A Preliminary Study on the Vowel Length Contrast in te reo Māori

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Abstract

Te reo Māori (the Māori language of New Zealand) has a long-short vowel contrast. Previous studies have shown some of the long vowels have been shortened, resulting in a reduction in durational distinction between short and long vowels. Present-day elders' vowel duration was compared with younger speakers, and we found that younger speakers have shortened their short vowels, resulting in an increased vowel distinction for certain vowels. An identification perception test was carried out to examine the categorical boundary of the long-short vowel contrast for Māori learners and advanced listeners, where the advanced listeners responded more ambiguously, suggesting they may be using cues beyond duration.

Index Terms: te reo Māori, long-short vowel contrast, acoustic analysis, speech perception

1. Introduction

Vowel length distinctions are found in a number of languages such as Czech [1], Danish [2], Swedish [3], Estonian [4], Finnish [4], Thai [5], Arabic [6], Japanese [7], and Mongolian [8], where the length of the vowels can change the meaning of a word. In these languages, short vowels are phonetically realised with shorter duration, while long vowels are phonetically realised with longer duration, and the obvious primary cue to distinguish between short and long vowels is, therefore, duration in most cases. Some languages also use secondary cues such as fundamental frequency (f0) and formant values. For example, f0 is a secondary cue in vowel length perception for Japanese listeners [9–12], whereas vowel formants affect vowel length categorisation in Swedish [3]. Vowel length perception can vary across languages, where linguistic background and experience of the listener, as well as their hearing abilities, can affect how a listener perceives a vowel to be long versus short [6, 10, 12–15]. For example, second language (L2) listeners cannot identify or distinguish between vowel length contrasts when their first language (L1) does not have length contrasts [10, 13], but having length contrasts in their L1 can sometimes help in the listeners' L2 vowel length perception [6, 14].

Māori is the language of New Zealand's indigenous people, and as with all Polynesian languages, it also contrasts in vowel length. It consists of five vowels /i, e, a, o, u/, each with a distinct long vowel version where vowel length is phonemic [16–18]. Word stress will usually lie on the first long vowel if present [17, 19], resulting in long vowels being often stressed.

Throughout the past 180 years, Māori has experienced increasing contact with English, with English-medium schooling becoming prevalent by the late 19th century [17]. The subsequent decades saw a significant shift towards English dominance, resulting in a decline in fluent Māori speakers [20, 21], causing an intergenerational transmission loss of the language. Revitalisation efforts since the mid-1980s have led to a resurgence in first language (L1) speakers [22, 23]. The ongoing reversal of language shift in Māori has created a distinctive dynamic between first language (L1) and second language (L2) users [21], where many of the current generation of L1 users learn from fluent L2 speakers. The revitalisation efforts have also facilitated a growing number of L2 learners [18, 24, 25]. The Māori and New Zealand English (MAONZE) project [26, 27] examined sound changes in Māori over the past century e.g.,[16, 27–30], consisting of analyses in vowel and consonant production, as well as prosody. The MAONZE corpus consists of speakers from three generations: historical speakers born in the 1880s and recorded in the 1940s, present-day elder speakers born in the 1930s, and present-day younger speakers born around 1980, where the present-day speakers were recorded in the early 2000s [16, 26, 27].

Regarding vowel length analysis, [18] reports on the average vowel length by speaker group and notes a reduction in the duration differences between long and short vowels in Māori over time, comparing historical speakers to present-day speakers. The long vowels of the historical speakers are typically twice the length of the short vowels, but this distinction has been reduced in the present-day speakers, especially for /i:/ and /u:/, possibly as a result of New Zealand English influences. However, [18] also notes that the length distinction between /a:/ and /a/ has largely remained, possibly due to the short and long vowel pair in corresponding New Zealand English (START and STRUT vowels). To our knowledge, there has not been any further published detailed acoustic analysis of Māori vowel length apart from [18]. There has been very little perceptual research published on Māori cues [30, 31], and none on the perception of Māori vowel length.

The current paper aims to provide a more detailed analysis of Māori vowel length using the MAONZE corpus, focusing on present-day elder and younger speakers. Preliminary findings of the acoustic analysis were presented at the 2023 New Zealand Linguistics Society Conference. A preliminary perception test was also conducted to examine categorical boundaries in the duration of Māori vowel length contrasts among learners and advanced users.

2. Methodology

2.1. Corpus analysis

In the current study, only the present-day elders and first language (L1) younger speakers from the MAONZE corpus were analysed [26]. There were nine male (mean age at time of

recording = 71.4, sd = 5.4) and eight female (age mean at time of recording = 73.5, sd = 7.3) speakers in the present-day elders (L1) group and five male (mean age at time of recording = 24.6, sd = 5.9) and six female (mean age at time of recording = 20.7, sd = 2.3) speakers in the younger L1 group.

The MAONZE project selected target tokens of vowels from contextual speech [27]. Thirty tokens per vowel (/i i: e e: a a: o o: u u:/) per speaker were chosen in CVC environments whenever possible. The start and end of the vowel tokens were hand labelled by the MAONZE team. The vowels selected by the MAONZE team were always stressed vowels, and they are the ones analysed in the current study. Query and duration extraction was performed using emuR [32], and linear mixed model analyses were used to analyse the duration data.

2.2. Vowel length identification

2.2.1. Stimuli

Three sets of target words were chosen using the recorded speech from the MAONZE corpus, where the speakers were instructed to say a series of hVt nonce words in the form of hV:tata and hVta. There were no minimal pair equivalents in the corpus, i.e., the short vowel equivalent to hātata was hata and not hatata. Recordings from a present-day elder female speaker affiliated with the Ngāti Pōrou iwi (tribe), born in 1930 and aged 77 at the time of recording, were selected due to the quality of the speech recorded. A present-day elder woman was chosen as they are a group reported to be more conservative in preserving vowel length distinction [33]. As young female speakers have been shown to lead sound change [16, 33–35], this was also in preparation for a future study where we will examine the differences in perception between present-day elder and young female speakers.

Table 1. *Word stimuli and their target vowel duration.*

word	target vowel duration (s)
/a:/ in ha:tata	0.17
first /a/ in hata	0.06
/e:/ in he:tata	0.20
/e/ in heta	0.09
/o:/ in ho:tata	0.17
/o/ in hota	0.07

Only three of the five vowels were chosen due to time constraints. They were: /a/ in the words hātata and hata, /e/ in the words hētata and heta and /o/ in the words hōtata and hota. The /a/ stimuli were chosen due to the reported vowel length distinction. We also included a front vowel set and a back vowel set, where hētata and heta were chosen over hītata and hita, and hōtata and hota were chosen over hūtata and huta according to the sound quality of the recordings. Table 1 shows the keywords selected and the duration of the target vowel, that is, the duration of the vowel (V) in hV:tata and hVta, measured in Praat [36] visually by the authors.

A Praat script [37] was used to automatically generate a 10-step continuum, where the short extreme value was the duration of the hVta word and the long extreme value was the duration of the hV:ta word. For example, the stimulus ‘hātata’ was manipulated from 0.17 in ten steps to 0.06. Similarly, ‘hata’ was manipulated from 0.06 in ten steps to 0.17. Due to the possibility of secondary auditory cues in perceiving long-short vowel contrast, both hV:tata and hVta continuum were included in the identification test.

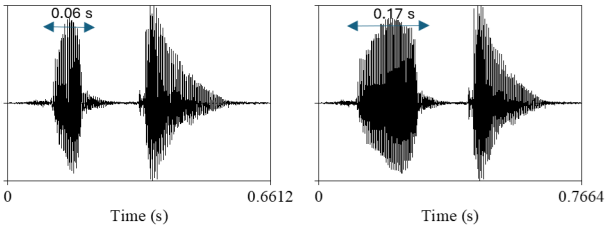

Figure 1: *Original ”hata” and step-10 hata where the first /a/ has been manipulated to be as long as the /a:/ in ha:tata.*

2.2.2. Participants

Eleven te reo Māori listeners of different language experiences were recruited. They were separated into two groups: learners and advanced users. The learner’s group consisted of 5 participants: 4 female listeners, 1 male listener, and no gender diverse (mean age = 27.2, sd = 6.9). The learners’ group has been exposed to te reo Māori through their New Zealand schooling and/or has taken language courses in secondary/tertiary education. None speak Māori in their daily life. The advanced group consisted of 4 participants: 3 female listeners, 3 male listeners, and no gender diverse (mean age = 37.8, sd = 16.45). The advanced group includes L1 speakers, fluent L2 speakers, teachers of te reo Māori, and speakers with Māori heritage who have taken advanced tertiary courses. Recruitment and participation in perception tests have been approved by the Ethics committee at the University of Auckland (26316). They were remunerated for their participation.

2.2.3. Test design

Before the experiment started, the listeners were given practice trials to familiarise themselves with the graphical user interface (GUI) and the type of speech sounds they would be listening to. A jspsych script modified from [38] was used [39]. For each set of keywords, they listened to the two extremes of the keywords. For example, they listened to ‘hata’ where the /a/ vowel is as short as 0.06 s and as long as 0.17 s (refer to Table 1 and Figure 1). The participants listened to the isolated words and were asked to identify which of the two words on the screen they heard, for example, ”hata” versus ”hāta”, ”hatata” versus ”hātata”, where the macron above the vowel is a common practice in te reo Māori to denote a long vowel. The words were presented in blocks, with the order of the blocks randomised, and the locations of the buttons were swapped halfway through the repetitions. There were 6 repetitions per word. This gave a total of 360 trials (6 words x 10-step continuum x 6 repetitions) per listener.

3. Results

3.1. Acoustic analysis

The duration data of the labelled long and short vowels from the MAONZE corpus were statistically analysed using a linear mixed effect model via the *lme4* package in R [40]. The fixed effects were: vowel type (/i, e, a, o, u/), duration type (long vs short), gender of speaker (female vs male) and age group of speaker (elder vs younger). The fitted model includes a four-way interaction between the above fixed effects and a random effect of the speaker. Post-hoc analysis for pairwise comparison was implemented by *emmeans* package [41]. A significant four-way interaction was found between vowel type, duration type, gender of speaker and age group of speaker

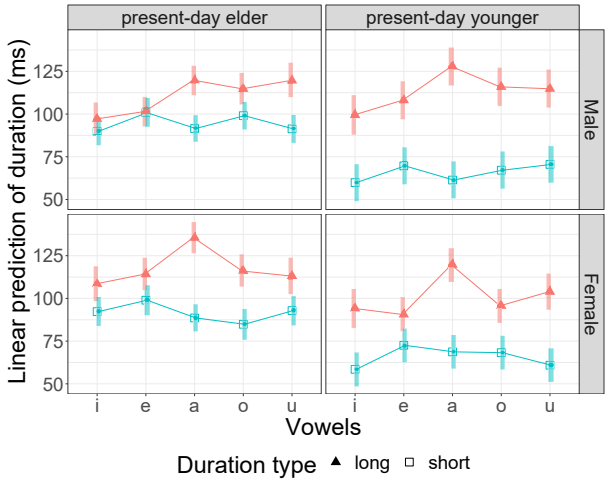

Figure 2: *Duration of vowels spoken by present-day elder and younger speakers from the MAOZNE corpus.*

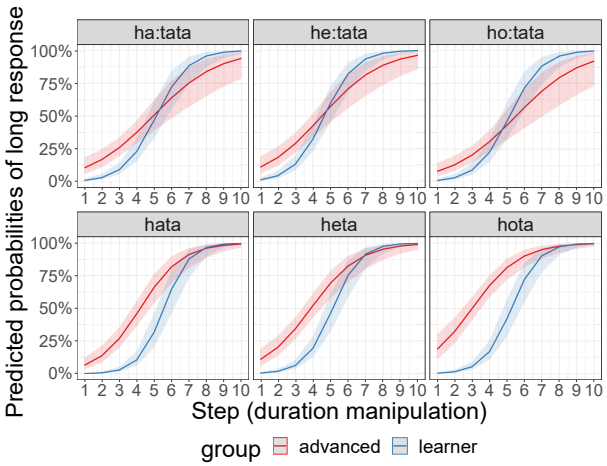

Figure 3: *Predicted long vowel responses by keyword.*

$(\chi^2(4) = 18.91, p < 0.001)$.

Figure 2 displays the duration estimates of the five long-short vowel pairs in terms of the four groups of speakers (elder male, elder female, younger male, younger female) from the fitted model. The colour and shape of the plot indicate the duration type of the vowel, where pink/triangle displays the long vowel measurements and square/blue displays the short vowel measurements. We observed that the short vowels have become shorter in the younger speakers regardless of gender. In general, differences between the short and long vowels have also become larger for the younger speakers than the elder speakers.

Due to space constraints, tables containing the pairwise contrasts from the statistical analyses are not included, and the results are described textually only. With the exception of /e/ and /i/ in the elder male speakers, all vowels produced by the four groups of speakers significantly differ in length between their short and long variants. Apart from elder male speakers, the much more frequent /a/ has the largest differences between its short and long variants compared to the other four vowels. The differences between the long and short variants of /a/ range from an estimate of 28.3 ms difference in the elder male speakers to 66.5 ms differences in the younger male speakers.

Significant differences were found between the duration of /a:/ and the other long vowels (/i:/, /e:/, /o:/, /u:/) for the two groups of female speakers. For the male speakers, there were differences between /a:/ and the front vowels (/e:/ and /i:/) for the elder male speakers, and between /a:/ and /i:/, /e:/ and /u:/ for the younger male speakers. The differences between /a:/ and the other vowels ranged from 29.11 ms between /a:/ and /e:/ for younger female speakers and 13.04 ms between /a:/ and /u:/ for the younger male speakers. For the short vowels, there were only significant differences in duration between /a/ and /e/ for the elder speakers but not for the younger speakers, where the /a/ was significantly shorter than /e/.

Between the male and female speakers compared within their respective age groups, there were significant differences between the elder male and female speakers for /a:/ and /o/, and between younger male and female speakers for /e:/ and /o:/, with the male speakers' production longer than the female speakers' production of /o/ by 14.17 ms, /e:/ by 17.52 ms and /o:/ by 20.27 ms, and shorter for /a:/ by 15.83 ms. Between the elder and younger groups comparing within the gender of the speakers, elder speakers had significantly longer short vowels than younger speakers, regardless of gender, ranging from 16.64 ms between the female elder and younger speakers' /o/ to 33.79 ms between the female elder and younger speakers' /i/. The elder female speakers also had significantly longer /a:/, /e:/ and /o:/ compared to their younger counterparts.

3.2. Identification perception results

The identification results were analysed statistically using a generalised linear mixed model (GLMM) with the R package [42] lme4 [40] using `glmer`. Two GLMM models were implemented, one by the individual keywords and another by the word form (hV:tata and hVta) and the vowel type (/a, e, o/). The other fixed effects were step (10-step continuum), group (learners vs advanced) and a by-participant random slope over each stimulus. Significance in fixed effects was determined using a likelihood ratio test by comparing a model with the effect in question with a model without the effect. Plots were created with the R package sjPlot [43] and emmeans [41].

3.2.1. By keyword

Significant two-way interactions were observed between the keyword and step $(\chi^2(5) = 24.62, p =< 0.001)$, between group and step $(\chi^2(1) = 8.28, p = 0.004)$, and between group and keyword $(\chi^2(5) = 54.51, p < 0.0001)$. The interactions can be observed in Figure 3, displaying predicted probabilities of a participant in their groups responding a long vowel to the stimulus played. The red curve represents responses from advanced listeners, while the blue curve represents responses from learners across six keywords over a ten-step continuum from short to long extremes. Advanced listeners showed less steep curves compared to learners for all keywords. Learners perceived similarly across keywords, whereas advanced listeners' responses varied by keyword. Additionally, the learners displayed a tighter confidence interval, indicating less variation within the group, whereas the advanced group exhibited a wider confidence interval, indicating more variation.

For learners, the 50% boundary point was found to be between steps 5 and 6 for all keywords except for 'he:tata'. Advanced listeners demonstrated more variations, where their responses did not form a clear sigmoid curve. The boundary for 'hata', 'heta', and 'hota' occurred earlier between steps 3 and 4 for the advanced learners. For 'ha:tata', 'he:tata', and 'ho:tata', there were no instances of 100% extreme responses (either short or long). This trend was also observed for the short extreme responses of 'hata', 'heta', and 'hota'.

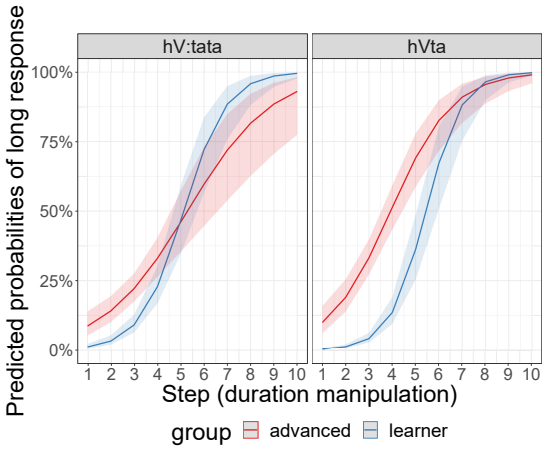

Figure 4: *Predicted long vowel responses by word form.*

3.2.2. *By word form and vowel type*

Analysis of the perceptual data by keywords indicates that advanced participants perceive hV:tata stimuli differently from hVta stimuli. This section presents an analysis based on word form and vowel rather than individual keywords. Significant two-way interactions were observed between the word form and step ($\chi^2(1) = 21.18, p < 0.0001$), group and step ($\chi^2(1) = 8.37, p = 0.004$), and group and word form ($\chi^2(1) = 48.54, p < 0.0001$), in addition to a main effect of vowel type ($\chi^2(1) = 8.72, p = 0.01$). Figure 4 displays the responses as a long vowel by the two participant groups separated by word form (hV:tata and hVta).

For the learner group, the 50% boundary is between steps 5 and 6 regardless of the word form, whereas for the advanced group, it is around step 6 for hV:tata stimuli and step 4 for hVta stimuli. This suggests that advanced listeners require more duration to perceive hV:tata as a long vowel compared to hVta, where a shorter duration elicits the perception of a long vowel.

In terms of the effect of vowels, the odds ratio contrast between /a/ and /e/ is 0.72, between /a/ and /o/ is 0.84 and between /e/ and /o/ is 1.17, regardless of the speaker groups.

4. Discussion and Conclusions

Previous analyses on vowel length contrast in Māori have noted a reduction in the durational distinction between short and long vowels in Māori. Specifically, aside from /a:/, the distinction between the vowel length pair has shortened compared to historical elders, where the duration of the long vowels was double that of the short vowels. Our analyses corroborate this trend to some extent. Compared to historical data presented in [18], present-day elder speakers exhibit shorter distinctions between the two vowel lengths. However, despite the overall reduction in durational distinction, present-day female elder speakers and male elder speakers still significantly distinguish their vowel length in terms of duration for all vowels apart from /i/ and /e/ for the male elder speakers. On the other hand, present-day younger speakers demonstrate increased durational differences between their long and short vowels compared to their present-day elder counterparts. While their long vowel durations are comparable to the elder speakers, their short vowels have reduced significantly. All short vowels among younger speakers have shortened compared to their elder counterparts, thus widening the durational distinction between the younger speakers' long and short vowel production. Changes in the present-day younger speakers may be a product of New Zealand English influences, which have been observed in other acoustic features such as vowel formants [16, 18]. Possible reasons for the reverse trend in increased durational differences observed in the younger speakers may also be hyper-articulation to compensate for the influences from New Zealand English, considering the regrets from the community regarding the intergenerational transmission loss of the language [16, 21, 25]. Future research should examine current speakers to understand how vowel lengths are realised nowadays, as the younger cohort in this study was recorded 20 years ago. Additionally, like other languages that use secondary acoustic cues such as formants and pitch contour [3, 5, 9], other acoustic cues may also be present in Māori vowel length contrast, and further acoustic analyses beyond duration is needed.

In terms of perception, we found the word and the 10-step continuum affect advanced and learner listeners differently. Word form affects advanced listeners' perception more so than learners, where the word form is how the vowel was recorded originally (i.e., the long vowels were recorded in the form of hV:tata and short vowels were recorded in the form of hVta). The advanced listeners' responses exhibit less steep slopes and more variations in general, especially for the hV:tata stimuli, indicating that the stimuli are more ambiguous to them. This ambiguity may be due to the use of nonce words as stimuli and the advanced listeners' reliance on cues other than duration. The advanced listeners may be listening for some sort of a stressed pattern when deciding whether the vowel is long or short, as word stress is often assigned to the long vowels [17]. Additionally, long vowels have also been reported to differ somewhat in vowel quality from their short variants [17], and advanced listeners may be listening for the quality as opposed to solely basing their judgement on duration, a strategy most likely to be employed by the learners. Compared to the production (acoustic analysis) part of the study, the long vowels chosen in the perception test appeared exaggerated, possibly due to the recording conditions and the use of nonce words. The /e/ stimuli elicit more long responses, likely due to the longer duration of the /e/ words selected for the study. The unusually long /e/ could be attributed to New Zealand English conflation and its status as a less frequent vowel, contributing to the speaker hyper-articulating the nonce keywords during recording.

The speaker of the stimuli was a present-day elder speaker, who, as shown in the acoustic analyses part of the study had a smaller distinction between long and short vowel contrasts compared to present-day younger speakers for certain vowels. Another possibility for advanced listeners to have more ambiguous responses is that they may be employing different listening strategies based on the age and type of speaker as they have more experience listening to Māori. One major limitation of the current study is the small number of listeners in the advanced group, and within the group, there was a wide range of experiences and daily Māori usage.

These observations suggest that advanced listeners are utilising cues that learners may not be using. Further acoustic feature analysis and production studies are needed to understand these differences. A cue-weighting approach to manipulate duration and other acoustic features such as the fundamental frequency in the stimuli could provide deeper insights into the perceptual strategies used by different listeners. As we had a diverse group of advanced listeners, more L1 and fluent L2 listeners are needed to understand the effect of language experiences on how Māori vowel length is perceived.

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6. References

[1] V. J. Podlipský, K. Chládková, and Š. Šimáčková, "Spectrum as a perceptual cue to vowel length in Czech, a quantity language," *The Journal of the Acoustical Society of America*, vol. 146, no. 4, EL352–EL357, 2019, ISSN: 0001-4966.

[2] D. J. Morris and H. Juul, "The long and the short of vowel length perception in Danish," *The Journal of the Acoustical Society of America*, vol. 152, no. 5, pp. 2953–2961, 2022.

[3] D. Behne, T. A. Arai, B. Czigler, and K. Sullivan, "Vowel Duration and Spectra As Perceptual Cues To Vowel Quantity: a Comparison of Japanese and Swedish," *International Congress of Phonetic Sciences (ICPhS)*, pp. 857–860, 1999.

[4] I. Lehiste, "The Function of Quantity in Finnish and Estonian," *Language*, vol. 41, no. 3, pp. 447–456, 1965.

[5] A. S. Abramson and N. Reo, "Distinctive vowel length: duration vs. spectrum in Thai," *Journal of Phonetics*, vol. 18, no. 2, pp. 79–92, 1990, ISSN: 00954470.

[6] K. Tsukada, "The perception of Arabic and Japanese short and long vowels by native speakers of Arabic, Japanese, and Persian.," *The Journal of the Acoustical Society of America*, vol. 129, no. 2, pp. 989–998, 2011, ISSN: 00014966.

[7] L. Labrune, *The phonology of Japanese*. Oxford: Oxford University Press, 2012.

[8] A. Min, D. Baiyila, and A. Li, "Production and perception of long and short vowel contrast in Mongolian," in *International Congress of Phonetic Science (ICPhs2023)*, 2023, pp. 302–306.

[9] K. Kinoshita, D. M. Behne, and T. Arai, "Duration and F0 as perceptual cues to Japanese vowel quantity," *Proceedings of the 7th International Conference on Spoken Language Processing*, no. 1, pp. 757–760, 2002.

[10] H. Lehnert-LeHouillier, "A cross-linguistic investigation of cues to vowel length perception," *Journal of Phonetics*, vol. 38, no. 3, pp. 472–482, 2010, ISSN: 00954470.

[11] I. Takiguchi, H. Takeyasu, and M. Giriko, "Effects of a dynamic F0 on the perceived vowel duration in Japanese," *Speech Prosody*, pp. 14–17, 2010, ISSN: 23332042.

[12] C. T. J. Hui and T. Arai, "Elderly listeners' identification of Japanese long vowel pair 'obasan' and 'obaasan' using pitch and duration," *Acoustical Science and Technology*, vol. 40, no. 2, pp. 105–115, 2019, ISSN: 1346-3969.

[13] S. Ylinen, A. Shestakova, P. Alku, and M. Huotilainen, "The perception of phonological quantity based on durational cues by native speakers, second-language users and nonspeakers of finnish," *Language and Speech*, vol. 48, no. 3, pp. 313–338, 2005, ISSN: 00238309.

[14] I. Takiguchi, "The role of vowel duration cue in L1: Effects on L2 learners' identification of phonological vowel length in Japanese," *ICPhS*, pp. 1–5, 2015.

[15] C. T. J. Hui and T. Arai, "Pitch and duration as auditory cues to identify Japanese long vowels for Japanese learners," *Acoustical Science and Technology*, vol. 41, no. 5, pp. 797–799, 2020.

[16] C. I. Watson, M. A. Maclagan, J. King, R. Harlow, and P. J. Keegan, "Sound change in Māori and the influence of New Zealand English," *Journal of the International Phonetic Association*, vol. 46, no. 2, pp. 185–218, 2016, ISSN: 14753502.

[17] R. Harlow, *Māori - A linguistic introduction*. Cambridge: Cambridge University Press, 2007.

[18] J. King, R. Harlow, C. I. Watson, P. J. Keegan, and M. Maclagan, "Changing pronunciation of the Māori language implications for revitalization," *Indigenous Language Revitalization: Encouragement, Guidance and Lessons Learned*, pp. 85–96, 2009.

[19] B. Biggs, *Let's Learn Māori : A Guide to the Study of the Māori Language*. Reed, 1969.

[20] R. A. Benton, "The Maori Language: Dying or reviving?" New Zealand Council for Educational Research., Wellington, Tech. Rep., 1997, p. 47.

[21] J. A. Fishman, "Maori: The Native Language of New Zealand Background," in *Reversing Language Shift: Theoreticdal and Empirical Foundations of Assistance to Threatened Languages*, 1991, p. 19.

[22] R. Benton and N. Benton, "RLS in Aotearoa / New Zealand 1989 – 1999," in *Can Threatened Languages Be Saved?* J. A. Fishman, Ed., Multilingual Matters, 2001, ch. 18, pp. 423–450.

[23] R. Harlow and J. Barbour, "Māori in the 21st Century: climate change for a minority language?" In *Language ecology for the 21st century: Linguistic conflicts and social environments*, 2013, pp. 241–266.

[24] S. May, "Introduction bilingual/immersion education in Aotearoa/New Zealand: Setting the context," *International Journal of Bilingual Education and Bilingualism*, vol. 8, no. 5, pp. 365–376, 2005, ISSN: 13670050.

[25] P. J. Keegan, C. I. Watson, J. King, M. Maclagan, and R. Harlow, "The role of technology in measuring changes in the pronunciation of Māori over generations," in *Language Endangerment in the 21st Century: Globalisation, Technology and New Media, FEL XVI*, Auckland, 2012.

[26] J. King, M. Maclagan, R. Harlow, P. Keegan, and C. Watson, "The Maonze Corpus: Establishing A Corpus Of Maori Speech," *New Zealand Studies in Applied Linguistics*, vol. 16, no. 2, pp. 1–16, 2010, ISSN: 1173-5562, 1173-5562.

[27] J. King, M. Maclagan, R. Harlow, P. J. Keegan, and C. I. Watson, "The MAONZE Corpus: Transcribing and analysing Maori speech," *New Zealand Studies in Applied Linguistics*, vol. 17, no. 1, pp. 32–48, 2011, ISSN: 1173-5562, 1173-5562.

[28] P. J. Keegan, J. King, M. Maclagan, C. I. Watson, and R. Harlow, "Changes in the pronunciation of Māori and implications for teachers and learners of Māori," in *LED*, 2009.

[29] M. Maclagan, R. Harlow, J. King, P. J. Keegan, and C. I. Watson, "Acoustic Analysis of Māori: Historical Data," *Proceedings of the 2004 Conference of the Australian Linguistic Society*, no. October, pp. 1–16, 2004.

[30] L. Thompson *et al.*, "Adventures in Mita-Reading : Examining Stress ' Rules ' and Perception of Prosodic Prominence in the Maori Language," *ICPhS*, no. February 2016, pp. 1–4, 2011.

[31] C. I. Watson *et al.*, "Prosodic clues in language recognition: how much information do listeners need to identify Maori and English?" *Te Reo*, vol. 54, p. 83, 2011.

[32] R. Winkelmann, J. Harrington, and K. Jänsch, "EMU-SDMS: Advanced speech database management and analysis in R," *Computer Speech and Language*, vol. 45, pp. 392–410, 2017, ISSN: 10958363.

[33] J. King, M. Maclagan, R. Harlow, P. Keegan, and C. Watson, "Prestige norms and sound change in Māori," *Language Ecology*, vol. 4, no. 1, pp. 95–114, 2020, ISSN: 2452-1949.

[34] J. Holmes, "Maori and Pakeha English : Some New Zealand Social Dialect," *Language in Society*, vol. 26, no. 1, pp. 65–101, 1997.

[35] J. Holmes, "Setting New Standards: Sound Changes and Gender in New Zealand English," *English World-Wide*, vol. 18, no. 1, pp. 107–142, 1997.

[36] P. Boersma and D. Weenink, *Praat: doing phonetics by computer*, 2016. [Online]. Available: `http://www.fon.hum.uva.nl/praat/`.

[37] M. B. Winn, *Make duration contiuum*, 2014. [Online]. Available: `http://mattwinn.com/praat.html#durationContinuum`.

[38] L. Sullivan, *Basic forced choice task*, 2020. [Online]. Available: `https://lisasullivan.ca/sample_experiments/forced_choice_no_feedback.html`.

[39] J. R. de Leeuw, R. A. Gilbert, and B. Luchterhandt, "Jspsych: Enabling an open-source collaborative ecosystem of behavioral experiments," *Journal of Open Source Software*, vol. 8, p. 5351, 85 May 2023.

[40] D. Bates, *Linear mixed model implementation in lme4*, 2007.

[41] R. Lenth, *emmeans: Estimated Marginal Means, aka Least-Squares Means*, 2019. [Online]. Available: `https://cran.r-project.org/package=emmeans`.

[42] R Core Team, *R: A language and environment for statistical computer*, 2015. [Online]. Available: `https://www.r-project.org/`.

[43] D. Lüdecke, *sjPlot: Data visualization for statistics in social science*, Available at https://cran.r-project.org/package=sjPlot, 2018. [Online]. Available: `https://cran.r-project.org/package=sjPlot`.