PATTERNS OF CONSTRICTION DEGREE IN SPANISH HETERORGANIC CONSONANT SEQUENCES

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ABSTRACT

This study explores some of the predictions made by the theory of Articulatory Phonology regarding the combined effects of distinct constriction degrees at the global vocal tract level. Data from peninsular Spanish are used to test whether the constriction degrees of two adjacent heterorganic consonants (stop+stop or stop+nasal) in words such as *abdicar* or *abnegar* influence each other as a function of context and speaking rate. Results show a variety of patterns in constriction degree realization, ranging from full occlusion to wide lenition for both consonants in the sequence. In addition, Pearson correlation coefficients show strong positive correlations between the constriction degrees of the consonants in the sequences, especially when they are both voiced stops, but also in stop+nasal combinations. These results are taken as evidence that the constriction degree of an individual gesture can have output effects at the vocal tract level beyond the individual gesture's constriction location specification.

Keywords: constriction degree, Spanish stop lenition, tube geometry.

1. INTRODUCTION

1.1. Constriction degree in Articulatory Phonology

In standard Articulatory Phonology theory [1, 2] gestures are defined on the basis of a set of simple tract variables. Of these, constriction degree (CD) and constriction location (CL) are usually identified as correlates of the more traditional phonological notions 'manner of articulation' and 'place of articulation', respectively. The relationship between these two basic gestural attributes and whether they can be activated independently of each other remains a point of contention in the theory. A distinction is made in [1] between 'input' and 'output' features; while the 'input' features refer to more strictly articulatory, production aspects at the individual gestural/articulator level, 'output' features have to do with more 'global' consequences at the vocal tract level which take into consideration aspects not only of articulation per se, but also aerodynamics and acoustics.

Similar observations are made in [3] in a claim for a less localized view of articulatory gestures. This distinction between input and output features is particularly relevant for CD, given that the overall aerodynamic and acoustic nature of a given utterance will depend to a great extent on the different constriction degrees that are activated at any given point in time during the production of a sound or sequence of sounds. The tube geometry proposal in [1] is an attempt to formalize the composite output effects of CD at different points in the vocal tract; the idea is that the effect of different CDs for different gestures percolates up the geometry hierarchy to produce an overall vocal tract CD. The study reported on here aims to test the predictions regarding global CD effects mentioned above by looking at heterorganic stop sequences in Spanish.

1.2. Stop lenition in Spanish

It is well known that Spanish voiced stops /b, d, g/ lenite (spirantize) in all positions except in absolute initial position, after nasals and, for /d/, after /l/. Given that Spanish also systematically assimilates nasals to the point of articulation of following consonants, the non-leniting contexts for /b, d, g/ (other than absolute initial position) always involve homorganic sequences: /mb/, /nd/, /ld/, /ŋg/. If we understand spirantization as essentially the result of articulator undershoot [4, 5], the homorganicity of nasal+stop sequences can be seen as largely responsible for the lack of lenition in the stops. Work by [6] shows that the nasal+stop sequences are in fact produced with one single articulatory gesture. Since the nasal requires full occlusion, the gesture is realized as a complete closure, which prevents undershoot in the stop. This accounts for the different outcome in homorganic /ld/, with no lenition, compared to heterorganic /lb/ or /lg/, which show lenition.

While most work on Spanish stop lenition has focused on the contexts outlined above, there are other possible sequences in the language which challenge the idea that lack of lenition, understood as a reduction in CD, is necessarily linked to homorganicity, an agreement in CL. Sequences of two stops in words such as *adquirir*, *abdicar*, *adverso*, *subcampeón*, or stop+nasal as in *abnegar*, *admirar*, *asignar*, present interesting study cases because they are all heterorganic and therefore the presence or absence of lenition cannot be accounted for in the same terms as with the more common homorganic sequences. In [7] similar contexts are described as ranging from stops with complete closures and varying degrees of voicing to lenited (approximant) realizations. It remains to be seen, however, to what extent the CD specifications for each member of the stop+stop or stop+nasal sequences influence each other in these heterorganic clusters.

The predictions within Articulatory Phonology's tube geometry proposal indicate that when two tubes are joined in series, the resulting CD should be that of the narrowest constriction. Thus, if there is a complete occlusion within the tongue tube for C1, then the closed CD would percolate all the way to the vocal tract level, which would in turn condition C2 to appear as fully constricted as well. If, on the other hand, C1 is lenited and therefore the vocal tract tube allows for a certain degree of laminal airflow, we would expect C2 to show signs of lenition as well. Thus, in a word like *abdicar*, if /b/ is fully occluded then we would expect /d/ to be fully occluded as well. If, on the other hand, /b/ is lenited, we would expect /d/ to show signs of lenition too. These predictions would account for the variations observed by [7].

2. METHOD

2.1. Stimuli and subjects

In order to test this hypothesis, an acoustic study was carried out with a set of words that included stop+stop sequences and stop+nasal sequences, as shown in Table 1. Due to the limited number of Spanish lexical items with these sequences, it was not possible to control for all possible combinations of place of articulation or voicing, especially as regards C2. The set used here, however, is made up of words that are by no means unusual or unfamiliar to any educated speaker of Spanish.

Table 1: Words included in the study

	labial C1	dental C1	velar C1
$C1_{\text{voiced stop}}$ + $C2_{\text{voiced stop}}$	*abdicar*	*adverso*	*rugby*
$C1_{\text{voiced stop}}$ + $C2_{\text{voiceless stop}}$	*subclase*	*adquirir*	———
$C1_{\text{voiced stop}}$ + $C2_{\text{nasal}}$	*abnegar*	*admirar*	*asignar*

Six native speakers of peninsular Spanish from the Madrid area read the words ten times in carrier sentences at two different speaking rates, slow and fast, as established by an automatic computer presentation of the stimuli (3 second intervals and 1 second intervals between slides for the slow and fast rates, respectively). The two rates were included in order to encourage the production of more lenited tokens (at the faster rate) and more occluded tokens (at the slower rate), following [8]. The data were obtained in a soundproof booth using a professional condenser microphone and digitized using Adobe Audition.

2.2. Data analysis

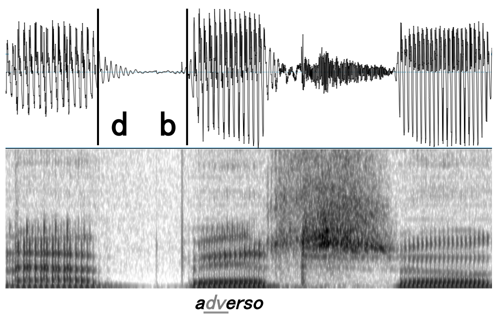
Measurements of consonant duration and relative amplitude were obtained for both C1 and C2. Segmentation was done using the Praat analysis software and facilitated, especially for the lenited tokens, by the use of an automated event identification procedure based on first derivative traces of signal intensity. Relative amplitude was obtained by calculating the difference in intensity between the consonants and the flanking vowels. In this paper, only results for relative amplitude will be reported.

3. RESULTS

3.1. Constriction degree patterns

Despite a great deal of variability in the data, from a qualitative point of view it is possible to identify a series of main patterns in the way that the constriction degrees of C1 and C2 are realized as a function of context and speaking rate. A large number of the tokens analyzed for the six subjects show the fully occluded pattern illustrated in Figure 1.

Figure 1: Example of fully occluded stops in an instance of the word *adverso*.

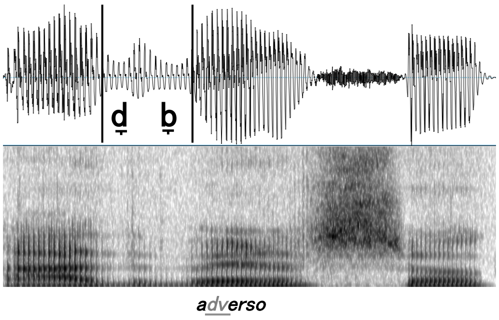


In these cases, both C1 and C2 are consistently fully occluded. Even though this pattern can occur in any of the C1-C2 combinations, as in the $C1_{\text{voiced}}$

$_{\text{stop}}$ + $C2_{\text{voiced stop}}$ sequence shown in the figure, it is particularly common in slow rates and when C2 is a voiceless stop. Such a configuration resembles the situation in cases where the same stop occurs across syllable boundaries, as in *obvio* or *adducir* [7], which commonly result in a long, fully-occluded sequence.

At the other extreme of the occlusion continuum, many tokens show the pattern illustrated in Figure 2. Here, an example of the same word *adverso*, both C1 and C2 are lenited, as shown by the higher amplitude of the waveform and the uninterrupted formant traces clearly visible in the spectrograph.

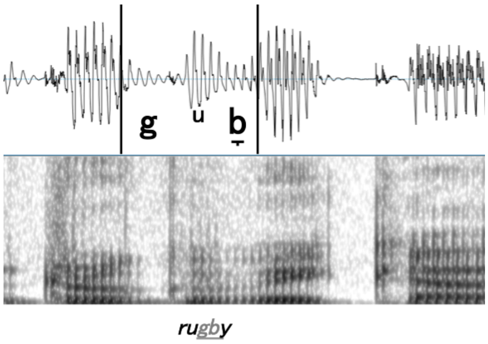
Figure 2: Example of lenited stops in an instance of the word *adverso*.



As expected, the lenited patterns show up more frequently in fast tokens and in $C1_{\text{voiced stop}}$ + $C2_{\text{voiced stop}}$ sequences. However, it is not uncommon to find examples of reduced constriction degrees in $C1_{\text{voiced stop}}$ + $C2_{\text{nasal}}$ for both the stop and the nasal, as well as in a few instances of $C1_{\text{voiced stop}}$ + $C2_{\text{voiceless stop}}$, where again both stops show incomplete closures.

Figure 2 also shows a common occurrence in those cases where both C1 and C2 show large degrees of lenition, i.e., the presence of a small vocalic element between the two stops. This vocalic element shows spectral characteristics that are a continuation of those of the previous vowel. The size of this element is highly variable and tends to occur more frequently in combinations where C1 is velar, as illustrated in Figure 3 for the word *rugby*.

Figure 3: Example of vocalic element between the two stops in an instance of the word *rugby*.



In some of these cases, as in the figure, the vocalic element is large enough to induce lenition of C2 even if C1 shows a more occluded constriction degree. This reproduces the standard behavior of voiced stops in VCV sequences, even if the first V is not an actual vowel but the result of the spatiotemporal coordination between C1 and C2.

Overall the patterns illustrated here show the existence of a continuum of constriction degree in the realization of C1-C2 sequences that goes from full occlusion to clear lenition. In addition, at least from a qualitative point of view, it seems that the actual constriction degree of C2 is largely influenced by that of C1 even when they are not homorganic, as would indeed be predicted by tube geometry.

3.2. Quantitative analysis

In addition to the qualitative observations briefly reviewed in 3.1., the data were analyzed quantitatively using Pearson product-moment correlation coefficients. The rationale for the analysis is that the relationship between the constriction degrees of C1 and C2 should show a certain degree of linearity. Thus, if the constriction degree of C2 is determined by that of C1, we should be able to obtain significant degrees of correlation between the amplitude values for C1 and C2. These correlations are expected to be higher for the $C1_{\text{voiced stop}}$ + $C2_{\text{voiced stop}}$ sequences than for the others, as it is the voiced stops that are more consistently and more substantially affected by lenition.

Table 2 shows *r* coefficient values for the correlation analyses performed by word and rate. As can be seen, the results in general corroborate the predictions regarding the relationship between the constriction degrees of C1 and C2.

Table 2: Results (*r* coefficients) of the Pearson product-moment correlation analyses.

	fast (n=60)	slow (n=60)
abdicar	.7251	.5196
adverso	.6953	.2277
rugby	.3510	.1464
subclase	-.1393	.1878
adquirir	.4844	.5925
abnegar	.6005	.3160
admirar	.5393	.2327
asignar	.6121	.5135

First of all, there is a clear difference in the results with respect to the rate variable, with correlations always being higher for the fast rates than for the slow rates, except for the $C1_{\text{voiced stop}}$ + $C2_{\text{voiceless stop}}$ sequences, including the word *subclase*, which shows a negative correlation for the fast rate. This is consistent with the expectation that an increase in speaking rate would favor higher degrees of lenition.

Second, regarding the type of consonant sequence, $C1_{voiced\ stop}$ + $C2_{voiced\ stop}$ sequences, illustrated by the words *abdicar* and *adverso*, show the strongest correlations in the fast rate (.7251 and .6953, respectively), followed by the $C1_{voiced\ stop}$ + $C2_{nasal}$ sequences, illustrated by the words *abnegar*, *admirar* and *asignar*, which show medium to strong correlations for the fast rate (.6005, .5393 and .6121, respectively). An exception to this trend is the word *rugby*, which shows a weak correlation (.3510) even in the fast rate. A possible explanation for this difference has to do with the observed presence of a vocalic element between C1 and C2. As mentioned above with reference to Figure 3, the presence of a significant vocalic element often results in lenition of C2, independently of the degree of constriction of C1, hence the low correlation between the two consonants for this word.

Finally, the $C1_{voiced\ stop}$ + $C2_{voiceless\ stop}$ sequences, as in the words *subclase* and *adquirir*, show low or even negative correlations (-.1393 and .4844, respectively) even for the fast rate. This seems to indicate that, despite the fact that voiceless stops can often be produced with incomplete occlusions, especially in intervocalic position and in fast rates, in consonant sequences the potential incomplete closure of C1 is insufficient to trigger lenition in C2. This and the fact that in these sequences C1 and C2 differ in voicing may be resulting in a more complex set of patterns than anticipated. In this sense, it is worth mentioning that a sizeable number of tokens of these two words showed considerable degrees of frication and partial devoicing of C1. Thus, further research is needed in order to understand the interaction between constriction degree and voicing in these sequences.

4. DISCUSSION AND CONCLUSIONS

The main purpose of this study was to investigate global effects of constriction degree by looking at the degree of lenition in non-homorganic sequences of stops in Spanish. Based on the predictions stated by the Articulatory Phonology theory, as well as related work, it was hypothesized that there should be a clear relationship between the constriction degrees of C1 and C2, where C1 is a voiced stop. In tube geometry terms, the prediction is that if there is a complete occlusion within the tongue tube for C1, then the closed CD would percolate all the way to the vocal tract level, which would in turn condition C2 to appear as fully constricted as well. If, on the other hand, C1 is lenited and therefore the vocal tract tube allows for a certain degree of laminal airflow, we would expect C2 to show signs of lenition as well.

The results obtained with heterorganic stop+stop and stop+nasal sequences in Spanish appear to give support to such an interpretation. The correlation coefficients obtained, especially for the $C1_{voiced\ stop}$ + $C2_{voiced\ stop}$ sequences, indicate that the constriction degrees of the two consonants are intricately related in spite of the fact that they differ in constriction location. This also points at the fact that the directionality of the prediction (C1 determining the constriction degree of C2) is probably a simplification of the actual facts, which seem to point rather to a composite output effect as a result of a process of blending of the constriction degrees of the two consonants.

The results also provide support for a less localized view of articulatory gestures, as suggested in [3]. The standard assumption in Articulatory Phonology is that gestures operate locally as the result of the activation of individual tract variables and, therefore, constriction degree and constriction location specifications for a particular gesture cannot be disassociated. However, the results obtained in this study show how the constriction degree of a particular gesture can be altered by or even blended with that of another gesture with a different constriction location specification, at least as far as the output features are concerned. Thus, the observed relationship between the resulting constriction degrees of C1 and C2 seems to hold independently of their constriction location specifications (labial+velar in *subclase*, dental+velar in *adquirir*, velar+labial in *rugby*, etc.). Further research will help clarify these issues by investigating the temporal effects on individual stops in these heterorganic sequences.

In addition to the findings regarding constriction degree and the claim for a less localized view of articulatory gestures, this study also contributes to our knowledge and understanding of Spanish stop lenition by providing phonetic detail of contexts that have not been the subject of much previous research, in the hope that it will contribute to a better and more thorough understanding of the phenomenon.

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