Interspeech 2022
18-22 September 2022, Incheon, Korea

When Phonetics Meets Morphology: Intervocalic Voicing Within and Across Words in Romance Languages

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Abstract

Intervocalic voicing is a process whereby a voiceless segment such as /ptk/ is realized as partially or totally voiced [bdg] when occurring between two vowels. It supposedly happens across-the-board in connected speech, where phonetics is blind to morphological boundaries (in our case, word edges) but only word-internal intervocalic voicing actually phonologizes, as in Lat. *vita* → Spa. *vida*. This means that a change currently happening can be identified if phonetic variation patterns differently at word edges and word-internally. We provide an analysis of ~1000h of automatically aligned connected speech in five Romance languages to investigate intervocalic voicing of /ptk/ – as well as resistance to devoicing of /bdg/ – as a function of the stop's position in the word, i.e., internal (VCV), initial (V#CV), final (VC#V) and in isolation (V#C#V). Results show that voicing alternations in Portuguese are sensitive to word edges while French and Romanian are sensitive to the right word edge only and Spanish and Italian show no difference at word edges or internally. However, the surprising result is that word edges do not only sometimes show resistance to intervocalic voicing, but even tend toward devoicing of voiced stops.

Index Terms: intervocalic voicing, lenition, fortition, large corpora, automatic alignment with pronunciation variants

1. Introduction

Intervocalic voicing is a process whereby a voiceless segment such as /ptk/ is realized as partially or totally voiced [bdg] when occurring between two vowels. Phonetically, it is described as an articulatory undershoot [1,2] resulting in the partial or total maintenance of the vibration of the vocal folds [1,3,4,5], articulatory reduction [3,4,5] and reduced duration [3,5,6,7,8]. It has been shown to operate in connected speech in numerous languages, both within words (ex. Sp. *médico*, [méðiɣo], "physician") and across word boundaries (ex. Sp. *lo que digo* [loɣeðiɣo], "what I am saying") (see [9,10] on Romance languages; [11,12] on Spanish; [13] on Spanish and French; [4] on Italian).

Phonologically, intervocalic voicing is also one of the most consensual and well-attested types of diachronic lenition [9,14,15,16,17], a process whereby a segment is "weakened", i.e., undergoes (a series of) transformations ultimately resulting in its deletion, as in the transition from Latin *vita* into Spanish *vida* or French *vie*, "life". However, lenition, as a historical process, is also defined as a strictly positional phenomenon [17]: From the observation of the evolution from Latin to Western Romance languages, for instance, it can be concluded that consonants in syllable-final position (aka codas, VC#) and in word-internal intervocalic position (VCV) are in weak positions, and thus prone to weakening, while syllable-initial consonants (aka onsets, #CV) are in strong position, and thus prone to strengthening or, at the very least, to resistance to weakening.

A paradox emerges from this double definition (phonetic *vs* phonological). Intervocalic voicing supposedly happens across-the-board in connected speech, where phonetics is blind to morphological boundaries (e.g., word edges) but these same variational phenomena are the breeding ground for diachronic phonological changes [18], where only some contexts actually phonologize. In Romance languages for instance, word-internal intervocalic stops (VCV) have undergone lenition (Lat. *ripa* → Fr. *rive*, "shore") while word-initial consonants preceded by a vowel (V#CV) have resisted lenition (Lat. *illa porta* → Fr. *la porte*, "the door"). Hualde [19] builds on the observation of Judeo-Spanish to propose a solution: Sound changes start as across-the-board processes but are later lexicalized only within the word-domain. We build on this proposal to suggest that, when a phonetic variational pattern behaves differently at morpheme boundaries (word edges) and morpheme- (word-) internally, it means that the change may be on the way to phonologization.

In the present study, we aim to contribute to the current state of knowledge on intervocalic voicing in Romance languages. This language family indeed displays voice alternation patterns at word edges that lead us to believe that word-initial fortition is on its way to phonologization in Portuguese [20] and that word-final devoicing may be phonologizing in French and Romanian [21,22]. We investigate ~3M intervocalic stops in three Western Romance languages (Portuguese, Spanish and French) and two Eastern Romance languages (Italian and Romanian) to establish (i) if /ptk/ exhibit intervocalic voicing, and /bdg/ resist devoicing, and (ii), if so, if the observed trends are different at word edges and word-internally.

The outline of the paper is as follows. In Section 2, we present our data and methodology. In Section 3, we present the results regarding the voicing patterns of voiceless stops, the devoicing of voiced stops, and the comparison of the two, before sharing preliminary results on the effect of gender of the speaker. Section 4 concludes and discusses the results.

2. Corpus and Methodology

Investigating such a subtle, ongoing phenomenon requires analyzing massive data, to make sure to spot the alternations when they happen and draw a reliable picture [23]. Such

10.21437/Interspeech.2022-10725

research is made possible today thanks to the access to large corpora and to automatic processing methods.

In the present study, we analyze five Romance languages to establish whether (i) voiceless stops /ptk/ are realized as voiced [bdg] and (ii) voiced /bdg/ are still realized as voiced [bdg] in intervocalic position word-internally (VCV), word-initially (V#CV), word-finally (VC#V) and in isolation, i.e., one-consonant words labeled as monophones below (V#C#V), e.g., Fr. *t'*, "you (object)" or *d'*, "of, from".

2.1. Corpora

We investigate 1000+ hours of speech in Portuguese, Spanish, French, Italian and Romanian. The characteristics of the corpora used in this study are given in Table 1.

Table 1: *Data characteristics: language, duration of the corpus (in hours), number of word tokens (in millions, M), number of word types (in thousands, k), average number of variants/word when allowing voicing alternation for each stop*

Language	nb of hours	word token (M)	word types (k)	nb of variants
Portuguese	114	1.1	46.1	1.02
Spanish	223	2.6	61.9	1.1
French	176	2.5	55.7	2.1
Italian	168	1.8	58.8	1.0
Romanian	374	3.6	47.0	1.0

Our corpora are representative of journalistic speech from TV and radio shows. They were acquired from the Linguistic Data Consortium (LDC) or the European Language Resources Association (ELRA), or developed in the framework of international research projects [24,25,26,27,28,29]. Associated manual reference transcriptions are provided for almost all of the audio data. An exception is Romanian, which has only 7h manually transcribed, and the remainder automatically transcribed with a Romanian speech-to-text transcription system [30]. Language-specific baseline pronunciation dictionaries are also incorporated in the respective speech recognizers used for the alignment (see subsection 2.2).

2.2. Methodology

This study adopts the method proposed by Adda-Decker and Hallé [31] to study voicing alternations of the stops /ptkbdg/ by introducing specific variants in the pronunciation dictionaries. The augmented lexicons contain both each word's so-called canonical pronunciation and potentially altered, non-canonical variants [32]. A language-specific speech recognition system is then used to carry out a forced alignment of the speech with the reference transcription, using the original (canonical) or augmented (canonical + variants) pronunciation dictionary, allowing the system to select the best matching pronunciation during the process. LISN-CNRS speech recognition systems for each language, all comparable in terms of architecture, were previously trained on similar data to that used in this study (cf. [10]).

Therefore, voicing (or devoicing) is decided based on whether the best matching phone model corresponds to the original voiceless (or voiced) canonical phone or to the voiced (or devoiced) variant, much like an automated ABX judgement task. The system compares the acoustic realizations of each consonant with the corresponding voiceless or voiced phone models and selects the best one. Thus, for any occurrence of a voiceless stop /ptk/, the system can align either the canonical [ptk] transcription or its voiced counterpart [bdg] and, conversely, for any occurrence of a voiced stop /bdg/, it can select either the canonical [bdg] transcription or its voiceless counterpart [ptk]. For instance, the French word *toux*, /tu/, "cough", could be transcribed as [**t**u] or [**d**u], but the French word *doux* /du/, "sweet", could also be transcribed either as [**d**u] or [**t**u]. This will allow us to investigate not only voicing (*toux* pronounced as [du]), but also resistance to devoicing (*doux* not pronounced as [tu]).

This method, using large corpora and automatic alignment with pronunciation variants, has proven reliable and useful to the investigation of voicing alternations, aka of the realization of the laryngeal feature, in several recent works on Romanian [21,22], French [21,35,36], Spanish [33,34] and pools of several Romance languages [10,20].

2.3. Data

In total, the corpora and methodology allow us to investigate the realization of almost 3 million intervocalic stops (detailed in Table 2), 60.38% of which are voiceless consonants /ptk/.

Table 2: *Counts of stops taken into account for the study as a function of their position in the word: as one-consonant words (monophones) or as first, internal and last segments in the word (word-initial, word-medial and word-final respectively).*

	mono-phone	word-initial	word-medial	word-final	Total
Por	0	140851	237793	163	378807
Spa	3	231087	135220	23	366333
Fre	18116	301029	240980	13686	573811
Ita	1422	228532	180553	894	411401
Rom	16	426226	533791	21642	981675
Total	19557	1327725	1328337	36408	2712027

3. Results

Here we describe the patterns of intervocalic voicing of /ptk/ (3.1), those of resistance to devoicing of /bdg/ (3.2) and conclude by comparing the two (3.3). Finally, we propose an analysis of the effect of gender on these realizations (3.4).

3.1. Intervocalic voicing of /ptk/

All languages pooled, we investigate ~1.6M voiceless stops /ptk/ (detailed in Table 3), 8.35% of which are realized non-canonically, i.e., as voiced [bdg].

Table 3: *Counts of voiceless stops /ptk/ in each language as a function of their position in the word*

	mono-phone	word-initial	word-medial	word-final	Total
Por	0	84169	135553	118	219840
Spa	0	90854	70117	6	160977
Fre	5886	163380	176995	11622	357883
Ita	8	117192	133505	380	251085
Rom	6	217265	410031	20337	647639
Total	5900	672860	926201	32463	1637424

As can be seen in Figure 1, all languages pooled, rates of intervocalic voicing are similar in all positions, ranging from

6.36% in word-final position to 11.03% for one-consonant words (Δ=4.67%). The word-medial position is thus not the one favoring voicing the most, with 8.79% voicing.

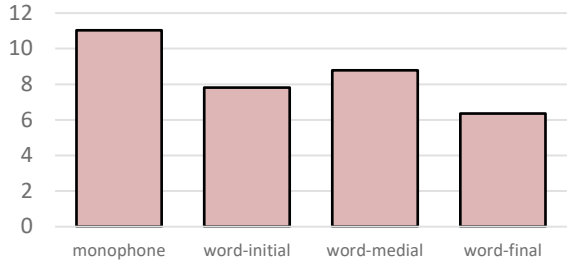

Figure 1: *Rates of non-canonical, voiced realizations of /ptk/ as a function of position with regards to word boundary.*

However, since all languages do not share the same phonotactic profile (see Table 3), it is doubtful that they all behave the same. Let us now investigate the stops' behavior in each language.

Table 4: *Rates (%) of intervocalic voicing of /ptk/ in each language in each position in the word*

	mono-phone	**word-initial**	**word-medial**	**word-final**	**mean**
Por	NA	7.62	13.10	12.71	11.00
Spa	NA	9.54	10.93	50.00	10.14
Fre	10.99	7.88	7.76	8.82	7.90
Ita	37.50	12.12	12.58	8.68	12.36
Rom	16.67	4.77	6.21	4.86	5.69

In Table 4, we can see that Portuguese displays a fair amount of intervocalic voicing when the consonant is word-internal or word-final (Δ=0,39%), but less when it is word-initial (Δ=5.48%). Since the position in the word is correlated to the realization of non-canonical variants (χ^2=1597.4, df=2, p<0.0001), we conclude that this language "sees" word boundaries. Whether this means that it displays phonologized intervocalic voicing will be investigated in the subsection 3.3.

Spanish consonants voice a lot word-finally, but this ratio actually stems from the observation of 6 tokens only. In word-initial and word-medial position, however, the rates of voicing are similar (Δ=1.39%). Also in this language, the position of the stop regarding word boundaries is statistically correlated with non-canonical realizations (χ^2=94.972, df=2, p< 0.0001).

French has, in general, similar rates of devoicing across all positions, although monophones and, to a lesser extent, word-final consonants, voice more than the mean (Δ=3.09%) and the word-internal context is the one voicing the least (Δ=3.23% compared to the highest rate), which is surprising.

Italian is the language displaying the most intervocalic voicing, with a mean rate of 12.36%. Monophones are the most prone to voicing, but then again, with only 8 tokens, the results are not robust. Position in the word and voicing are however mildly correlated (χ^2=21.334, df=3, p<0.0001).

Finally, Romanian is the language displaying the least intervocalic voicing, with a mean of 5.69%. Like French and Italian, it voices one-consonant words the most (10.98% above the mean). This is probably due to the fact that one-consonant words are often frequent function words that therefore tend to be reduced. Word-medial is nonetheless the second context most favoring voicing, which is consistent with our expectations. However small the rates, the position of the stop *vis-à-vis* the word boundaries is correlated with non-canonical realizations (χ^2=572.42, df=3, p<0.0001).

To compare similar datasets in terms of quantity, word-initial consonants (n=672860), historically supposed to favor fortition (in our case, resistance to voicing), and word-medial consonants (n=926201), historically supposed to favor lenition (in our case, voicing), differ only in Portuguese (Δ=5.48% in favor of the internal context, χ^2=1596.6, df=1, p<0.0001) but are similar in Spanish (Δ=1.39%, χ^2=84.374, df=1, p<0.0001), French (Δ=0.12%, χ^2=1.5864, df=1, p=0.2), Italian (Δ=0.46%, χ^2=1.0914, df=1, p=0.3) and Romanian (Δ=1.44%, χ^2=541.84, df=1, p<0.0001), thus advocating against phonologizing intervocalic lenition in these four languages.

However, before drawing any conclusion, we should compare the rates of /ptk/-voicing to the rates of /bdg/'s resistance to devoicing.

3.2. Resistance to devoicing by /bdg/

In this subsection, we focus on the 1.1 million voiced stops detailed in Table 5.

Table 5: *Counts of voiced stops /bdg/ in each language as a function of their position in the word*

	mono-phone	**word-initial**	**word-medial**	**word-final**	**Total**
Por	0	56682	102240	45	158967
Spa	3	140233	65103	17	205356
Fre	12230	137649	63985	2064	215928
Ita	1414	111340	47048	514	160316
Rom	10	208961	123760	1305	334036
Total	13657	654865	402136	3945	1074603

Among them, only 5.90% are realized as non-canonically devoiced [ptk]. This rate is low, as expected from the intervocalic context, but not null, and deserves more attention.

Table 6: *Rates (%) of intervocalic devoicing of /bdg/ in each language in each position of the word*

	mono-phone	**word-initial**	**word-medial**	**word-final**	**mean**
Por	NA	19.84	11.23	24.44	14.30
Spa	0.00	3.75	2.74	29.41	3.43
Fre	4.31	4.49	4.87	9.54	4.64
Ita	4.74	4.62	5.88	4.86	4.99
Rom	0.00	4.35	5.15	13.87	4.68

In Table 6, we can see that Portuguese is, by far, the language that displays the most devoicing, *despite the intervocalic context*, even in word-medial position, historically supposed to favor lenition, i.e., voicing. Moreover, devoicing and position of the stop are strongly correlated (χ^2=2209.2, df=2, p < 0.0001).

Spanish on the other hand, is the language where stops devoice the least, with a mean devoicing rate of only 3.43%. The rate of final devoicing may seem impressive, but again

stems from the observation of a reduced number of tokens (n=17) and is thus not alarming, even though devoicing and position of the phone are correlated (χ^2=171.7,df=3,p<0.0001).

In French, Italian and Romanian, rates of devoicing are relatively similar, with the notable exceptions of word-final devoicing in French (4.67% above the word-medial rate) and Romanian (8.72% above the word-medial rate). Devoicing and position of the stop in the word are correlated in all three languages (χ^2=95.779, df=3, p<0.0001 for French; χ^2=110.57, df=3, p<0.0001 for Italian; and χ^2=358.69, df=3, p<0.0001 for Romanian).

3.3. Comparison between voicing and devoicing

What the results from subsection 3.2 show, is that, even in intervocalic, typically leniting contexts, /bdg/ is sometimes devoiced. This is surprising and can be due to a number of reasons. When the rates are low, it is possible that there is an inevitable error rate from the ASR system (due to erroneous transcriptions, or background noise on the audio file, dysfluencies from the speakers… [37]). To compensate this error rate, we provide the differential between voicing rates (expected) and devoicing rates (unexpected) in each position in the word in each language in Table 7.

Table 7: *Deltas (%) between voicing and devoicing rates as a function of position for each language. Voicing is taken as the reference, positive values mean that the context displays more voicing than devoicing, negative values mean that the context displays more devoicing than voicing.*

	mono-phone	**word-initial**	**word-medial**	**word-final**	**Mean**
Por	NA	-12.22	1.88	-11.73	-3.30
Spa	0.00	5.79	8.19	20.59	6.72
Fre	6.68	3.39	2.89	-0.73	3.26
Ita	32.76	7.50	6.70	3.82	7.37
Rom	16.67	0.42	1.06	-9.01	1.00

When the rates are adjusted, we have a global picture of voicing alternations in intervocalic context. Almost all values are positive, meaning that the intervocalic context indeed massively favors voicing. The context disfavoring voicing the most is the word-final position, with Portuguese, Romanian and to a lesser extent French even displaying final devoicing, despite the intervocalic context, which advocates for the presence of phonologizing word-final devoicing in these languages [21].

Portuguese has a peculiar behavior, being the only language displaying overall 3.30% more devoicing than voicing, which is in line with previous studies [20, 38].

To compare similar datasets, word-initial stops, historically supposed to favor devoicing (n=1,327,725), and word-medial stops (n=1,328,337), historically supposed to favor voicing, differ in Portuguese (Δ=10.34%) and to a much lesser extent in Spanish (Δ=2.40%), but are similar in French (Δ=0.50%), Italian (Δ=0.80%) and Romanian (Δ=0.64%).

3.4. Effect of the gender of the speaker

In this last subsection, we provide some preliminary results on the effect of gender on voicing alternations in Portuguese, Spanish and Italian (gender labels are not available for most of the French and Romanian data). Table 8 displays the rates of non-canonical realizations of /ptk/ (on the left) and /bdg/ (on the right), with regard to gender of the speaker.

Table 8: *Rates (%) of non-canonical realizations for voiceless /ptk/ and voiced /bdg/ (all positions in the word pooled) as a function of speaker gender.*

	/ptk/ voicing		/bdg/ devoicing	
	Female	Male	Female	Male
Por	9.99	11.03	16.66	13.50
Spa	6.67	12.76	3.40	3.45
Ita	8.83	14.59	3.08	6.32

Male speakers voice /ptk/ more than female speakers, especially in Spanish (Δ=6.09%, χ^2=1606.3, df=1, p<0.0001) and Italian (Δ=5.76%, χ^2=1824.5, df=1, p<0.0001).

Regarding the devoicing of /bdg/, the results differ in each language. Male speakers devoice /bdg/ more than female speakers in Italian (Δ=3.23%, χ^2=854.44, df=1, p<0.0001), suggesting that, in this language, both alternations in the realization of the laryngeal feature pattern similarly from a sociolinguistic point of view. In Spanish, male and female speakers devoice /bdg/ at the same rate (Δ=0.05%, χ^2=0.38122, df=1, p=0.5), suggesting that voicing of /ptk/ may have a different socio-linguistic effect. Finally, in Portuguese, male speakers devoice /bdg/ less than female speakers (Δ=3.17%, χ^2=254.05, df=1, p<0.0001), and the difference is larger than that between female and male voicing rates. These results suggest that there may be hypercorrection to avoid intervocalic voicing in Portuguese.

4. Conclusion and Discussion

In this paper, we analyze more than 1000h of speech in five Romance languages to investigate the realization of the laryngeal feature in almost 3 million stops in intervocalic position. This context was chosen because it allows to establish whether the voicing of voiceless stops is a phonetic phenomenon, resulting from undershoot, or already a phonological phenomenon, that takes morphological boundaries into account.

Our results show that there is intervocalic voicing in all positions in the word in all languages, and male speakers voice more than female speakers. It is however counterbalanced by some instances of devoicing that bring us to conclude that intervocalic voicing is stronger in word-internal position in Portuguese only, a language where consonants at word edges tend to devoice. In Spanish, French, Italian and Romanian, word-initial and word-medial rates are similar, suggesting that voicing in these languages remains mere phonetic undershoot and cannot yet be considered lenition.

Future research should help us establish whether the behavior of word-initial onsets and word-final codas is similar to the one of their word-internal counterparts. In particular, since we have shown that Portuguese is prone to devoicing at word edges, we expect a similar, if not stronger effect in word-internal (VC.**C**V and V**C**.CV) position.

5. Acknowledgements

This research was partially supported by the DATAIA / MSH Paris-Saclay “Excellence” grant, as well as the Labex EFL.

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