ACOUSTIC PROPERTIES OF THE DENTAL VS. ALVEOLAR CONTRAST IN MAPUDUNGUN

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ABSTRACT

In this paper we undertake an acoustic analysis of dental and alveolar segments in Mapudungun, an indigenous language of Chile. We calculate locus equations for dental and alveolar segment pairs of different manners. We find that dentals differ from alveolars of the corresponding manner in lowering the onset F2 of following vowels. We validate these results by means of a linear mixed model analysis.

Keywords: Mapudungun, dental, alveolar, locus equation.

1. INTRODUCTION

Mapudungun (also called Mapuche or Araucanian) is an isolate spoken in Chile and Argentina. It is classified by UNESCO as "definitely endangered" [12]. Mapudungun exhibits a consonantal contrast which has been described as one in dental vs. alveolar place of articulation. The extent of the contrast across manners is in dispute, with authors from different epochs and locales professing different opinions.

With respect to Mapudungun spoken in Chile, the early studies of [9] and [1] recognize an alveolar vs. dental distinction for three manners: stops, nasals, and lateral liquids. The issue of whether this contrast persists in contemporary Mapudungun in Chile has been a matter of debate in previous literature. While [15, 16] cite an alveolar vs. dental contrast for all three manners in which it is historically attested, neither [11] nor [4] could find a native speaker capable of producing the distinction in a consistent manner.

With respect to Argentinian Mapudungun, while [6] cites an alveolar vs. dental distinction for all three manners, [5] claims that the contrast persists for nasals and lateral liquids, but not for stops, and that only dental stops remain.

[18] concludes that an alveolar vs. dental distinction is not valid for synchronic Mapudungun, although the distinction did exist historically.

Nevertheless, on the basis of palatographic evidence, [14] documents the existence of a dental/alveolar contrast in stops, nasals, and lateral liquids in the Mapudugun dialect spoken in Isla Huapi, in the commune of Puerto Saavedra, on the Pacific coast of the 9th region of Chile, La Araucanía.

The aim of this article is to characterize the acoustic phonetic nature of this dental/alveolar contrast in stops, nasals, and lateral liquids in the Isla Huapi dialect of Mapudungun. This project is of interest not only because the Isla Huapi dialect would preserve the distinction in all manners for which it is historically documented and which many modern dialects have apparently lost, but also because a dental/alveolar contrast is still somewhat rare among the world's languages and previously unreported for indigenous languages of the Americas.

We will show that, for each manner, the only acoustic phonetic difference between the dental and alveolar place of articulation resides in F2. In particular, dentals cause a greater depression in the onset F2 of following vowels than do alveolars.

2. METHODS

2.1. Stimulus design

Informants were prompted with a Spanish word and gave in response the translation in Mapudungun, repeating the word three times in succession. Interviews were carried out in Mapudungun and Spanish.

In elaborating our list of elicitation prompts, we sought to collect multiple instances of each segment of interest, viz. dental and alveolar stops, nasals, and lateral liquids, occurring both word initially and word medially. A total of 60 different words were prompted, a few of which were prompted more than once. Table 1 lists minimal and near-minimal pairs given by our informants on the prompt indicated, illustrating the type of data collected. Table 2 summarizes the total number of alveolar and dental segments analyzed, categorized by manner.

2.2. Recording

Recordings were made using a Tascam portable cassette deck and a Shure Prologue 14H-LC Micro-

Table 1: Examples of prompts and speaker responses.

Speaker 1	Prompt (Sp.)	Eng. translation
ˈkɯla	tres	three
ˈkɯl̪a	quila (árbol)	bambu (tree)
məˈna	mucho, bastante	much, a lot
məˈn̪a	primo materno	maternal cousin
məˈt̪a	cuerno de animal	animal horn
tun	tomar, agarrar	take, grasp

Table 2: Tally of total alveolar and dental segments analyzed, categorized by manner.

	Stop	Liquid	Nasal
Alveolar	37	67	29
Dental	18	44	22

phone and were digitized using a sampling rate of 44.1 kHz with 16 bit quantization.

The recordings were carried out in February 2012 in the homes of the informants in Isla Huapi, a rural area, in quiet rooms.

2.3. Participants

We recorded two speakers. Both were male; one was in his fifties and the other in his sixties at the time of the recording. Both were born, raised, and had lived their entire lives in the locality of Isla Huapi. Both are native speakers of Mapudungun and Spanish. It should be noted that almost the entirety, if not the entirety, of native speakers of Mapudungun are bilingual in Spanish [7].

We analyzed the recordings of one speaker, the one in his sixties, and we report here only the results of this speaker.

2.4. Statistical Analysis Design

We compared the effects of dentals vs. alveolars on the formant structure of immediately following vowels by means of locus equations. A locus equation is a linear equation which relates the value of F2 at the onset of a vowel with its value at the midpoint [10].

(1) $F2_{onset} = m * F2_{midpoint} + b$

Locus equations have been analyzed as correlating with place distinctions for voiced stops in CV sequences independently of vowel context [20], [8]. In particular, in plotting mean locus equations for the voiced stops [b], [d], [g] across all speakers studied, [20] found significant differences between each pair of stops and 95% confidence intervals placed around the slopes did not result in any overlap.

We calculate locus equations for dental and alveolar stops, nasals, and lateral liquids; and then contrast the effects of dentals vs. alveolars by plotting their locus equations on the same graph, along with 95% confidence intervals.

The program Praat [3] was used to collect acoustic information from the digitized sound files. Boundaries around segments were put in place manually and annotated in consultation with a native speaker of (the Isla Huapi dialect of) Mapudungun, the second author.

Formants were calculated using Praat's To Formant (burg) function, with a maximum formant value of 5400 Hz, as this setting appeared to most accurately track F2.

For vowels following a given segment of interest, viz. a dental or alveolar stop, nasal, or lateral liquid, the mean values of F2 were measured across a 10ms window adjacent to the segment with a 5ms offset and in a window centered at the midpoint and lasting 20% of the duration of the vowel or 10ms, whichever was larger.

All statistical analysis was performed using JMP 11 software [17] and R [13].

3. RESULTS

3.1. Locus Equations

The locus equations calculated from all instances of dental and alveolar nasals analyzed from speaker 1 are plotted in Figure 1. As can be seen in Figure 1, the plot of the locus equation for dentals is below that of alveolars. That is to say that for each F2 value of the midpoint of a vowel, the value of its F2 onset is lower when following a dental nasal than an alveolar nasal.

The locus equations calculated from all instances of dental and alveolar lateral liquids analyzed from speaker 1 are plotted in Figure 2. Figure 2 shows that dental lateral liquids force lower onset F2 values for vowels with medium and high midpoint F2 values, although for vowels with low F2 midpoint values, the onset F2 value is lower for alveolars. This is consistent with the pattern observed for nasals, where the F2 onset value was lower for dentals than alveolars.

The locus equations calculated from all instances of dental and alveolar stops analyzed from speaker 1 are plotted in Figure 3. Although the range of values of midpoint F2 of following vowels is more re-

Figure 1: Locus equations for alveolar (dark grey solid line) and dental (light grey dotted line) nasals from speaker 1. Surrounding bands indicate 95% confidence intervals.

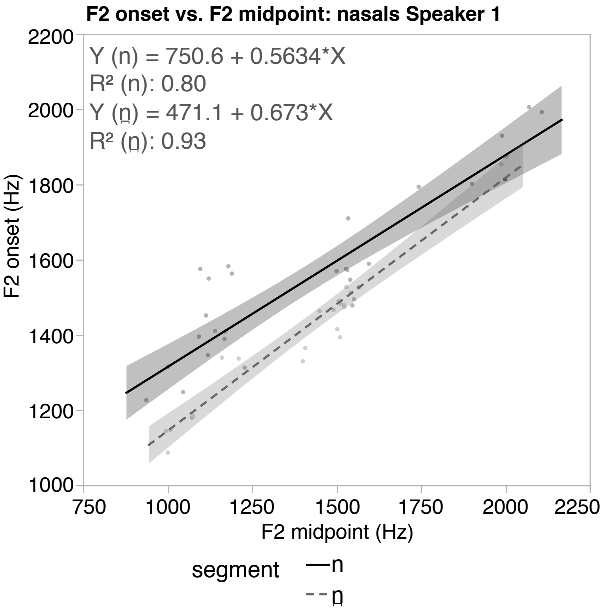
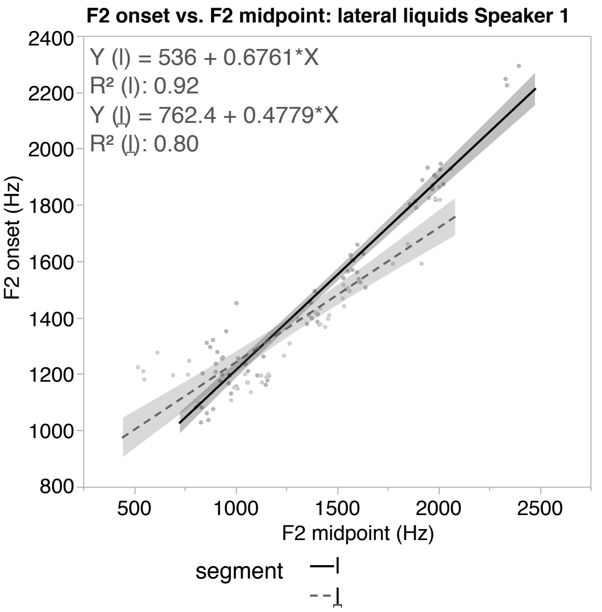
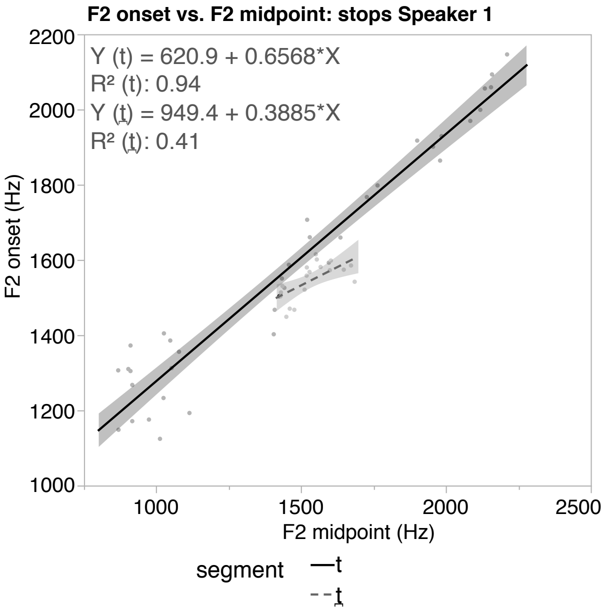


Figure 2: Locus equations for alveolar (dark grey solid line) and dental (light grey dotted line) lateral liquids from speaker 1. Surrounding bands indicate 95% confidence intervals.



duced for dental stops than alveolars for speaker 1, it is clear from Figure 3 that the F2 onset values are lower for dentals than alveolars.

Figure 3: Locus equations for alveolar (dark grey solid line) and dental (light grey dotted line) stops from speaker 1. Surrounding bands indicate 95% confidence intervals.



3.2. Linear Mixed Model Analysis

R [13] and lme4 [2] were used to perform a linear mixed effects analysis of the relationships between F2 of the vowel and the place (dental vs. alveolar) and manner (liquid vs. nasal vs. stop) of the preceding consonant. Onset F2 and midpoint F2 were fit to separate models. As fixed effects, we used vowel quality as well as place and manner of the preceding alveolar consonant. An intercept for the stimulus item was included as a random effect.

Likelihood ratio tests using maximum likelihood estimation were conducted to assess whether a given fixed effect should be included in a model. An initial model with no fixed effects and a single random effect for the intercept of the stimulus item was adopted. Each fixed effect in question was then added to a nested model, which was compared via a likelihood ratio test (LRT) to the reference model that omits that fixed effect. If the LRT yields a significant difference, then the nested model was adopted; otherwise, the fixed effect in question was excluded and the reference model was retained. An iterative process that tested each of the fixed effects was applied, until a final model that best fit our data was arrived at. Once all simple fixed effects had been investigated, fixed effects for 2-way interaction terms were investigated.

The final model that was obtained for F2 at the vowel onset confirmed that a preceding dental consonant lowers F2, relative to a preceding alveolar consonant (β = –49 Hz, $p < 0.01$). Mean values for F2 at vowel onset is shown categorized by manner and place of the preceding consonant in Figure 4. In addition, a significantly lower F2 following liquid consonants relative to stops was discovered (β = –60 Hz, $p < 0.05$). No significant difference between nasals and stops was found however (β = 29 Hz, p = 0.32). Unsurprisingly, vowel quality had the largest effect on F2 with front vowels having raised F2 relative to [a] ([e]: β = 405 Hz, $p < 0.001$; [i]: β = 638 Hz, $p < 0.001$) and back vowels having lowered F2 ([o]: β = –306 Hz, $p < 0.001$; [u]: β = –233 Hz, $p < 0.001$).

The iterative process suggested a 2-way interaction term between place and manner of the preceding consonant. However, the model that included this interaction term had high correlation between some of the fixed effects. Notably the correlation between the fixed effect for dental consonants and the interaction between liquids and dental consonants was –0.891, indicating an unsuitable fixed effect. As a result, the 2-way interaction term was excluded. However, it is possible that, with a larger data set designed to investigate such an interaction, that this effect is real; our data set is too small and does not support such a conclusion.

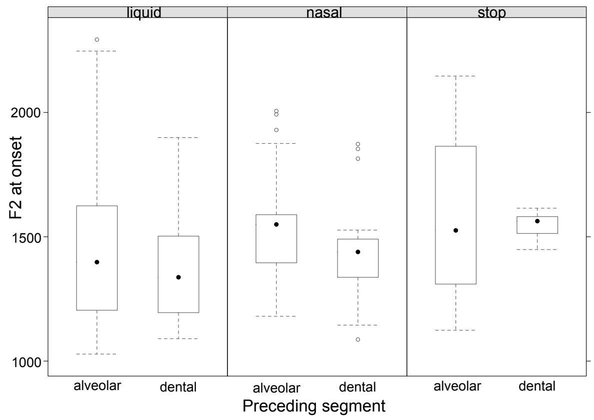
F2 at the midpoint of the vowel was not affected by the place features of a preceding consonant. The final model included only vowel quality and preceding consonant manner as fixed effects. However, the estimates for the fixed effect of preceding consonant manner were not significant relative to the stop baseline (liquids: β = –20 Hz, p = 0.54; nasals: β = 67 Hz, p = 0.07). F2 at the midpoint was completely determined by the vowel quality then, with front vowels having raised F2 ([e]: β = 461 Hz, $p < 0.001$; [i]: β = 772 Hz, $p < 0.001$) and back vowels having lowered F2 ([o]: β = –462 Hz, $p < 0.001$; [u]: β = –528 Hz, $p < 0.001$).

4. DISCUSSION

In this paper we have established the existence of a dental vs. alveolar contrast in the manners of stops, nasals, and lateral liquids in the Isla Huapi dialect of Mapudungun; thus confirming the findings of [14]. Moreover, we have characterized this contrast acoustically.

We have calculated locus equations for each pair of dental and alveolar segments for each manner, finding that, for each manner, the dental segment corresponded with a lower onset F2 value than the alveolar segment.

Figure 4: Onset F2 value of vowels following dental/alveolar consonants categorized by place and manner



These same acoustic results were confirmed with a linear mixed model analysis, which showed that dental consonants significantly lower the F2 at the onset of a following vowel, but that this effect does not persist to the midpoint. In addition, an effect of manner was discovered whereby F2 was lower in liquids than in stops.

Our results concord with the findings of [19] that a dental vs. alveolar place distinction correlates with a drop in F2 for surrounding vowels for dentals.

Moreover, by validating the results of the locus equation analysis with a linear mixed model analysis in this way, not only is our acoustic analysis of the difference between dental and alveolar segments in Mapudungun further supported, but so too is the usefulness of locus equations as a means of distinguishing place of articulation, even to as fine a degree as that between dentals and alveolars. This finding contrasts with that of [21], which stated that a locus equation analysis “is capable of encoding gross differences in degree of coarticulation (such as that between an alveolar and a velar) but not more subtle differences such as those between the various coronal articulations.” Furthermore, as we have obtained consistent results for Mapudungun nasals and lateral liquids, which are voiced, and for voiceless stops, the results of our investigation suggest that the calculation of locus equations is useful also for distinguishing the place of articulation of these types of segments, and not just voiced stops, as suggested in [20].

5. REFERENCES

[1] de Augusta, F. F. J. 1916. *Diccionario Araucano-Español y Español-Araucano*. Santiago, Chile: Imprenta Universitaria.

[2] Bates, D. M., Maechler, M., Bolker, B. 2012. lme4: Linear mixed-effects models using S4 classes. Computer program. R package version 1.1-7.

[3] Boersma, P., Weenink, D. March 2014. Praat: doing phonetics by computer. Computer program. Version 5.3.67, retrieved 17 March 2014 from http://www.praat.org/.

[4] Croese, R. 1980. Estudio dialectológico del mapuche. *Estudios Filológicos* 15, 7–38.

[5] Fernández Garay, A. V. 1981. Algunos sufijos verbales mapuches. *Revista Latinoamericana de Estudios Etnolingüísticos* 1, 5–24.

[6] Golbert de Goodbar, P. 1975. *Epu Peñiwen (los dos hermanos). Cuento tradicional araucano*. Buenos Aires: Centro de Investigaciones en Ciencias de la Educación.

[7] Gundermann, H., Canihuan, J., Clavería, A., Faúndez, C. 2009. Permanencia y desplazamiento, hipótesis acerca de la vitalidad del Mapuzugun. *RLA: Revista de lingüística teórica y aplicada* 47(1), 37–60.

[8] Iskarous, K., Fowler, C. A., Whalen, D. H. 2010. Locus equations are an acoustic expression of articulator synergy. *Journal of the Acoustical Society of America* 128(4), 2021–2032.

[9] Lenz, R. 1896. *Estudios Araucanos: Materiales para el estudio de la lengua, la literatura y las costumbres de los indios mapuches o araucanos*. Santiago, Chile: Imprenta Cervantes. Originally published in 12 separate articles in volumes 90-1, 93-4, and 97-8 of the (A)nales de la Universidad de Chile.

[10] Lindblom, B. 1963. On vowel reduction. Technical Report 29 The Royal Institute of Technology, Speech Transmission Laboratory. Stockholm, Sweden.

[11] de Moesbach, E. W. 1962. *Idioma Mapuche, dilucidado y descrito con aprovechamiento de la Gramática Araucana de Padre Félix José de Augusta*. Padre Las Casas, Chile: Imprenta 'San Francisco'.

[12] Moseley, C., (ed) 2010. *Atlas of the World's Languages in Danger, 3rd edn*. Paris: UNESCO Publishing. Online version. http://www.unesco.org/culture/en/endangeredlanguages/atlas.

[13] R Core Team, 2015. R: A language and environment for statistical computing. Computer program. R Foundation for Statistical Computing, Vienna, Austria.

[14] Sadowsky, S., Painequeo, H., Salamanca, G., Avelino, H. 2013. Mapudungun. *Journal of the International Phonetic Association* 43(1), 87–96.

[15] Salas, A. 1970. El verbo en el mapuche de Chile. *Segunda Semana Indigenista* Temuco, Chile. Escuelas universitarias de La Frontera 61–95.

[16] Salas, A. 2006. *El Mapuche o Araucano*. Santiago, Chile: Centro de Estudios Públicos.

[17] SAS, 2014. JMP®, version 11. Computer program. Cary, NC.

[18] Smeets, I. 2008. *A Grammar of Mapuche*. Number 41 in Mouton Grammar Library. Berlin: Mouton de Gruyter.

[19] Stevens, K. N., Keyser, S. J., Kawasaki, H. 1986. Toward a phonetic and phonological theory of redundant features. In: Perkell, J. S., Klatt, D. H., (eds), *Invariance and variability in speech processes: Proceedings of the Symposium on Invariance and Variability of Speech Processes met at M.I.T. "In honor of Kenneth N. Stevens"*. Lawrence Erlbaum Associates, Inc. chapter 20, 426–449.

[20] Sussman, H., McCaffrey, H. A., Matthews, S. A. 1991. An investigation of locus equations as a source of relational invariance for stop place categorization. *Journal of the Acoustical Society of America* 90(3), 1309–1325.

[21] Tabain, M. 2000. Coarticulation in CV syllables: a comparison of locus equation and EPG data. *Journal of Phonetics* 28(2), 137–159.