Exploring temporal reduction in dialectal Spanish: a large-scale study of lenition of voiced stops and coda-s

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Abstract

Large scale studies of temporal reduction are of interest to obtain linguistic knowledge and this understanding can potentially help improve speech technologies. Automatic speech recognition (ASR) supports the processing of very large corpora and can be used to enrich linguistic studies with models of speech production and perception grounded on observed commonly used pronunciations. In return, ASR can benefit from the linguistic findings by including pronunciation variants that reflect the linguistic variability. This study focuses on two temporal reduction phenomena in Peninsular and Latin American varieties of Spanish: lenition of intervocalic voiced stops V/bdg/V and coda-s. First, the two phenomena are investigated via a study of transcription errors produced by a speech recognition system designed for Peninsular Spanish which can be potentially attributed to lenition. In a second step, automatic forced alignment experiments are conducted using specific pronunciation variants with and without lenition to measure the extent of the phenomenon as a function of geographical and stylistic repartition. The results show that the distribution of pronunciation variants across Peninsular and Latin American Spanish varieties is consistent with trends depicted by classical linguistic studies. The speaking style appears to be the main factor affecting the +/-lenition variation. The findings also suggest that including such variants in ASR system's lexicon may improve performance when processing multiple Spanish varieties.

Index Terms: lenition, intervocalic voiced stop, coda-s, speech recognition, Spanish varieties

1. Introduction

This paper reports on a large scale study of two temporal reduction phenomena in Peninsular and Latin American varieties of Spanish: lenition of intervocalic voiced stops V/bdg/V and coda-s. Large scale studies of temporal reduction can be facilitated by automatic speech processing technologies, to confront linguistic theories with real-world speech recordings and to provide quantitative measures of observed pronunciation variations. In return, the linguistic findings benefit the acoustic and lexical models used in the speech technologies. This study focuses on two temporal reduction phenomena in Peninsular and Latin American varieties of Spanish: lenition of intervocalic voiced stops V/bdg/V and coda-s. Both phenomena benefit from a long linguistic tradition, resulting in extensive studies of the historical mechanisms that triggered lenition [1], the connection with corresponding reduction phenomena encountered in other Romance languages [2], the acoustic features underlying the weakening processes [3], [4], and of the dialectal and/or social patterns of lenition [5]. Studies of lenition from large scale corpora processed with automated tools are fewer [6], although consistent efforts to build corpora which portray the geographical and stylistic variation of Spanish can be mentioned

for both Peninsular [7] and Latin American Spanish [8]. With respect to ASR studies, several approaches have been dedicated to address the challenge of dialectal variation in speech recognition accuracy [9]. Different strategies have been adopted in order to deal with the multi-dialectal variation of Spanish: building dialect-specific ASR systems, trying the suitability of a dialect specific system on another dialect (cross-dialect recognition) or building a single system capable of recognizing all dialects. The first strategy is defended by [10] who analyses the performance for voice search on Arabic, English and Spanish of Google's multi-dialectal ASR systems and concludes that among Spanish recognizers the Mexican Spanish one covers the best the variability of different Peninsular, Latin American and US Spanish sources. In contrast, the relevance of dialect dependent ASR systems for Spanish varieties is put forward in [11]. In particular, the lexicons are built to encode specific dialectal pronunciations including post-nuclear -s and voiced stop lenition for specific Latin American varieties. Finally, the robustness of Spanish multi-dialectal systems is studied in [12].

The present paper explores the lenition of /bdg/ and coda-s (which refers in this study to both word and syllable final-s) through the effects on ASR accuracy and quantifies its incidence in different corpora. The remainder of this paper is as follows. In Section 2 a state-of-the-art of the two lenition processes according to the linguistic literature is presented. Section 3 focuses on the corpora and methodology and describes the baseline speech recognition system used to estimate the impact of lenition on transcription errors and on the further experiments with pronunciation variants. Section 4 presents a typology of automatic errors including the lenition-related ones, and it is followed by the description of the pronunciation variants selected to quantify the lenition (Section 5). In section 6 the forced alignment experiment results are given followed by conclusions in Section 7.

2. Voiced stop /bdg/ and coda-s lenition in Spanish: linguistic overview

According to standard descriptions of Spanish, voiced stops **/bdg/** are pronounced as fricatives /βðɣ/ or approximants in intervocalic position. Described as intervocalic stop lenition, this reduction phenomenon was studied both as an historical and a synchronous process of variation from Latin to modern Romance languages, to this extent allowing to distinguish between Western, in which it was an active sound change, from Eastern Romance languages [1]. In many Romance languages intervocalic consonant lenition applies within words and across word boundaries as an essentially obligatory allophonic phenomenon and it represents an important aspect of the phonology of these languages. Also called spirantisation or consonant weakening, it is a reduction phenomenon with various degrees of realization according to languages, varieties and speaking styles. Al-

Table 1: *Summary of data sources. Peninsular (Spa) and Latin American (LA).*

Corpus	Words	Distinct	Audio	Speech	Speak.F/M
CVC LA	14k	3k	1h40	1h40	7/24
BN LA	32k	6k	3h40	3h20	72/88
BN Spa 2014	37k	7k	3h20	3h15	70/81
BN Spa 2009	47k	7k	9h	8h	126/213
BC Spa	3k	1k	0h45	0h44	1/7
CTS LA	1k	0.4k	0h15	0h13	4/3
CTS Spa	59k	6k	5h10	5h	17/19
Total	251k	35k	24h	22h10	297/35

though it is mainly associated and largely studied for Spanish varieties from both Peninsular and Latin America, intervocalic consonant lenition also occurs in Catalan, Portuguese and Italian from Southern Italy and concerns voiced /bdg/ and voiceless stops /ptk/ [4], [1], [3], [5], [13]. In terms of acoustic features, the intervocalic consonant lenition is defined as the phonetic mechanism by which consonants become more similar to the surrounding vowels as a consequence of the gestural overlap and of the aerodynamic constraints on consonant voicing [14], [15], [16], [17]. As for coda-s lenition, in Spanish both coda and word final-s can be variably aspirated or entirely deleted [13]. Following the demonstration made by [18], in [1] it is underlined that coda-s lenition is concrete evidence that "an active process at the phonetics-phonology interface in one language may mirror a completed sound change in another language". While today the phenomenon consists of a variable aspiration and deletion of the voiceless fricative in many Spanish dialects, centuries ago it was responsible of a full sound change in French (Lat. escuela vs Sp. escuela /ehkwela/ or /ekwela/ vs Fr. école /ekol/). Coda-s reduction was investigated through acoustic measurements which indicated various degrees of weakening involving duration reduction, voicing, aspiration and deletion [6]. A few recent studies have addressed the analysis of lenition in large scale corpora. In [6], the acoustic patterns of coda-s lenition were investigated from 86 hours of audio books in Peninsular and some Latin American varieties of Spanish. In a recent paper, we present overall preliminary rates of lenition of intervocalic /bdg/ and coda-s in Peninsular and Latin American Spanish [19].

3. Data and methodology

3.1. Corpora

This section presents the corpora and methodology used in these studies.The data are the same as in [19] and illustrate varieties of Spanish both from Spain and Latin America countries, and different speaking styles: monologues, broadcast prepared speech, broadcast conversations and telephonic conversations. All corpora are manually orthographically transcribed. The Table 1 below summarizes the various corpora. The following varieties and speaking styles are compared:

1. **Semi-prepared broadcast news (BN)**: broadcast data are gathered both from Peninsular (BN Spa) and Latin American (BN LA) Spanish. The former consists of broadcast news in Castilian recorded during the years 2009 and 2014, the latter are from the Caribbean variety (mainly Equator and Venezuela, years 2015-2016).

2. **Broadcast conversations (BC)**: this corpus contains interviews in Castilian Spanish.

3. **Semi-prepared monologues**: these were selected from the recordings of the *Catalogo de Voces Hispanicas*, available at Centro Virtual Cervantes [1]. This corpus includes 31 samples from Argentina (5 samples), Mexico (4), Bolivia (2), Colombia and Venezuela (3), Peru and Chile (2), and one for the remaining countries Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Panamá, Paraguay, Puerto Rico, Dominican Republic, Uruguay. The samples have been merged in 5 main varieties: Andean, Caribbean, Mexican, Rioplatense, Chilean [20].

4. **Telephonic conversations CTS**: they correspond to fully spontaneous conversations in both Peninsular and Latin American (Caribbean) varieties of Spanish.

3.2. Spanish ASR system

ASR errors were assessed on the hypotheses of a DNN-based system (acoustic models with 4-hidden layers and 10M parameters). The final model has about 10k tied-state targets and is obtained via discriminative sequence training, using state-level minimum Bayes risk (sMBR) as objective function [21]. The acoustic models were trained on data from both Peninsular and Latin America. For the language models, more than 2 billion words from several Peninsular Spanish and Latin American sources (transcriptions, dialogues, news, blogs, Web sites) were used. Component language models trained on each individual source are combined via linear interpolation, with weights automatically estimated to maximize the likelihood of a development data set. The system vocabulary contains 250k words. For both systems, the pronunciation lexicon is obtained using a data-driven grapheme-to-phoneme converter. The phone set comprises 32 phonemes: 10 vowels, 19 consonants and three special units to model silence, breath and filler words. The WER ranges from 11.2% for BN Spa to 15.9% for BN LA and 18.0% for CVC LA.

Previous studies [22] showed that more pronunciation variants are selected during alignment with context-independent acoustic models than with context-dependent ones that inherently capture some coarticulatory effects. Thus, for the phonetic alignment performed in this study, it was decided to use context-independent acoustic models trained on Peninsular Spanish. For the alignment gender-independent acoustic models were trained using standard cepstral features from about 165 hours of speech.

4. Dialectal phonetic variation and ASR errors

It is commonly accepted that dialectal variability can degrade ASR. It can occur at different linguistic levels including the phonemic encoding and the patterns of phonetic variation. Concerning the performances of the ASR system for the varieties of Spanish, the differences in phonemic inventories and in handling temporal reduction were mentioned as the main sources of errors [12]. Among the phenomena falling in these categories, it is worth mentioning the *yeismo* and the *seseo* as phonemic differences, and the lenition of intervocalic voiced stops /bdg/ and of coda-s, all of them highly represented in our corpora.

Phonemic differences. The phenomena called *yeismo* (with the variants *Lleismo* and *Zeismo*) and the *seseo* are often mentioned as inter-dialectal phonemic differences with impact for ASR [12].The former refers to allophonic status of /ʎ/, /j/ and

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Table 2: *Examples of ASR errors as function of variation pattern (in upper case).*

Dialect feat.	Examples of ASR errors
Yeismo	REF: ALLA LAS COLUMNATAS
	HYP: **** AYALA COLUMNATA
Seseo	REF: ZORROS
	HYP: SORDOS
V/bdg/V lenition	REF: con ellos también ESTÁBAMOS en el lugar
	HYP:con ellos también ESTAMOS en el lugar
Coda-s lenition	REF: PRINCIPIOS que él señaló EN SUS DISCURSOS
	HYP: PRINCIPIO que él señaló ** SU DISCURSO

Table 3: *Substitution errors due to coda-s lenition.*

Corpus	Substitution freq.(%)
CVC LA	7.2
BN LA	3.8
BN Spa 2014	3.4
BN Spa 2009	1.7

/ʒ/, whereas the latter concerns the neutralization between /θ/ and /s/. Both phenomena occurs at different degrees in all dialects of Spanish, but the magnitude can make a strong difference, for instance *seseo* being much more widespread in Latin America than in Spain [23]. In our corpora, 3% of the words are potentially concerned by the *yeismo* and 16% by the *seseo*. The variation in pronunciations observed in Peninsular vs Latin American Spanish, arising from these phonemic differences are behind many transcription errors (Table 2).

Temporal reduction. Previous work has considered that the weakening and/or full deletion of **coda preconsonantal or word final-s** is a dialect specific feature that impacts the ASR performance [12]. In [6], the forced alignment of variants /s/, /h/ or /z/ was used to capture the weakening of syllable and word final-s. We found that data from both Spain and Latin American varieties are highly sensitive to this phenomenon and many substitution errors may be attributed to coda-s lenition (Table 3). Coda-s lenition affects nominal and verbal declensions, very frequent pronouns (*lo/los*, *le/les*), articles (*una/unas*) and auxiliary verbs (*ha/has*) being reduced in particular in Latin American varieties. The errors due to weakening or **lenition of the intervocalic stops /bdg/** which are pronounced as fricatives /βðɣ/ or are fully deleted, are underestimated in the ASR literature. However, in our corpora, taken together /b/, /d/ and /g/ concerns 22% of the lexicon. The deletion of /b/ and /d/ may disrupt the verbal paradigm as the former makes the difference between past and present tense in many verbs, whereas the latter marks the participle (Table 2).

5. Pronunciation variants

In what follows we focus on the lenition of intervocalic voiced stops /bdg/ and of coda-s and on their realization in the different corpora. To do so, forced alignment is used to select pronunciation variants with and without lenition. The ASR system receives as input the speech data, the corresponding reference transcriptions and a lexicon with pronunciation variants, in this case pronunciations with presence or absence of the consonants /b/, /d/, /g/ and /s/ respectively as illustrated by Figures 1 and 2. Note that for the intervocalic stops /bdg/ the pronunciation as fricatives /βðɣ/ is already encoded in the lexicon.

On the basis of the available acoustic information, the system will select the phonetic representation that best matches the
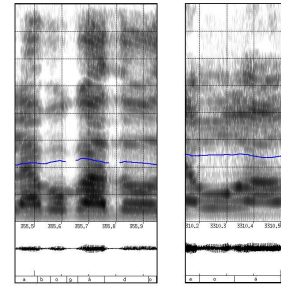

Figure 1: *The word /abogado/ 'attorney' are aligned with /aβoɣaðo/ (left) vs. /aoao/(right).*
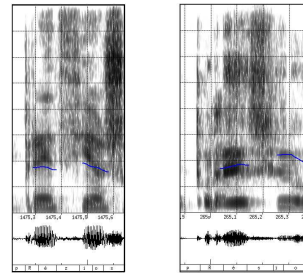

Figure 2: *The words /prezios/ 'prices' are aligned with /prezios/ (left) vs. presio (right).*

pronounced word. Temporal reduction has been described as both a categorical and a continuous phenomenon [24]. In the present study we opted for a preliminary solution consisting of a binary encoding of the lenition, the lexicon being enriched with non canonical variants in which one or several targeted sounds are missing. We are aware that in order to provide a fine-grained picture of the inter-dialectal patterns of lenition, further work will have to consider additional variants referring to intermediate levels of weakening. In the case of the words with more than one V/bdg/V or coda-s sequences, it is worth noting that the addition of new pronunciations may increase dramatically the variants. Table 4 illustrates variants for lenition of the voiced stops in the words *abono* 'compost' and *abogado* 'attorney', as well as for the coda-s in word-internal (*desde* 'from') and word-final position (*estos* 'from').

6. Results

The lenition rate is computed for each corpus according to the parameters of geographical origin (Peninsular vs Latin American Spanish, and Andean, Caribbean, Mexican, Rioplatense, Chilean inside the Latin American domain) and speaking style (from prepared professional to spontaneous telephonic conversations). The rates are computed at the item level, that is each V/b/V, V/d/V, V/g/V and coda-s available in the corpora (by opposition to the word level), as 10% (2428) of the V/bdg/V

Table 4: *Pronunciation variants for voiced stop and coda-s lenition.*

Pron. var.	Examples
V/bdg/V	**abono** /aβono/ /aono/
	abogado /aoao/ /aβoao/ /aoɣao/ /aβoɣao/ /aoaðo/
	/aβoaðo/ /aoɣaðo/ /aβoɣaðo/
Coda-s	**desde** /dede/ /desde/
	estos /eto/ /esto/ /estos/

Table 5: *Voiced-stop lenition across corpora.*

Corpus	Frequency(%)			Lenition(%)		
	VbV	VdV	VgV	VbV	VdV	VgV
CVC LA	3.7	6.8	2.0	30.2	43.6	21.4
BN LA	4.2	8.4	1.6	34.0	46.8	34.6
BN Spa 2014	4.3	8.7	2.0	19.8	22.8	26.8
BN Spa 2009	4.0	8.9	1.8	21.9	22.7	29.5
BC Spa	3.4	6.5	1.4	31.0	40.2	31.3
CTS LA	4.5	4.9	1.0	60.0	75.8	71.4
CTS Spa	3.0	5.1	1.7	46.4	58.7	49.7
Average	3.8	7.4	1.8	30.1	35.7	34.5

Table 6: *Voiced-stop lenition in Latin American varieties.*

Variety	Frequency(%)			Lenition(%)		
	VbV	VdV	VgV	VbV	VdV	VgV
Andean	2.5	6.4	1.8	17.6	37.1	8.1
Mexican	4.2	5.8	1.8	26.6	53.0	29.0
Caribbean	4.1	7.0	1.5	38.3	58.7	24.1
Chilean	3.3	8.0	1.6	82.7	71.5	11.1
Rioplaten	3.0	6.6	2.6	36.6	72.6	31.0
Average	3.4	6.6	2.0	34.7	42.2	23.8

Table 7: *Coda-s lenition across corpora.*

Corpus	Frequency(%)	Lenition(%)
CVC LA	23	34.2
BN LA	25	27.2
BN Spa 2014	26	15.3
BN Spa 2009	25	9.0
BC Spa	23	25.3
CTS LA	14	62.1
CTS Spa	18	62.9
Average	23	27.8

Table 8: *Coda-s lenition in Latin American varieties.*

Variety	Frequency(%)	Lenition(%)
Andean	22.6	16.0
Mexican	23.8	20.4
Caribbean	24.9	45.3
Chilean	25.0	68.2
Rioplaten	22.8	47.8
Average	23.5	34.4

and 6.5% (880) of the coda-s words contain more than one item (i.e. *adecuada* 'appropriate' counts twice for V/d/V lenition and *puestos* 'positions' for coda-s lenition). Tables 5 and 6 show the lenition rate for V/bdg/V items according to the geographical source of the data (Spa vs LA). The corpora are ordered from most to least formal speech, that is from monologues (CVC LA) to telephonic conversations (CTS Spa and LA).

Regardless of the origin and the speaking style, all corpora are concerned by V/bdg/V lenition. The stops have comparable overall reduction rates across the data sets, with V/d/V being the most frequent and having the highest lenition rate. Multi-item reductions concerns 5.4% of the V/bdg/V lenitions (as in *universidad* [unieRsiád] 'university', *jugadores* [xuaóRes] 'players', *preguntaba* [pReuntáa], 'to wonder', past tense). The difference in distribution across corpora is statistically significant for V/b/V (χ^2(5, N=17142)=1258.3, p<.001) and V/d/V (χ^2(5, N=31417)=426.09, p<.001). Two clear trends emerge for all voiced stops: the rate of lenition is higher for Latin American varieties and increases with the degree of spontaneity of the data. When looking only at the Latin American varieties, the resulting lenition rates (Table 6) are in line with classical linguistic trends which underline that "Low Lands" have a greater tendency to delete [25]: Andean and Mexican ("High Lands") present lower rates than Caribbean, Chilean and Rioplatense ("Low Lands") dialects.

As for the coda-s lenition, although the average reduction rate is slightly below the one for voiced stops (27.8% vs above 30%), its impact is greater due to the high frequency in the data (Table 7). Multi-item reductions within a word also occur, however they are less frequent (words like *turistas* [tuRíta], *ustedes* [utéde] or *estamos* [etámo] represent only 2.8% of the coda-s tokens). Lenition trends follow those observed for V/bdg/V, that is the Latin American corpora show higher lenition rates than the Peninsular Spanish ones. The variation across corpora is statistically significant (χ^2(5, N=37108)=4415.8, p<.001). This difference is especially evident for broadcast news data (7BN LA vs BN Spa), however with regard to spontaneous conversations all dialects are concerned by a high rate of lenition (above 60%). Within the Latin American group, the same pattern is observed as was seen for voiced stops: Andean and Mexican varieties have a greater tendency to retain coda-s, Caribbean, Chilean and Rioplatense more frequently drop coda-s.

7. Discussion

This study quantifies two frequent lenition phenomena in Spanish from large-scale data processed via forced alignment. It supports the observation that ASR errors are a good basis to identify instances of lenition which can be later measured by means of quantitative methods such as the rate of different variants aligned by an ASR system. The results show that the selection of pronunciation variants with and without lenition for both intervocalic stops V/bdg/V and coda-s depends on the geographical origin of the recording and the speaking style, the latter factor being even more important than the variety itself. The results also confirm classical phonetic assumptions which underlined the relevance of the two factors using smaller data sets and put forward the relevance of the method based on pronunciation variants in validating linguistic descriptions from large data sets. As regards to the potential gain brought by the modeling of linguistic variation, preliminary ASR experiments show that by adding supplementary data and also including pronunciation variants for the *yeismo* and *seseo* consonants, and for voiced stop (V/bdg/V) and coda-s lenition, the WER is reduced for LA Spanish (14.8% for BN LA and 17.8% for CVC LA) with no impact on BN Spa. Further work will focus on better identifying the level of weakening by using continuous instead of binary pronunciation variants, and by conducting acoustic analyses of instances aligned as retained or deleted. One aim is to improve modeling of lenition for ASR systems.

8. Acknowledgements

9. References

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