LOSING ONE ALLOPHONE AT A TIME: AN ACOUSTIC AND STATISTICAL STUDY ON MAPUDUNGUN'S SIXTH VOWEL

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ABSTRACT

This study focuses on the mid-central vowel /ə/ in Mapudungun, the largest Amerindian language spoken in Chile. Although most studies agree that phonologically Mapudungun has 6 vowels and that /ə/ has two allophones, [ɯ] and [ə], there is no consensus on which variables are better at explaining /ə/'s variability, its underlying representation, or even whether the existence of both [ɯ] and [ə] are justified. To investigate this, statistical models were built to evaluate the effects of stress, position of vowel in word, and phonetic context on normalized F1, F2 and F3 values from 791 tokens of /ə/. While the acoustic data shows that there is considerable overlap of the vowel space of /ə/ and that of other vowels, analyses showed that, contrary to expectations, there is not sufficient evidence to justify the existence of two allophones, which we interpret as indicative of the loss of vitality of /ə/.

Keywords: Mapudungun, schwa, sixth vowel, vowel system, linear mixed models

1. INTRODUCTION

1.1. About Mapudungun and its speakers

Mapudungun is an agglutinative and polysynthetic language ([27]), and classified as an isolate language ([23]). The number of speakers ranges between 140,000 and 400,000 people ([32]), mainly concentrated between the Biobío and Los Lagos Regions of central-southern Chile. From a sociolinguistic standpoint, the vitality of the Mapuche language is considered to be seriously threatened ([12]). According to official estimates, the percentage of Mapuches that are not proficient in Mapudungun is 80%, although it is still possible to find proficient speakers of all ages in Alto Bío-Bío, to the east of the region ([12], [18]), and the area of interest in this study.

1.2. Vowel system: main controversies

The phonological vowel system of Mapudungun consists of /i, e, a, o, u/ and a "sixth vowel", sometimes represented as a close back unrounded /ɯ/ (e.g., [21]) and sometimes as /ə/ (e.g, [13]). In his dictionary of Mapudungun, [7] asserts that there are in fact 7 vowels, with /ə/ and /ɯ/ being phonemes. However, posterior studies overwhelmingly agree that there are six. Regarding the allophones of this sixth vowel, [8] proposes [ə] and [ɯ]; the first one is posited to occur in unstressed syllables and the second one in stressed ones. [26], [28], [24], [31] and [25] agree on this description, but suggest that their occurrence is not determined by stress. According to [26], [ɯ] is found in the syllabic onset, whereas in word-final position [ɯ] alternates with [ə]. [16] suggests that [ɯ] appears word-initially and in stressed syllables, while [ə] only occurs in unstressed syllables. [24] and [25] claim that [ɯ] only occurs word-initially, while [ə] alternates with [ɯ] in final position. [23] distinguishes between a central close-mid unrounded [ɘ] (closer to [ə]), which occurs in stressed syllables, and a central close lowered unrounded [ɨ̞] (closer to [ɯ]). Finally, [29] point out that [ɯ] occurs word-initially, but also after velar and retroflex consonants, while [ə] occurs in all other contexts.

Regarding quantitative evidence, relatively few studies have provided the result of acoustic measurements to support their findings regarding the size and nature of Mapudungun's vowel inventory, and those that do, tend to only include mean F1 and F2 values, often non-normalized ([9], [19], [4], [30]).

1.3. The proposal

Our proposal consists of assessing whether acoustic evidence obtained from /ə/ justifies the hypothesis of two allophones ([ɯ] and [ə]), and whether the variability of the data can be explained as an effect of the linguistic variables *stress*, *position of the syllable within the carrier word* and *phonetic context*.

2. METHODS

Recordings were made of the speech of 10 participants (5 males, 5 females), adult native speakers of Mapudungun from the Alto Biobío region. Recordings were conducted using a Tascam DR-100 digital recorder, set at a 44.1 kHz frequency rate and a 16 bit depth, in WAV mono format. Recordings were carried out in the participants' places of residence, and, when possible, external noises were minimized. Recording conditions were far from optimal, but an evaluation of the signal-to-noise ratio showed that the signals were adequate for a study of the spectral characteristics of vowels ($\bar{x}$ = 35.01 dB, σ = 4.75 dB). Regarding the task, subjects were asked to translate Spanish words into Mapudungun from a lexical list, loosely based on the one applied previously by [6].

The resulting signals were segmented and labelled in TextGrids of *Praat* ([3]). Each word was labelled in Spanish and in Mapudungun. All vowels were also segmented and labelled phonologically, as one of only 6 phonological categories, following expected realizations reported in previous studies (e.g. [6]). We chose to use the phonological representation of the vowels instead of the actual phonetic realization to avoid assuming the existence of two allophones of /ə/, which is a bias that has not been controlled in other recent studies (e.g., [30]). Using phonological categories has the additional advantage of revealing atypical realizations and the degree of overlap between phonological categories. Mean F1, F2 and F3 were measured at the internal 50% duration of each token, using Formant objects in Praat, which were created with a maximum frequency value of 5500 Hz for females and 5000 for males.

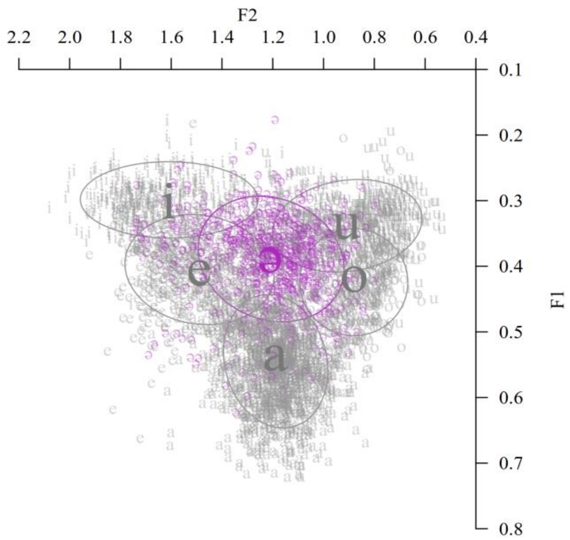
All vowels were also coded for *stress*. *Phonetic context* and *Position within word* were only coded for instances of /ə/. In the case of *stress*, each vowel was classified as belonging to a stressed or unstressed syllable; in the case of *phonetic context*, the vowel was classified as following an anterior, retroflex or posterior consonant, or a silent pause. Finally, in the case of *position within word*, instances of /ə/ were classified as being either in the word-onset, word-final, syllable-final (but not word-final) position or as "other".

3. RESULTS

In total, the corpus comprised 4423 tokens. A preliminary inspection of the data revealed the presence of some outliers that clearly were the result of measuring errors. These outliers were removed using the criteria of 2.5 absolute deviations from the mean, which is considered a conservative approach ([17]). After removing the outliers, the corpus was reduced to 4261 tokens. F1, F2 and F3 values were then normalized using the algorithms from Nearey 1 ([20], [1]).

A summary of the data can be seen in Figure 1, in which the normalized F1 and F2 values of /i, e, ə, a, o, u/ are represented in a vowel space. As can be seen, an important overlap exists between phonological categories, and particularly so in the case of /ə/. It is relevant to highlight that the plot does not show too many instances of [ɯ], which, if truly high back unrounded, should be located in close proximity to instances of [u] ([22]).

Figure 1: Vowel plot of the normalized F1 and F2 values of /i, e, ə, a, o, u/ (ellipses represent 68.3% confidence intervals from the true mean). Labels of each token were drawn from the phonological expectation for each segment, not from the phonetic realization. The mean of each phonological unit is shown with its corresponding symbol in a larger font size.



In order to evaluate the effect of the linguistic variables in the acoustic values of /ə/, a subset was created, containing only 791 tokens. Separate linear mixed models were built to evaluate the effect of the fixed factors *stress*, *position of vowel in word* and *phonetic context* on normalized F1, F2 and F3, using the *lmer* function in the *lmerTest* package in *R* ([14]). We also tested all relevant interactions, and "participant" was included as a random effect. Following [5], a stepwise procedure was used to build the models: first, a null model with the dependent variable and the random effect was created and then the independent variables were included and kept only when they significantly improved the model, as judged by an analysis of variance function (*anova*). Type-II analyses-of-variance tables for the main effects and interactions of each model were produced via the *Anova* function from the *car* package ([11]) and via de *ranova* function from the *lmerTest* package.

In the case of F1, including independent variables did not significantly improve the null model, suggesting that no linguistic variable explains the F1 variability found in the data.

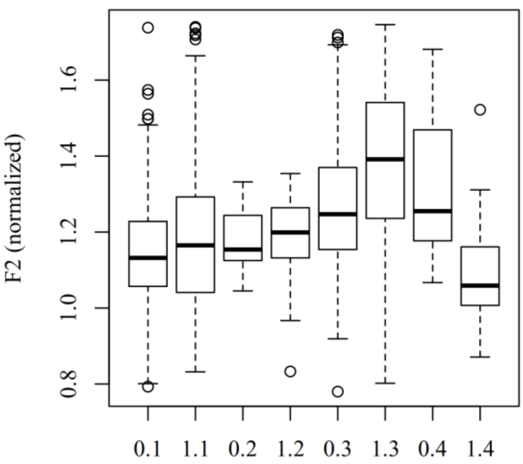
The best fit mixed-effects model for F2 is shown in Table 1. According to this model, there is a main effect of the independent variables *stress* and *phonetic context* on the normalized F2 values of /ə/, as well as a significant interaction between them. Including *position within word* in the model did not improve the model. In the case of *stress* (χ^2 (1) = 10.911, p < 0.001), stressed instances of /ə/ display significantly higher F2 values than non-stressed tokens. As to *phonetic context* (χ^2 (3) = 111.582, p < 0.001), tokens of /ə/ located after posterior consonants (reference level) display significantly higher F2 values than those located after anterior and retroflex consonants. Finally, in the case of the interaction between *stress* and *phonetic context* (χ^2 (3) = 21.184, p < 0.001), F2 values of posterior and non-stressed instances of /ə/ (reference level) are significantly higher than those stressed variants located after anterior, retroflex and following silent pause. The particulars of the interaction between *stress* and *phonetic context* can be visualized in Figure 2. As illustrated, F2 is higher in stressed instances; however, when F2 values of stressed and unstressed instances of /ə/ are compared for each level of *phonetic context* independently, the differences are not statistically significant only when the vowel is after retroflex consonants (this was evaluated via Bonferroni-corrected *t* tests, not reported here). It is important to note that the only case in which the values of F2 are significantly lower in stressed vowels when compared to unstressed ones is after silent pauses.

Table 1: Best fit mixed-effects model for F2, including *stress* and *phonetic context* as main effects, and *subject* as a random effect.

Fixed Effects	**Coefficient**	**Standard Error**	***t*-value**	***p*-value**
Intercept	1.26700	0.02111	60.020	< 0.001
Stress				
No stress	(ref. level)			
Stressed	0.11174	0.02519	4.435	< 0.001
Phon. context				
Posterior	(ref. level)			
Anterior	-0.12038	0.01885	-6.384	< 0.001
Retroflex	-0.08484	0.03901	-2.175	< 0.05
Silent pause	0.03363	0.03772	0.892	= 0.37285
*Stress * Context*				
Post. / Unstr.	(ref. level)			
Ant. / Stress	-0.07753	0.02966	-2.614	< 0.01
Retr. / Stress	-0.11699	0.04978	-2.350	< 0.05
Pause / Stress	-0.28698	0.06744	-4.255	< 0.001
Random Effects	**Log-likelihood**	**Degrees of Freedom**	**Likeli-hood ratio test stat**	**p-value**
Participant	231.42	1	32.097	< 0.001

For F3, the best fit mixed-effects only had a main effect for *phonetic context* (χ^2 (3) = 49.777, p < 0.001). The results show that when instances of /ə/ are located after anterior consonants, they display significantly higher values than those located after posterior consonants (reference level), and that those located after retroflex consonants display significantly lower values than the reference level.

Figure 2: Box plots of normalized F2 organized by the interaction between *stress* and *phonetic context*. The first number corresponds to *stress* (0 = "unstressed", 1 = "stressed") and the second to *phonetic context* (1 = "following anterior consonant", 2 = "following retroflex consonant", 3 = "following posterior consonant", 4 = "following silent pause").



3. DISCUSSION

The results showed that no independent variable was able to explain the variability of F1 despite the fact that previous studies had singled out these variables as relevant for /ə/ (e.g., [23]). Although no effect was found, some variability is apparent in that domain (see Figure 1), which is indicative of height differences in the realizations of /ə/. These results suggest that, in our data, height differences vary freely, at least in relation to linguistic factors, although perhaps sociolinguistic variables, currently undocumented, are able to explain some of the variability found in F1.

When considering the same variables in F2, there was a significant main effect for *stress* and *phonetic context*, but no effect for *position within word*. Regarding *stress*, the results showed that stressed syllables favour higher F2 values. Since higher F2 values correlate with more fronted realizations ([2]), it is possible to assume that stress favours more fronted realizations of /ə/, although most instances of /ə/ are probably better categorized as central, given their position in the vowel space (see Figure 1). This finding contradicts the previous consensus which states that [ɯ] is more frequent in stressed syllables (e.g., [8]), and probably suggests a process whereby all variants of /ə/ are converging to central realizations. However, as the interaction between *stress* and *phonetic context* shows, the tendency to have higher F2 values in unstressed syllables is reverted when /ə/ is articulated after stressed silent pauses. Only in this context, does the data match previous accounts. With respect to the main effect of *phonetic context*, instances of /ə/ displayed lower F2 values after anterior and retroflex consonants (when compared to after posterior consonants, the reference level), suggesting that more anterior phonetic contexts facilitate more posterior realizations of the vowel, and vice versa, again, contradicting previous accounts whereby retroflex and more posterior contexts facilitated posterior realizations of /ə/ ([29]) If the vitality of /ə/ is indeed at risk, it makes sense that it would not be produced in an articulatorily consistent region of the vowel space. This creates the possibility of "target overshoot" ([10]). If the productions of the 6th vowel are simply "centralized" realizations, without concrete articulatory specifications with relation to a point of articulation along the anterior-posterior continuum (as shown in Figure 1), it is entirely possible that speakers realize more backed productions following more fronted segments. This occurs because it is only necessary for the tongue to move from the more anterior position of the preceding segment back toward a generalized central zone. The opposite can occur as well with posterior preceding segments. In other words, from the posterior position of a more backed segment, the speaker simply attempts to move the tongue forward to a less specified central region of the mouth. As a consequence of articulatory habit, the lack of the need for a high degree of articulatory precision, and the fact that the vowel space of /ə/ is not shared with other phonological vocalic units in Mapudungun, the tongue "overshoots".

Regarding the interaction between *stress* and *phonetic context*, as already mentioned, when a stressed vowel occurs after anterior, posterior, or retroflex consonants, F2 tends to be higher, with the exception of those instances following silent pauses, in which the inverse is the prevailing tendency (unstressed instances of /ə/ display higher F2 values). Previous studies have reported that after a pause or a stressed syllable, productions of /ə/ tend to be higher and backed. The only context that provided evidence for the high backed productions was when /ə/ was in a stressed syllable following a silent pause. This might be a remaining vestige of [ɯ], given that this particular context would be highly resistant to change due to the marked nature of the phonetic context itself, as well as the likely tendency of speakers to expend more articulatory energy to stress syllables after silent pauses.

In the case of F3, the only variable that had a significant effect was *phonetic context*. The frequencies of this formant are lower when the vowel occurs after a retroflex consonant. This is the result of coarticulation given the direct relationship between the elevation of the tip of the tongue in retroflex realizations and the low frequency of F3 ([15]).

Taken together, the present data do not support the hypothesis of [ɯ] for several reasons. First, there was a notably high level of variability in the central region of the vowel space along the horizontal axis and not enough high measurements to justify the possibility of a higher allophonic variant. Second, there was notable evidence for F2 "target-overshoot" and the trajectory of the data was contrary to previous studies. The only possible evidence for /ɯ/ was found strictly in stressed syllables following silent pauses. Given the above, we conclude that there is a single [ə] allophone of a phonological unit that is better represented as /ə/. This can be interpreted as further evidence of the loss of vitality of an aspect of the Mapudungun phonological and phonetic inventory, possibly due to contact with Spanish, whose phonological inventory lacks /ə/.

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