PRODUCTION STUDY OF SPANISH SPIRANTIZATION IN NATURALISTIC SPEECH

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1 Introduction

Spirantization refers to an alternation between plosives and fricatives in speech production. This process is often labelled as a case of phonetic reduction, wherein oral closure movements may contribute to the failure to reach the target (a failed or reduced form) or muscles implicated in production of a full occlusion fail to achieve full activation. In Spanish, spirantization commonly affects the voiced plosive series (at velar, dental, and bilabial places of articulation). Thus, a spirantized /d/ would often be transcribed as an interdental fricative [ð]. This observation is cited as a case of phonetic undershoot [1] or articulatory ease [2,3]. Literature describes spirantization as occurring post- and intervocalically in Spanish [3,4], often following non-stressed vowels [5], within prosodic constituents [6] and during higher speaking rates [7].

However, there is an important aspect of Spanish spirantization that the literature does not address. The spirantized form [ð], an interdental fricative, differs not only in manner, but also in place of articulation from [d]. While it may be possible to account for this difference as undershoot in a 2-dimensional midsagittal space (e.g., [1]), an undershoot account becomes harder to support in 3 dimensions.

In a reduction account, spirantization is posited to be the result of failure to either achieve activation. If we were to measure a series of productions, we would expect to observe optimal target achieved most frequently, and increasing levels of "failure", (i.e. lenitions), would occur less frequently (in a /d/ target, more visible tongue). We might model this approach in a histogram as a unimodal distribution (Hypothesis 1 in Figure 1).

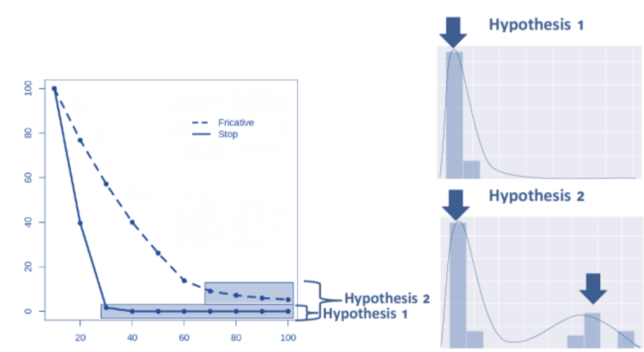

Figure 1: Schematic model distributions for each hypothesis, image adapted from [8]. Graphs on right represent the size of opening (y axis) corresponding with muscle activation (x axis)

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We can also consider a categorical approach to describe the spirantization process. This account would suggest that these spirantized plosives represent distinct targets (i.e., a motor abundance or modularization account [8,9]). If we were to consider a broad sampling of these productions where there are two potential targets, the most frequent productions would correspond to the targets, with production failures associated with each target. Thus, we can expect a bimodal distribution in a plotted histogram (Hypothesis 2 in Figure 1).

We propose that it is this second description that accounts for the spirantization of dental plosives in Spanish.

2 Method

2.1 Participants

Twelve videos of native Spanish speakers were extracted from the video platform YouTube. These videos were in vlog ("video blog") format in which speakers are recorded in frontal headshot format and normally produce extended running speech. This format was chosen in order to obtain the most naturalistic speech without sacrificing facial feature visibility. The speakers were located in Latin American countries (6) and in Spain (6). Each speaker was examined for productions of voiced (50 tokens), voiceless (20 tokens), and nasal (20 tokens) dental stops.

2.2 Annotations and Measurements

Each token was annotated for produced sound, stress patterns, and phonological environment. The frame was extracted at the peak of utterance (Figure 2). Frames were uploaded on ImageJ and measured for area of protruding tongue. Measurements were recorded in pixels, then normalized using the distance between the outer corners of the eyes, and converted to cm^2

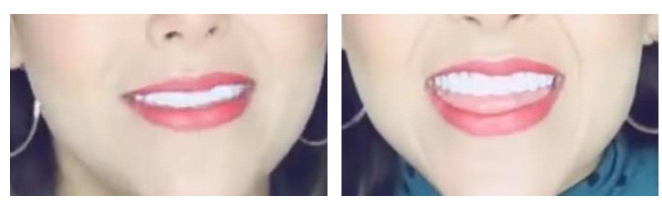

Figure 2: Non-spirantized (left) vs. spirantized (right) tokens of /d/

3 Results

3.1 Descriptive analysis

Results of the annotations of stress patterns and phonological environment showed no distinct pattern, occurring in free variation. Voiced tokens were spirantized far more frequently than the voiceless and nasal tokens. A chi-squared analysis on counts of spirantized vs. non-spirantized tokens indicated that differences observed across target sounds were significant ($p < 0.001$).

Table 1: Proportion of spirantized tokens within each target sound

	/d/	/t/	/n/
Spirantized	58.6%	3.3%	0.8%
Plosive	41.4%	96.7%	99.2%

3.2 Visible tongue analysis

The average visible tongue area for [d] tokens measured 0.142 cm^2, while average tongue area for [ð] tokens was 2.251 cm^2. ANOVAs were performed on area measurements, within and across speakers. Results were significant across the three target sounds ($p < 0.001$) as well as between spirantized and non-spirantized /d/ tokens ($p < 0.001$). Each discrete measurement was plotted on a histogram (Figure 3).

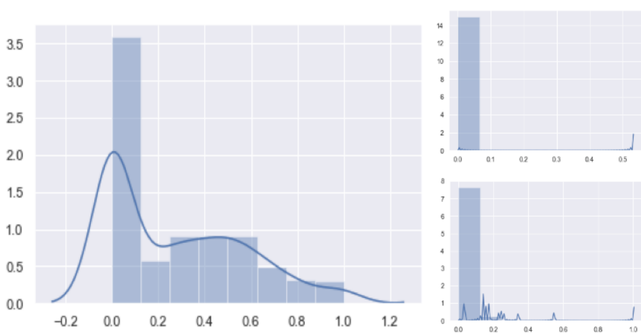

Figure 3: Distribution of each target (/d/, left; /n/, upper right; /t/, lower right) for all speakers combined, with proportion of visible tongue along the x axis and kernel density estimation on the y axis

In Figure 3, the plot of measured tongue area by token indicates a bimodal distribution in the voiced dental tokens, consistent with hypothesis 2. This contrasts with the strongly unimodal distributions of both the /n/ and /t/ tokens, which show little to no failure to reach target. These results are consistent with a view in which the spirantized variants of these /d/ tokens are not the result of weakening but rather the output of a separate module, consisting of a different set of muscles.

3.3 Biomechanical simulation

To further test this, we modeled productions of [d] and [ð] with a forward activation model using the BadinJawTongueHyoid model in the three-dimensional biomechanical simulation software Artisynth (http://www.artisynth.org/). Formation of the dental stop closure required activation of the superior longitudinal, transversus, and posterior and medial genioglossus muscles. In contrast, modelling of the interdental fricative required substantially increased activation of the transversus, verticalis and all portions of the genioglossus (anterior, medial, posterior). The exact parameters utilized in the simulation of both productions are described in Table 2 below. Crucially, we were unable to produce a [ð] configuration by reducing the activations used in the production of [d].

Table 2: Muscle activations used for simulation of [d] and [ð]

	SL	TRANS	VERT	GGm	GGp	GGa
[d]	30%	25%	0%	15%	20%	0%
[ð]	30%	45%	30%	45%	50%	10%

4 Discussion

The above simulation results are unsurprising considering that the tongue posture visible in the spirantized variant in Figure 2 does not appear to be an intermediate point along a trajectory towards the non-spirantized [d] configuration in Figure 2.

The current set of studies supports the hypothesis that spirantized and non-spirantized variants of the Spanish dental plosive result from activating distinct sets of muscles, each with its own end target.

Acknowledgments

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