

Evidence for the existence of secondary stressed as distinguished from both primary and unstressed is tenuous

- Some evidence from Chickasaw and Dutch (Gordon 2004, Rietvald et al. 2004)

In several languages, no distinction found between secondary and unstressed syllables

- Erzya Mordvin (Uralic, Lehiste et al. 2003), Pitjantjatjara (Pama-Nyungan, Tabain et al. 2014), Polish (Dogil 1999; Newlin-Łukowicz 2012), Brazilian Portuguese (Barbosa et al. 2013)

Stress in Polynesian languages: Tongan

Acoustic correlates (Garellek and White 2015): No direct comparisons of primary and secondary

- Duration: Primary > Unstressed, Unstressed > Secondary (!). Probably no difference between primary-secondary.
- F0: Primary > Unstressed, Secondary > Unstressed. Magnitude for secondary-unstressed was much smaller than primary-unstressed.
- Intensity (RMS energy): Primary > Unstressed, Secondary > Unstressed (but only for 3 of 5 vowels). Primary probably higher than secondary.

Phonetic duration and phonemic vowel length

Languages with a phonemic vowel length distinction show some variability in the long/short ratio. Some examples:

- Japanese: long vowels approx. 2.4x longer than short vowels (e.g. Hirata 2004, Akaba 2008)
- Thai: Averaged over following segment, long vowels are approx 2x longer than short vowels for stressed vowels, 1.5x longer for unstressed vowels (Potisuk et al. 1998)
- Kinyarwanda: long vowels approx 1.75x longer in environments where both long and short vowels can appear (Myers 2005)
- Hungarian: long vowels approx 1.8x longer than short vowels (Vogel et al. 2016)

ʻŌlelo Hawaiʻi (Eastern Polynesian)

	Bilabial	Labiodental	Alveolar	Velar	Glottal
Stop	p			k	ʔ
Fricative		v			h
Nasal	m		n		
Lateral			l		

	Front	Central	Back
High	i i:		u u:
Mid	e e:		o o:
Low		a a:	

Short diphthongs: /ae/, /ai/, /ao/, /au/, /ei/, /eu/, /iu/, /oi/, /ou/
Long diphthongs: /a:e/, /a:i/, /a:o/, /a:u/, /e:i/, /o:u/

(Parker Jones 2010, 2018; Elbert & Pukui 1979; Pukui & Elbert 1986; Schütz 1981, Kettig 2021)

Functional load hypothesis re: duration

Hypothesis: Languages that have a phonemic duration contrast will not use duration as a cue to stress (Berinstein 1979)

Mixed evidence has been reported (though much of it seems to be impressionistic, not measured)

Duration is not a cue to word-level stress:

- Hungarian (Vogel et al. 2016)

Duration is a cue to word-level stress:

- Aleut (Taff et al. 2001), Chickasaw (Gordon 2004)

Goals for analysis of ʻōlelo Hawaiʻi

1. ʻŌlelo Hawaiʻi is said to have primary, secondary and no stress. How many levels of stress are acoustically distinguished in spontaneous speech data and which acoustic correlates are most reliable?
2. Do speakers distinguish long/short vowels with duration?
3. Are the correlates of stress in long/short vowels the same?
4. Does ʻōlelo Hawaiʻi conform to the Functional Load Hypothesis and not use duration as a correlate to word stress?

Stress in ʻŌlelo Hawaiʻi

For words with only short vowels with up to 4 syllables (a focus of this talk), stress is trochaic with primary stress on the rightmost foot and secondary stress on the preceding foot (Schütz 1981, Parker Jones 2010):

- **/(ˈ$\sigma_L\sigma_L$)/:** /(ˈpu.ke)/ ‘book’, /(ˈki.ʔi)/ ‘picture’
- **/σ_L(ˈ$\sigma_L\sigma_L$)/:** /ʔe(ˈli.ma)/ ‘five’, /ma(ˈku.a)/ ‘parent’
- **/(ˌ$\sigma_L\sigma_L$)(ˈ$\sigma_L\sigma_L$)/:** /(ˌma.ka)(ˈhi.ki)/ ‘year’, /(ˌa.nu)(ˈhe.a)/ ‘soft fragrance’

Stress in ʻŌlelo Hawaiʻi

Syllables with long vowels are always stressed. The stressed vowel in the rightmost foot receives primary stress, and all other long vowels (are said to) receive secondary stress.

Examples:

- **/(ˌσ_H)(ˈσ_H)/:** /(ˌka:)(ˈla:)/ ‘money’
- **/(ˌ$\sigma_L\sigma_L$)(ˈσ_H)/:** /(ˌa.ni)(ˈla:)/ ‘weather’
- **/(ˌσ_H)(ˈ$\sigma_L\sigma_L$)/:** /(ˌku:)(ˈku.lu)/ ‘to stand’

Speakers

Data from Kettig (2021): comprised of 8 speakers from the Ka Leo Hawaiʻi Hawaiian language radio program that aired from 1972-1988 (Kaniʻāina, ulukau.org, Larry Kimura, producer)

Speakers were fluent childhood speakers of ʻōlelo Hawaiʻi who also spoke a variety of languages, including English and Hawaiʻi Creole

Passages were in ʻōlelo Hawaiʻi with no code-switching, except for occasional names or place names

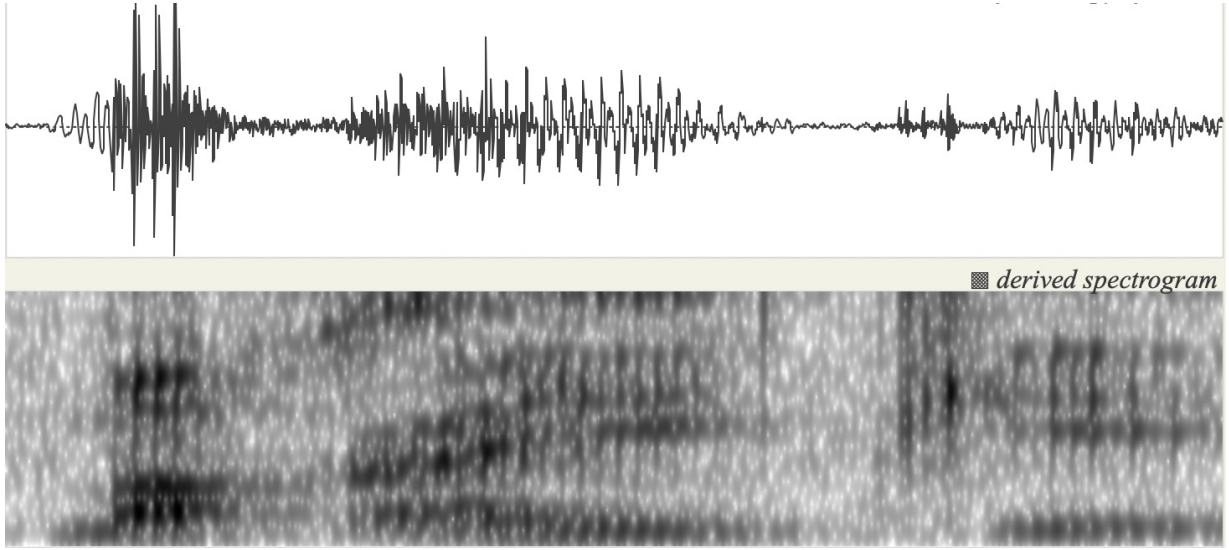
Materials

Data was force-aligned using the Montreal Forced Aligner (McAuliffe et al. 2017) trained on ʻōlelo Hawaiʻi

Two-, three- and four-syllable words containing only short vowels, and two syllable words containing only long vowels, surrounded by consonants, were identified in the transcripts

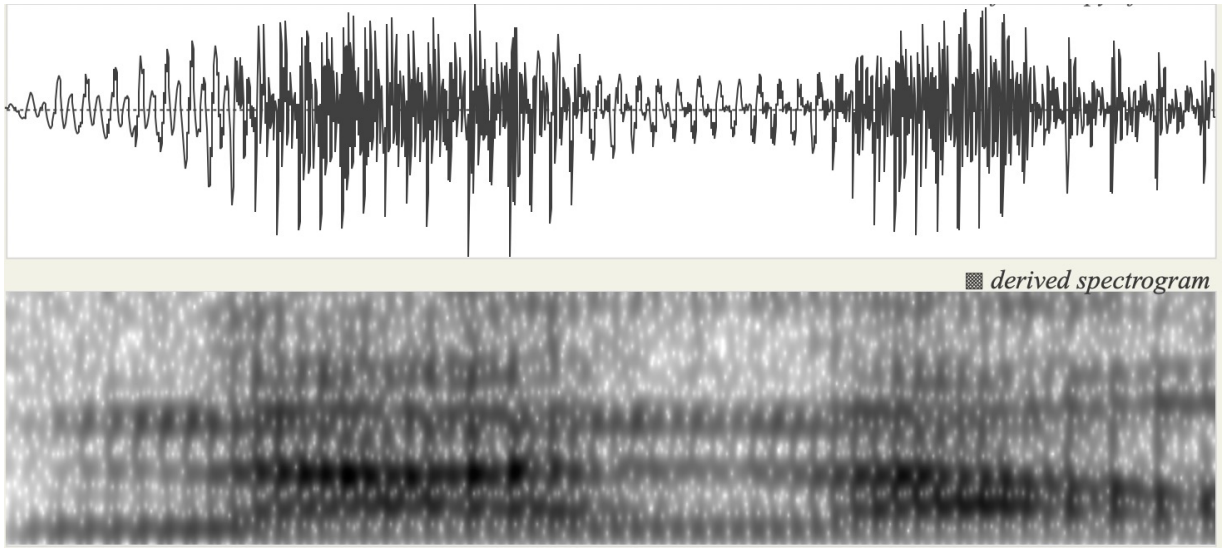
Pre-pausal, phrase-final and phrase-initial words were excluded

Examples (voice of Henry Machado)



m a k a h i k i

‘year’



n a: n a:

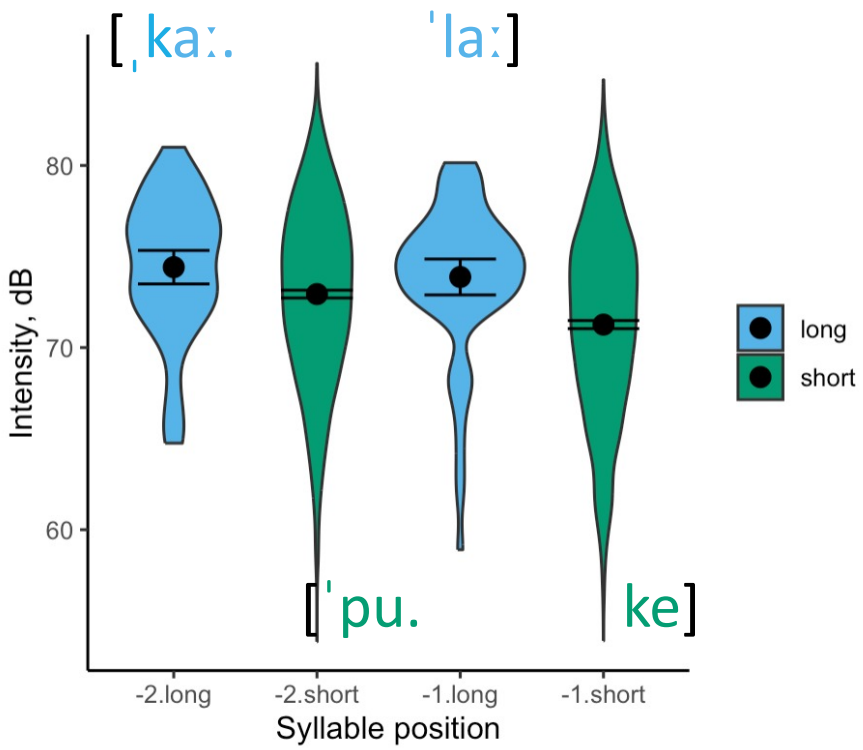
‘look’

Measures and analysis

For each vowel interval, three measures commonly associated with stress were extracted:

- Vowel duration and median intensity (RMS amplitude) using the FastTrack Praat plug-in (Barreda 2021)
- Mean F0 using REAPER

Results: Intensity



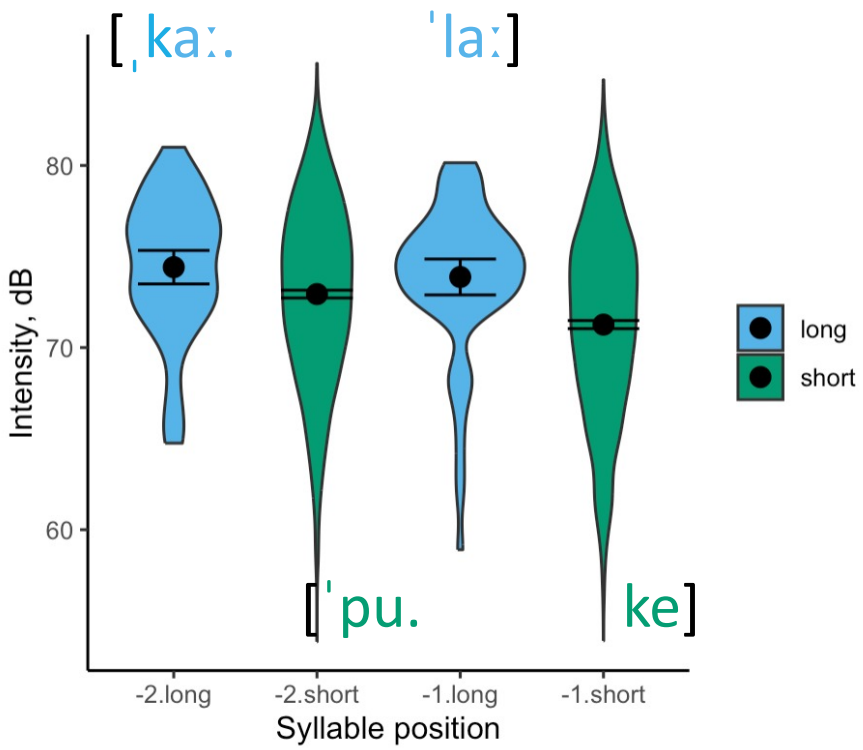
TWO SYLLABLE WORDS WITH SHORT VOWELS (N=2023)

TWO SYLLABLE WORDS WITH LONG VOWELS (N=77)

Considering short alone: Primary (penultimate) syllable **significantly louder** (β=1.73 dB, *p*<.001) than unstressed (final) syllable

Considering long alone: No difference between primary (final) syllable and secondary (penultimate) syllable

Results: Intensity



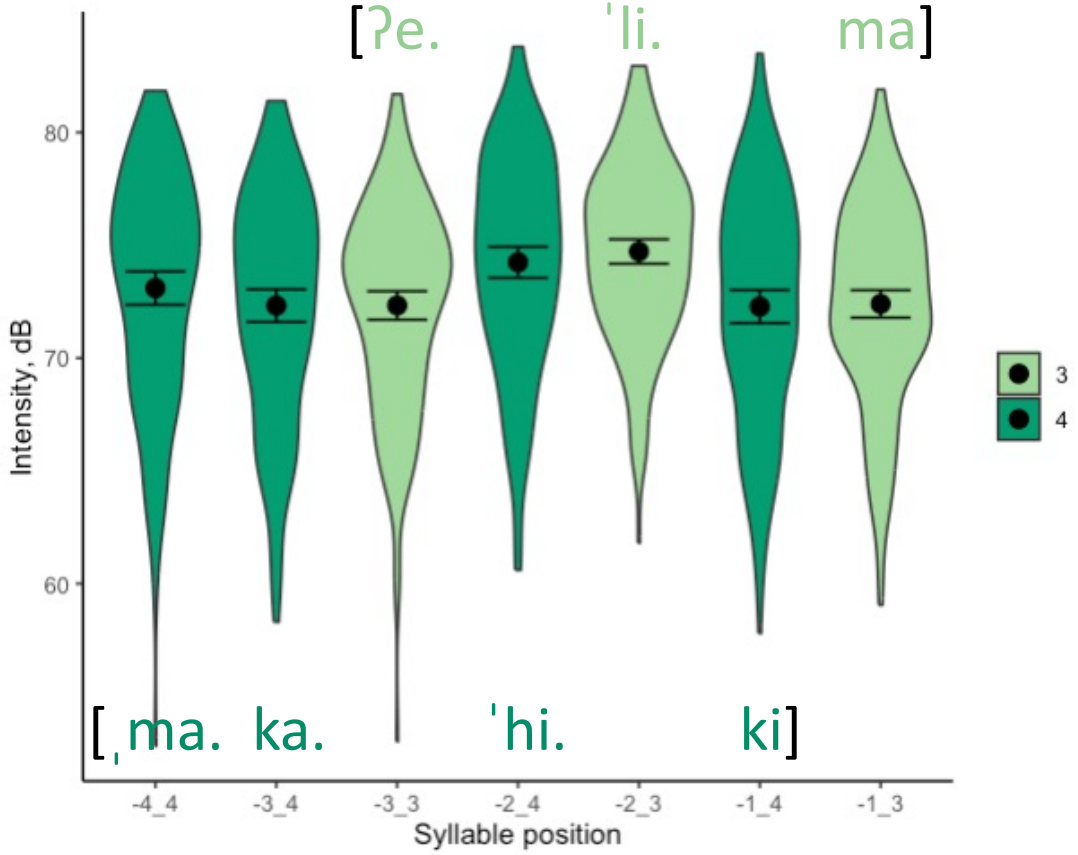
TWO SYLLABLE WORDS WITH SHORT VOWELS (N= 2023)

TWO SYLLABLE WORDS WITH LONG VOWELS (N=70)

Results:

- **Long vowels are louder than short vowels** (β=1.67 dB, *p*=.015)
- Significant interaction of length and syllable number (β=1.18 dB, *p*=.006): Penultimate short vowels are louder than final short vowels, but no difference for long vowels

Results: Intensity



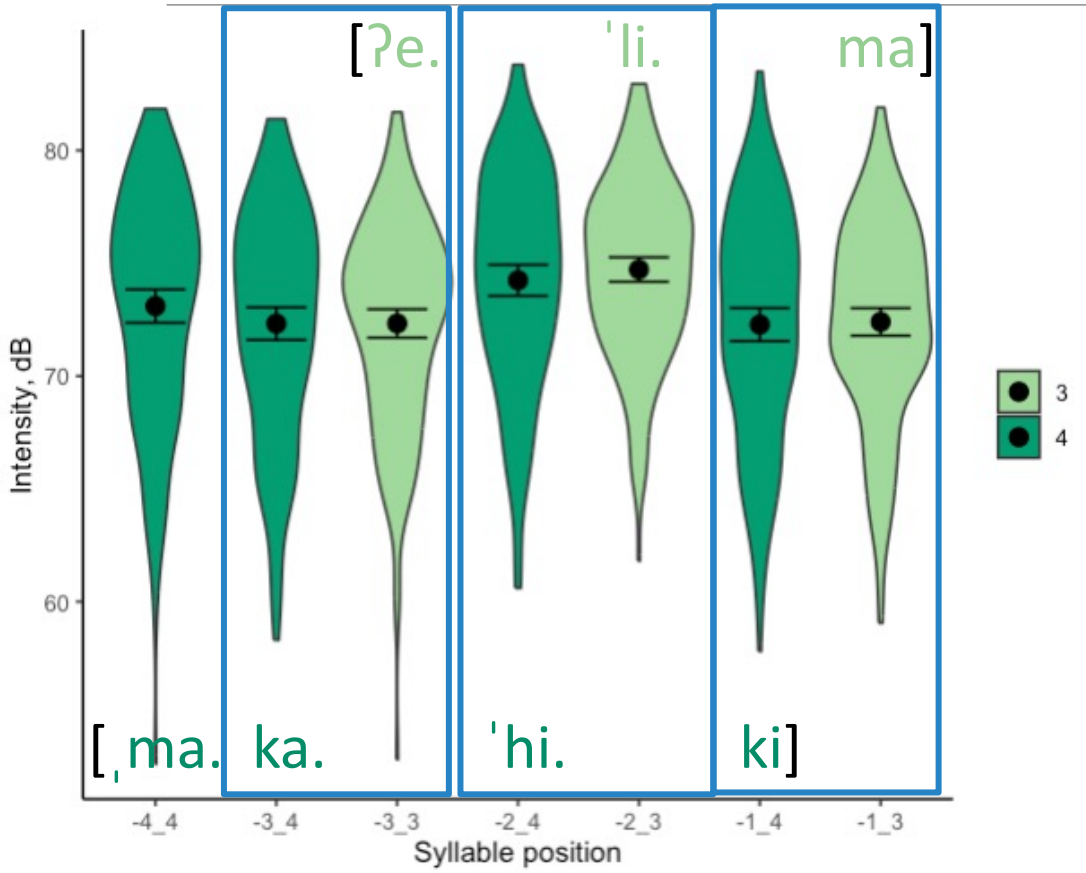
THREE SYLLABLE WORDS WITH SHORT VOWELS (N=206)

FOUR SYLLABLE WORDS WITH SHORT VOWELS (N=191)

(p<0.001 unless marked)

Considering 3-syll short: Primary (penultimate, li) **significantly louder** than final unstressed (ma, β=2.24 dB) and antepenultimate unstressed (ʔe, β=2.30 dB).
Considering 4-syll short: Primary (penultimate, hi) **significantly louder** than final unstressed (ki, β=2.05 dB) and antepenultimate unstressed (ka, β=1.36 dB).
Secondary (ma) **significantly louder** than final unstressed (ki, β=0.85 dB, *p*=.018) and antepenultimate unstressed (ka, β=1.54 dB) **but no sig. difference from primary**.

Results: Intensity



THREE SYLLABLE WORDS WITH SHORT VOWELS (N=206)

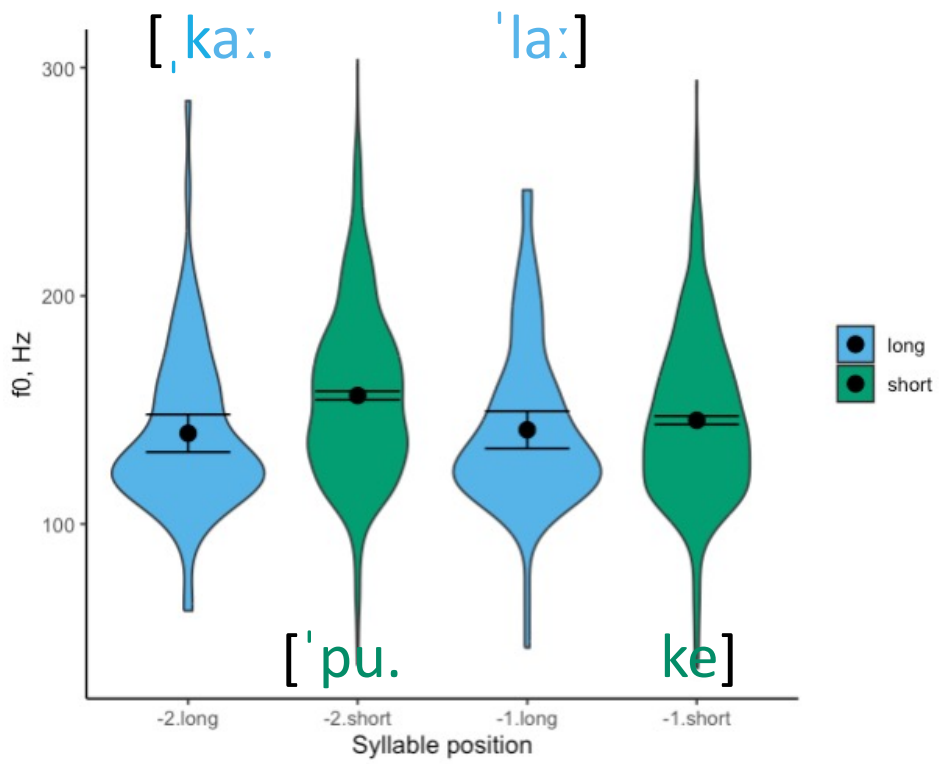
FOUR SYLLABLE WORDS WITH SHORT VOWELS (N=191)

(Comparison note: one 7-level fixed effect factor)

Pairwise estimated marginal means:

- No sig. difference between 3-syll final unstressed and 4-syll final unstressed
- No sig. difference between 3-syll primary and 4-syll primary
- No sig. difference between 3-syll antepenultimate unstressed and 4-syll antepenultimate unstressed

Results: f0



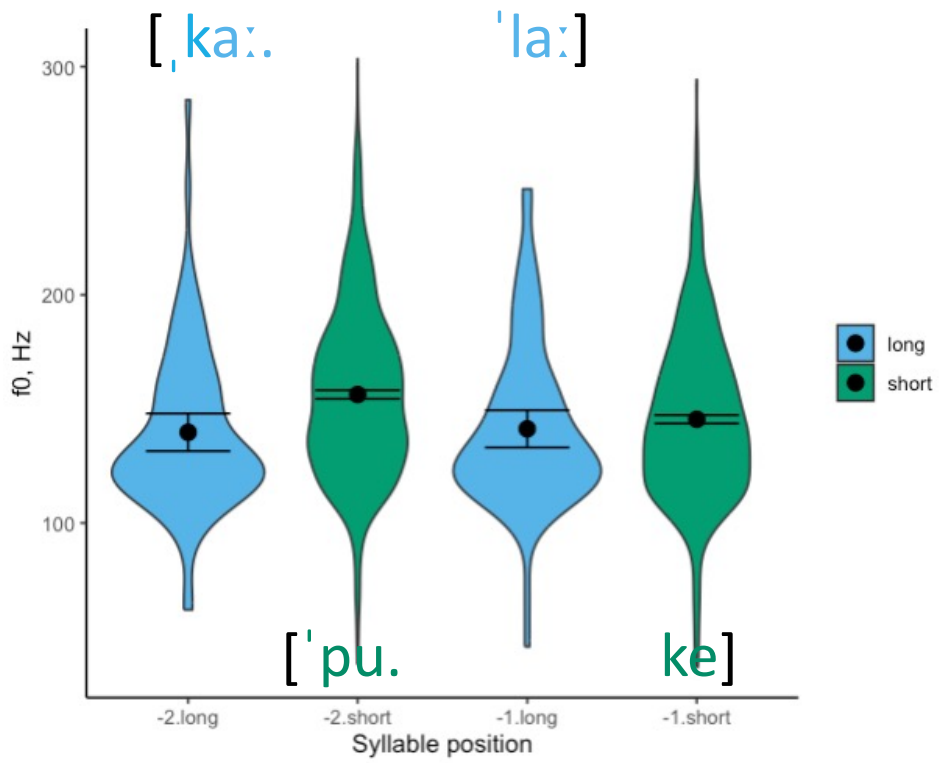
TWO SYLLABLE WORDS WITH SHORT VOWELS (N= 1545)

TWO SYLLABLE WORDS WITH LONG VOWELS (N=76)

Considering short alone: Primary (pu, penultimate) syllable **significantly higher** (ke, β=10.7 Hz, *p*<.001) than unstressed (final) syllable

Considering long alone: No difference between primary (la:, final) syllable and secondary (ka:, penultimate) syllable

Results: f0



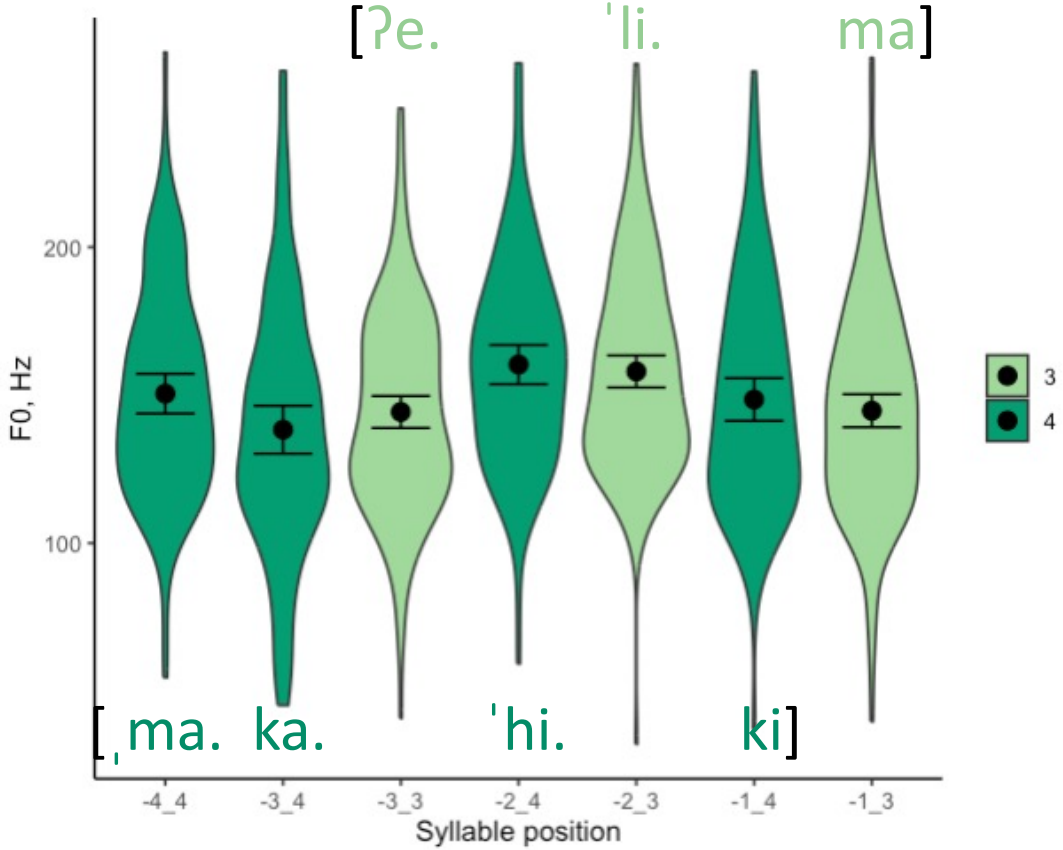
TWO SYLLABLE WORDS WITH SHORT VOWELS (N= 1545)

TWO SYLLABLE WORDS WITH LONG VOWELS (N=76)

Results:

- **No significant difference in F0 based on length**
- Significant interaction of length and syllable number (β=10.66Hz, *p*<.001): Penultimate stressed short vowels are higher than all other syllables.

Results: f0

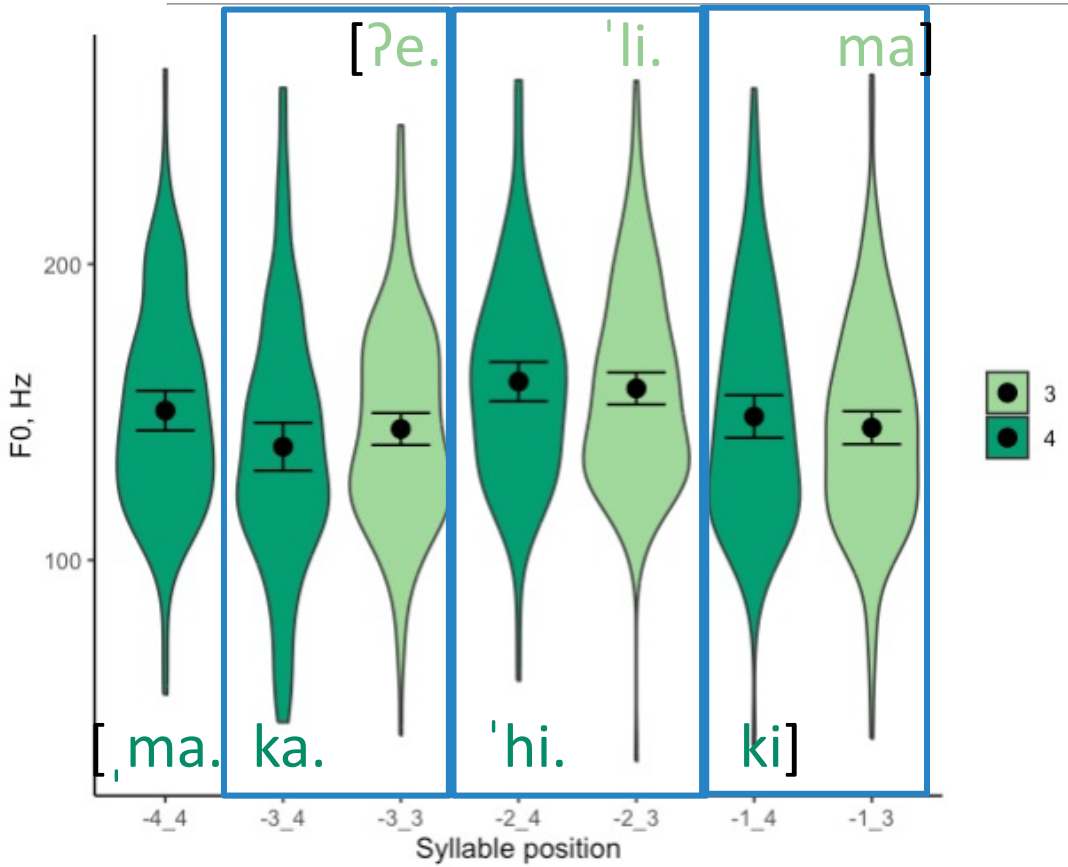


THREE SYLLABLE WORDS WITH SHORT VOWELS (N=155)

FOUR SYLLABLE WORDS WITH SHORT VOWELS (N=108)

Considering 3-syll short: Primary (li, penultimate) **significantly higher** than final unstressed (ma, β=13.7 Hz) and antepenultimate unstressed (ʔe, β=13.5 Hz).
Considering 4-syll short: Primary (hi, penultimate) **significantly higher** than final unstressed (ki, β=12.7 Hz) and antepenultimate unstressed (ka, β=18.9 Hz).
Secondary (ma) **significantly louder** than antepenultimate unstressed (ka, β=13.3 Hz, *p*<.001) **but no sig. difference from primary** (hi) **or final unstressed** (ki).

Results: f0



THREE SYLLABLE WORDS WITH SHORT VOWELS (N=155)

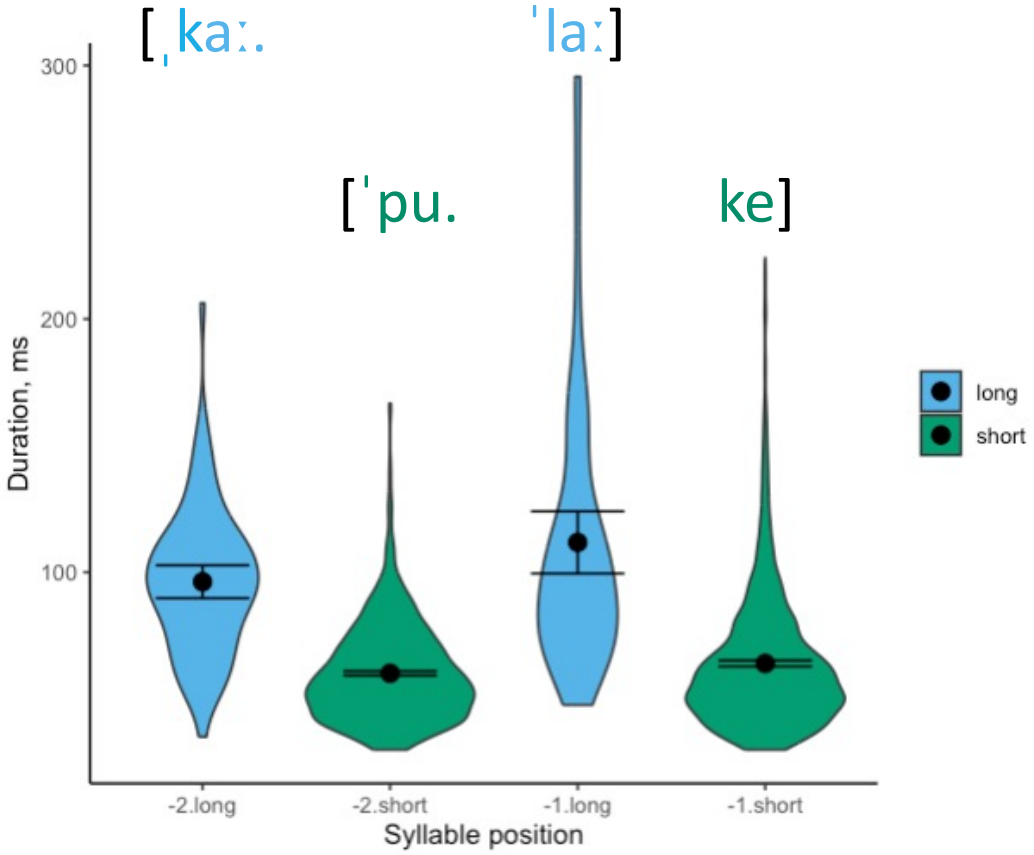
FOUR SYLLABLE WORDS WITH SHORT VOWELS (N=108)

(note: one 7-level fixed effect factor, all $p < 0.001$)

Pairwise estimated marginal means:

- No sig. difference between 3-syll final unstressed and 4-syll final unstressed
- No sig. difference between 3-syll primary and 4-syll primary
- No sig. difference between 3-syll antepenultimate unstressed and 4-syll antepenultimate unstressed

Results: Duration



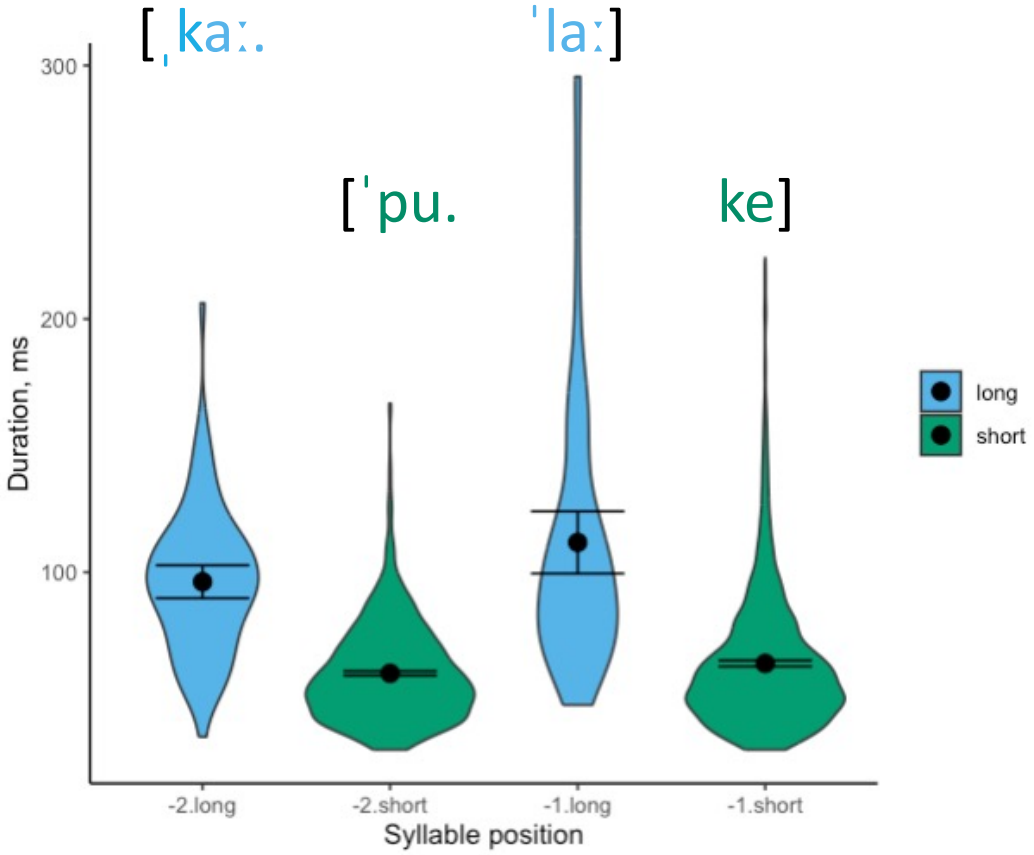
TWO SYLLABLE WORDS WITH SHORT VOWELS (N= 1998)

TWO SYLLABLE WORDS WITH LONG VOWELS (N=77)

Considering short alone: Primary (pu, penultimate) stress **significantly shorter** (β=-4.24 ms, *p*<.001) than unstressed (ke, final)

Considering long alone: Primary (la:, final) stress **significantly longer** (β=15.5 ms, *p*=.018) than secondary (ka:, penultimate)

Results: Duration



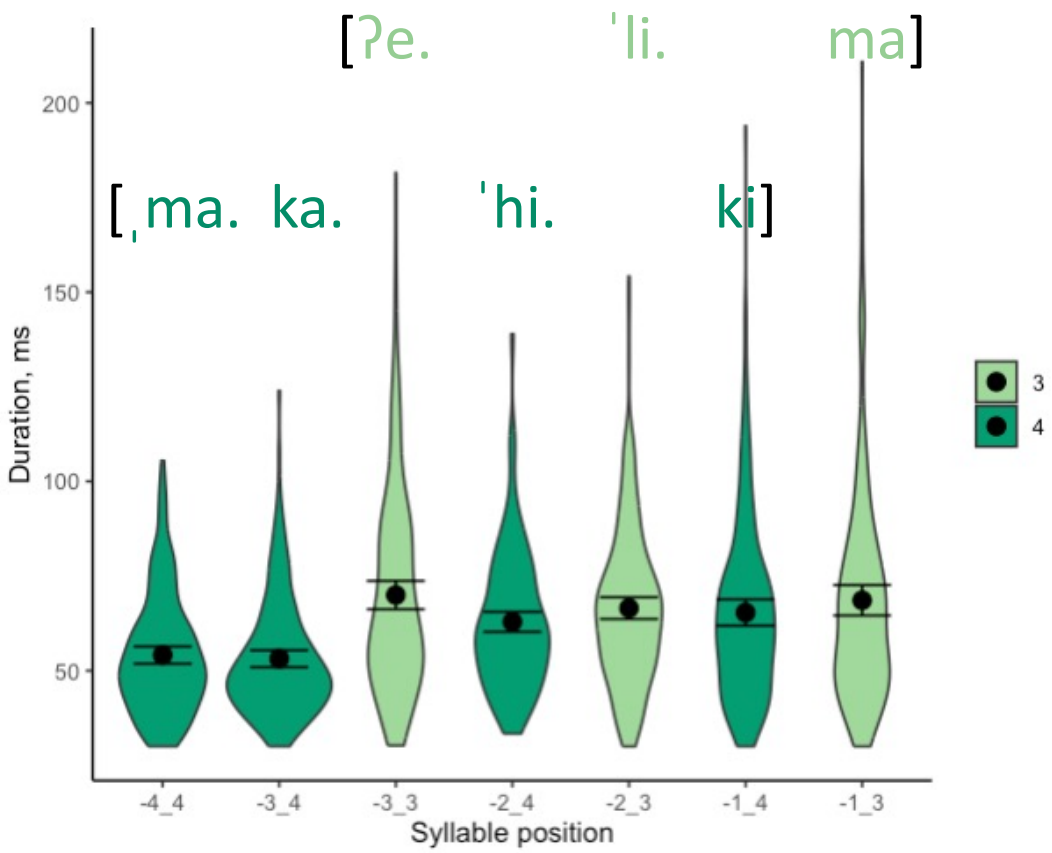
TWO SYLLABLE WORDS WITH SHORT VOWELS (N= 1998)

TWO SYLLABLE WORDS WITH LONG VOWELS (N=77)

Results:

- **Long vowels are longer than short vowels** (β=50.32 ms, *p*<.001)
- The **last syllable is longer than the first** (β=15.37 ms, *p*<.001), but a significant interaction of length and syllable number (β=11.13 ms, *p*<.001) indicates that (non-phrase-final) **word-final syllable lengthening is greater for long than short vowels**

Results: Duration



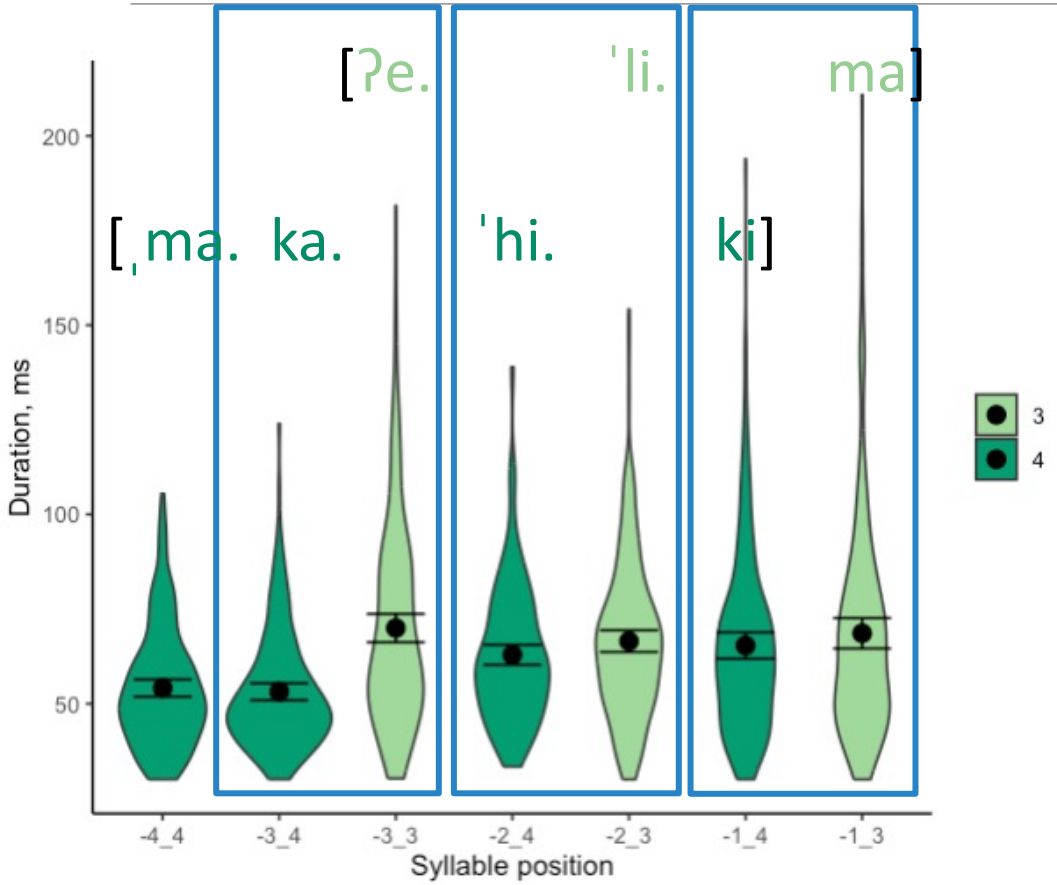
THREE SYLLABLE WORDS WITH SHORT VOWELS (N=205)

FOUR SYLLABLE WORDS WITH SHORT VOWELS (N=190)

Considering 3-syll short: **No significant differences between syllables**

Considering 4-syll short: Primary (hi, penultimate) **significantly longer** than secondary stressed (ma, β=8.41 ms, $p<.001$) and antepenultimate unstressed (ka, β=9.44 ms, $p<.001$). Final unstressed (ki) **significantly longer** than secondary stressed (ma, β=10.65 ms, $p<.001$) and antepenultimate unstressed (ka, β=11.67 ms, $p<.001$).

Results: Duration



THREE SYLLABLE WORDS WITH SHORT VOWELS (N=205)

FOUR SYLLABLE WORDS WITH SHORT VOWELS (N=190)

(Comparison note: one 7-level fixed effect factor)

Pairwise estimated marginal means:

- No sig. difference between 3-syll final unstressed and 4-syll final unstressed
- No sig. difference between 3-syll primary and 4-syll primary
- **Significant difference** between 3-syll antepenultimate unstressed and 4-syll antepenultimate unstressed (β=19.77 ms, *p*<.001)

Summary of results

Contrastive vowel length

Comparing long/short vowels in two syllable words:

- Primary stressed long vowels are 1.85x longer – [ˌka:.ˈla:] vs. [ˈpu.ke]
- Secondarily stressed long vowels are 1.6x longer than short primary stressed vowels – [ˌka:.ˈla:] vs. [ˈpu.ke]

Consistent with reports of most other languages

Summary of results

Intensity and F0

Primary and secondary stressed syllables are higher than unstressed syllables, but no difference between primary and secondary stress.

Same results for short and long vowels

Comparisons of words of different lengths show that correlates to stress are the same regardless of where the stressed or unstressed syllables are.

Summary of results

Duration

Increase pertains to the final syllable (2 syll words [('σ_L.σ_L)]) or final foot (4 syll words with short vowels, [(ˌσ.σ)('σ_L.σ_L)]) rather than just the stressed syllable itself

- NB: Longer final syllable in 2-syllable long vowel words [(ˌσ_H.'σ_H)] could be due to either final syllable or final foot

→ *Two levels of stress in ʻōlelo Hawaiʻi are distinguished by F0 and intensity: primary/secondary vs. unstressed*

- Duration is not a correlate of stress in ʻōlelo Hawaiʻi

Discussion: Acoustic correlates to levels of stress

The neutralization of primary with secondary, vs. unstressed may be less common compared to other languages with assumed 3 levels of stress when acoustic correlates are extracted:

- Gordon and Roettger (2017): “The most tenuous distinction in most cases was between secondary stress and lack of stress”
- Some languages are said to collapse assumed primary and secondary stress, but there is little instrumental evidence, e.g. Creek (Muskogean, Martin 2011) or Karitiana (Tupian, Everett 2006)

Discussion: Duration and FLH

ʻŌlelo Hawaiʻi does not use duration to distinguish between any levels of stress (including primary vs. unstressed)

This happens to be consistent with the functional load hypothesis, but other languages violate the FLH (e.g., Chickasaw, Aleut)

Lunden et al. (2017): of 82 languages with contrastive vowel duration, 55% are said to use duration as a stress correlate

- 72% of Austronesian languages use duration as a correlate, though not all have contrastive length
- Even when limiting their analysis to studies w/instrumental evidence (N=25), 68% of languages w/a duration contrast also use duration to signal stress

Discussion: Role of duration

Instead of marking stress, duration in ‘ōlelo Hawai‘i may be prosodically marking final syllables or feet

Cross-linguistic evidence for pre-boundary lengthening is strongest at higher prosodic boundaries, but some effects exist at the word level

- E.g. longer /ə/ in ‘poppa posed’ than ‘pop opposed’ (Beckman and Edwards 1990, Turk & Shattuck-Hufnagel 2000)

Conclusion

Contrastive vowel length ratio is similar to that found for other languages

ʻŌlelo Hawaiʻi marks two levels of stress: primary/secondary vs. unstressed

Duration is not a correlate of stress, but may instead indicate word edges

Acoustic correlates to stress are the same in long and short vowels

Future directions

- Are there other cues to stress, such as F1/F2?
- Putting all cues together into a multinomial regression predicting stress, rather than separate lmers with stress predicting each cue

Thanks/acknowledgments

Mahalo nui to Professor Larry Kimura, ʻŌiwi Parker Jones, and the invaluable voices of the *mānaleo* and others who appeared on the Ka Leo Hawaiʻi radio program and are reflected in this work:

- Rachel Mahuiki
- Alfred Apaka Sr.
- Ida Kapuʻihilani Feary-Milton Nāone
- Henry Hanalē Machado
- Lilian Victor
- David Kaʻalakea
- Sadie Kaluhiʻōpiopio Beebe
- Joseph Makaʻai