ACOUSTICS AND ARTICULATION OF SPANISH /d/ SPIRANTIZATION

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ABSTRACT

Recent acoustic research has challenged the traditional understanding of the spirantization of Spanish /b d g/. We compare acoustic and EPG results on the realization of /d/ in different contexts. Whereas we largely confirm recent observations regarding the postfricative context, we also show that after nasals and laterals the intensity curve associated with the voiced obstruent /d/ does not offer reliable information on occlusion.

Keywords: lenition, EPG, intensity curve, spirantization, approximants, Spanish

1. INTRODUCTION

A well-known phenomenon in the phonology of Spanish is the systematic weakening of the voiced plosives /b d g/ in postvocalic and many post-consonantal contexts. Traditionally the phenomenon has been understood as the complementary distribution of two allophones for each phoneme, stop and fricative/approximant [7]: Stops occur after pause and after a homorganic sonorant (after a nasal and, in the case of /d/ also after /l/); fricatives or approximants occur elsewhere. More recent work, based on acoustic analysis, has claimed that the facts do not support the traditional description. Instead, several studies have suggested that, rather than two allophones in complementary distribution for each of these two phonemes, there is a continuum of constriction. The degree of constriction depends on a number of conditioning factors [16], including the nature of the preceding segments, stress [4, 13], the presence of word boundaries [5] and tempo [17]. Even intervocalically, the nature of the flanking vowels may affect the degree of constriction of /b d g/ in Spanish [4, 13]. In particular, contrary to the traditional description, a preceding /s/ has been observed to trigger especially constricted realizations of /b d g/ [5, 12] in spectrographic and other acoustic studies. Acoustic analysis is thus somewhat at variance with the traditional view of the phenomenon.

Here we present acoustic and articulatory (electropalatographic = EPG) data related to the allophony of /d/ (expanding on [10]). We focus on this particular consonant because meaningful linguopalatal data can be gathered along with acoustic data. Acoustic measures focus on the intensity curve, which can be taken to provide indirect information on the degree of constriction of the consonant (in a continuum ranging from vowel-like approximant to narrow fricative to stop). EPG data provide direct information on the presence of occlusion, allowing for a sharp distinction between realizations with and without full contact between the articulators, in addition to making gradient measurements possible.

2. METHODS

Since traditionally the allophony of Spanish voiced plosives is said to be conditioned by the preceding environment, we made a list of tokens where /d/ was preceded by a nasal (*anda*, *banda*), a lateral (*caldo*, *balda*), a rhotic (*arde*, *sarda*), a sibilant (*desde*, *más da*) and a low vowel (*cada*, *hada*). These ten words were embedded in the carrier phrase *digo___ para ti* 'I say___for you'. Three native speakers of Peninsular Spanish participated in this experiment (S3 is an author). Data collection took place using the WinEPG Articulate Instruments system [1]. Participants were fitted with custom-made artificial palates and were asked to read the experimental materials as they appeared on a computer screen. Two speakers read the sentences five times and the third speaker three times. Acoustic data was recorded simultaneously using a head-mounted microphone.

2.1. Acoustic analysis of degree of constriction

Acoustic analysis was performed using PRAAT [2]. We segmented the portion of the sound wave corresponding to /d/ and the portion corresponding to the following vowel. We took two

measurements from the intensity curve. One measurement, IntDiff, is the difference between the maximum value during the vowel following the target consonant /d/ and the minimum in the portion of the signal corresponding to the consonant. The more open the constriction for the consonant, the smaller IntDiff is expected to be. Relative intensity, calculated either as a difference or as a ratio, has been used as an acoustic correlate of degree of constriction of Spanish /b d g/ in previous work [4, 13, 17]. The second measurement, MaxVel, is a calculation of the maximum rising velocity between the midpoint of /d/ and the midpoint of the following vowel. This was based on the methodology of [8], which in turn is a modified version of the procedure in [11]. The more open the consonant, the less abrupt the transition is expected to be and, consequently, the smaller the MaxVel value.

2.2. Electropalatographic analysis

We also took two measurements from the EPG signal, one categorical and one gradient. First, the vowel onset was demarcated based on the acoustic signal. The linguopalatal contact in four EPG frames preceding this point was examined (this 40 ms duration was estimated based on the reported duration of approximant and occlusive realizations of Spanish /d/, [9, 12]). Each EPG frame was examined for presence of an entire row of activated sensors, indicating complete occlusion in the front part of the artificial palate [5]. The presence or absence of complete occlusion was a categorical variable.

The second measurement, average Contact Centrality Index (CCI; calculated across the four frames) [15] indicates degree of central contact on the palate. CCI can be considered a gradient measure of constriction [6].

3. RESULTS

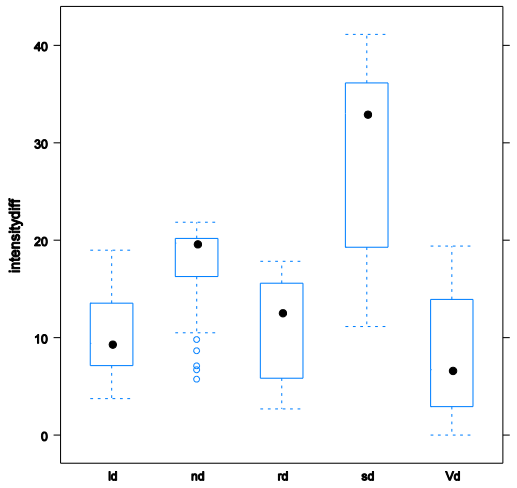
3.1. Acoustics

Fig. 1 shows the Intensity Difference (IntDiff) values in each of the experimental contexts for all three speakers. As can be seen, if we take IntDiff measurements as an indication of degree of constriction, in our data /d/ is most constricted after /s/ and least constricted after the vowel /a/.

A Linear Mixed Effects model with speaker as a random variable was run on all of the data presented here. For our speakers, IntDiff was associated with preceding context: $F(4,122) = 52.09$, $p < 0.0001$. Tukey's test revealed significance among the pairs as indicated in the following table (***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; n.s. not significant):

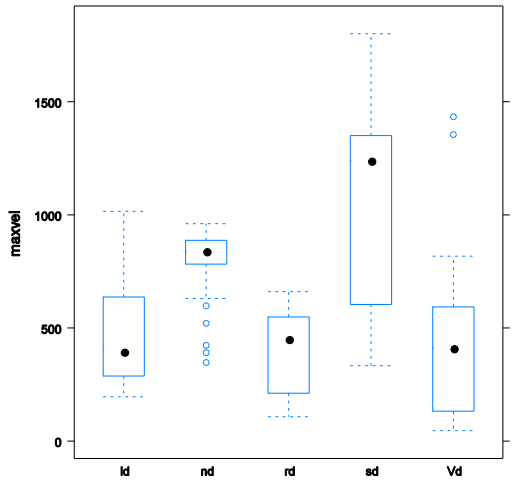
	/nd/	/ld/	/sd/	/rd/
/ld/	***			
/sd/	***	***		
/rd/	**	n.s.	***	
/Vd/	***	n.s.	***	n.s.

Figure 1: Intensity Difference for each sequence: /ld/, /nd/, /rd/, /sd/ and /Vd/.



Maximum rising velocity between /d/ and the following vowel, by preceding context, are shown in Fig. 2:

Figure 2: Maximum Rising Velocity for each sequence: /ld/, /nd/, /rd/, /sd/ and /Vd/



MaxVel results are in general agreement with IntDiff. MaxVel was also associated with the preceding context: $F(4,122) = 25.75$, $p < 0.0001$.

Tukey's test revealed significance among the following pairs:

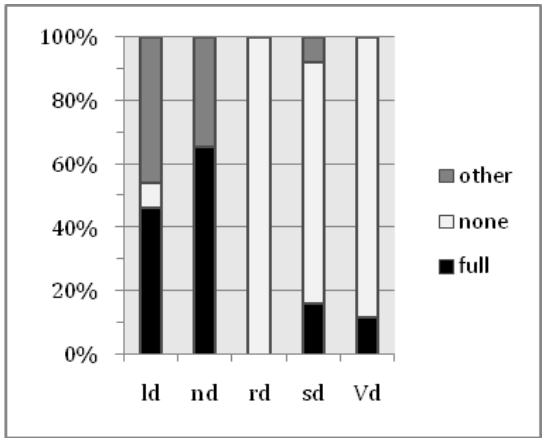
	/nd/	/ld/	/sd/	/rd/
/ld/	**			
/sd/	**	***		
/rd/	***	n.s.	***	
/Vd/	***	n.s.	***	n.s.

Both acoustic measurements reveal the same significant differences between contexts. In particular, if we interpret these measurments as an indication of degree of constriction, the context where /d/ shows greatest constriction is /sd/. This goes against the traditional description, according to which /d/ is a stop in /nd/ and /ld/ and a fricative/approximant in /sd/, /rd/ and /Vd/.

3.2. Electopalatography

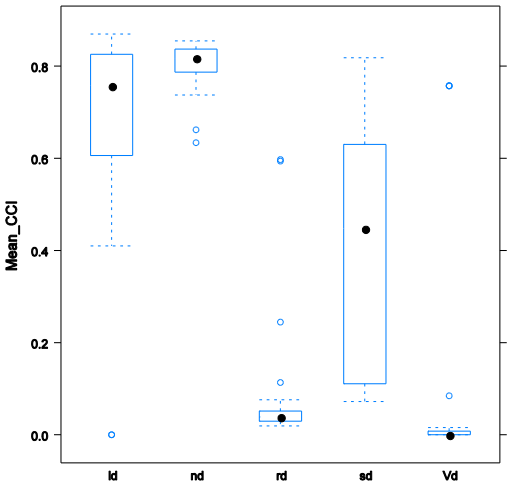
We also examined which frames in the 40 ms window showed complete occlusion. For the majority of tokens (106/129), either all four frames showed complete occlusion, or none of the four frames did. The interpretation of these cases is unambiguous in terms of occlusion, regardless of the exact duration of /d/. In Fig.3, counts of "full" occlusion indicate cases where all four frames manifested occlusion; counts of "none" indicate cases where none of the four frames manifest occlusion. Other cases (e.g. where the first two frames manifest occlusion, but not the third and fourth) are collapsed ("other").

Figure 3: The black bars indicate percentage of tokens in which all four frames under examination manifest complete occlusion. The white bars indicate tokens in which none of the four frames manifest complete occlusion. The gray bars represent other possible combinations.



Both the sequences /ld/ and /nd/ present the most cases of full occlusion (46% and 65%, respectively) across the entire 40 ms window, suggesting that /d/ is fully occluded in these contexts most often. On the other hand, /rd/ (unoccluded 100%), /sd/ (unoccl. 76%), and /Vd/ (unoccl. 88%) often manifest no evidence of occlusion, by our metric. S2 produced fully occluded /d/ in more than 50% of /Vd/ and /sd/ contexts, indicating a careful pronunciation by this speaker. The results of our other measurement, CCI, are shown in Fig.4.

Figure 4: Contact Centrality Index for each sequence.



Our CCI measure was also associated with sequence: $F(4,122) = 91.49$, $p < 0.0001$. For CCI, the context hierarchy is as follows, from most occluded to least occluded, /nd/ = /ld/ > /sd/ > /rd/ = /Vd/. Tukey's Test revealed significant differences between the following pairs:

	/nd/	/ld/	/sd/	/rd/
/ld/	n.s.			
/sd/	***	***		
/rd/	***	***	***	
/Vd/	***	***	***	n.s.

4. CONCLUSION AND DISCUSSION

According to the traditional view, Spanish /d/ is realized as a stop after /n/ and /l/ and as an approximant after any other consonant or a vowel. Our articulatory results, based on EPG, are in general agreement with this description. These data show that indeed, /d/ is most occluded after /n/ and /l/, and least occluded after a vowel or /r/. The context after /s/ is intermediate: /d/ generally lacks occlusion in this context, but shows considerable variability in constriction.

Our acoustic intensity results, however, appear to show that /d/ is especially constricted after /s/

and has less constriction after /n/ or /l/. In finding a high degree of constriction after /s/ we confirm recent claims by other authors, using other methodologies, such as [12].

Our acoustic and EPG measurements provide complementary information for some contexts: EPG shows that /d/ tends not to manifest occlusion after /s/. At the same time, a narrow passage between the articulators in this context will result in low intensity in the acoustic signal. After /n/ and /l/, on the other hand, EPG shows a clear prevalence of complete occlusions for /d/, but our acoustic measurements suggest a rather open realization. This, we believe, has to do with acoustic energy output during the realization of /d/ in postnasal and postlateral contexts.

A general lesson we draw from the current study is that acoustic measurements taken from the intensity curve, which have obvious practical advantages, must be interpreted with caution if we wish to understand /b d g/ constriction in specific postconsonantal contexts. In contexts, such as after a vowel, a good correlation between acoustic and articulatory measurements is to be expected [14]. After a lateral or a nasal, however, the intensity curve may not provide reliable information regarding the degree of constriction of /b d g/.

5. REFERENCES

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