Intervocalic lenition, contrastiveness and neutralization in Catalan

José-Ignacio Hualde
University of Illinois, Urbana-Champaign
jihualde@illinois.edu

Jennifer Zhang
University of Illinois, Urbana-Champaign
jz13@illinois.edu

Abstract

In this study we examine the effects of word boundaries on the lenition of intervocalic voiceless plosives in Catalan in order to test the role of phonological contrastiveness in phonetic processes. Here we test the hypothesis that word-final intervocalic voiceless plosives (VC#V) will show greater lenition than word-internal and word-initial intervocalic tokens (VCV, V#CV), since in word-final position the contrast between /ptk/ and /bdg/ is neutralized. Lenition should be manifested acoustically as greater intensity, shorter duration and greater voicing. We find weaker support for the hypothesis than in a parallel study on Basque, suggesting the existence of phonological differences between

the two languages. On the other hand, we find a strong effect of style on intervocalic lenition, with conversational speech promoting more lenited consonants. Intervocalic stop lenition in Catalan does not appear to be driven by temporal reduction.

Keywords: Catalan, intervocalic lenition, word-final neutralization.

1. Introduction

Consonant phonemes often show weaker articulations in specific phonological contexts. Diachronically this may give rise to lenitive sound changes, and synchronically it may be manifested in conventionalized patterns of allophony. A famous example of this type of diachronic evolution is the lenition of intervocalic stops in Western Romance languages (e.g., Lat. *sapēre* > Fr. *savoir*); and a well-known example of synchronic allophony is the systematic spirantization (approximantization) of the voiced plosives /b d g/ in intervocalic and in some postconsonantal contexts in both Spanish and Catalan. Given its systematicity, the latter process, which Mascaró (1991) referred to as "Iberian Spirantization" (as it is also found in Basque, Galician and Northern Portuguese), is often formulated as a categorical phonological rule (Harris 1969, etc.).

Analogous patterns of weakening have also been described at the level of phonetic variation. In particular, in Spanish and Catalan, the voicing lenition of the intervocalic voiceless plosives /p t k/ has been described as a much more variable phenomenon than the spirantization of /b d g/. Although this is not a systematic process, it is of some interest for phonologists, especially because it could potentially lead to the loss of the contrasts between the two phonological series in intervocalic position (O'Neill 2010, Hualde, Simonet & Nadeu 2011). In spite of important differences in the systematicity of the lenition process, both /p t k/ and /b d g/ show substantial variation in the degree to which they are lenited, as manifested acoustically in their duration, intensity and, in the case of the underlyingly voiceless series, their partial or complete voicing (for articulatory data, see Hualde, Shosted & Scarpace 2011, Parrell 2014). Some work over the last two decades or so has been concerned with investigating the factors that may condition this variation, such as the position of the consonant in the word, speech style and speech rate, position of the word-stress and the height of preceding and/or following vowels, in addition to possible interactions between the place of articulation of the plosive and vowel quality (Cole, Hualde & Iskarous 1999, Lewis 2001, , Ortega-Llebaria 2004, Colantoni & Marinescu 2010, Eddington 2011, Carrasco, Hualde & Simonet 2012, Simonet, Hualde & Nadeu 2012, Recasens 2017, Rogers & Mirisis 2018, Tetzloff 2020, Melero-García 2021, among others; see also Torreira & Ernestus 2011, where Spanish and French are compared).

An interesting question that arises is whether potentially conditioning factors on lenition may also be of a phonological nature, having to do with the organization of the system of phonological contrasts and also, perhaps, with the presence versus absence of contrasts in specific positions. Relevantly, Rafel (1976) remarks that in those dialects of Catalan that have an independent phoneme /v/, such as Majorcan, the labial plosive /b/ is realized as a stop in contexts where, in other Catalan varieties, it is systematically realized with incomplete occlusion (see also Recasens 1991). Hualde,

Nadeu and Simonet (2010) find support for this description, based on acoustic measurements of energy in intervocalic /p t k b d g v/ in Majorcan Catalan. The facts are consistent with the predictions that follow from the operation of contrast preservation between phonemes as a constraint on lenition (Recasens 1991, Wheeler 2005), although Hualde, Nadeu and Simonet (2010) explore other possible explanations. Ortega-Llebaria (2004) also attributes the greater intervocalic lenition of /b/ in Spanish than in English to the fact that in Spanish there is no phonemic contrast with /v/.

Eager (2017) also finds support for system-related conditioning of lenition in Spanish. Eager compares the realization of intervocalic voiced and voiceless stops in three Spanish varieties (Cuzco, Peru; Lima, Peru; and Valladolid, Spain) and finds that the degree to which the consonants in one of the series is weakened correlates with the weakening of the other series, both at the level of the speech community and at the level of the individual speaker. Eager's (2017) results, showing interrelations between phonemes, are compatible with those of Chodroff and Wilson (2017) who find covariation between plosives in VOT for individual speakers in American English.

Regarding other obstruents, Hualde and Prieto (2014), using data from Map Tasks, find that intervocalic /s/ is weaker in Madrid Spanish than in Catalan, having a shorter duration and a greater propensity to voice, which could be related to the existence of a phonemic contrast /s/-/z/ in Catalan but not in Spanish.

The question that we want to ask here is whether the presence of a phonemic contrast in a given position, versus its absence in another position, may also condition lenition. For instance, in a language that has a contrast between two phonemes /p/ and /b/ which is neutralized in certain contexts, the phoneme /p/ may undergo less voicing lenition in those positions where it contrasts with /b/ than in other contexts where it does not. Catalan presents a distribution of voiced and voiceless plosives that allows us to test this hypothesis. In Catalan, like in all other Romance languages, there is a contrast between voiced and voiceless plosives in syllable-initial position, both word-initially and word-medially, as shown with examples in (1):

(1)   *pala* /palə/ 'spade' vs *bala* /balə/ 'bullet'   (Catalan)
        capa /kapə/ 'cape' vs *cava* /kabə/ 'cave'

This contrast, however, is neutralized word-finally in favor of the voiceless series. This positional neutralization gives rise to numerous morphophonological alternations, as in the examples in (2a), where word-final voiced stops are replaced by their voiced counterparts word-medially. In other examples, like those in (2b), on the other hand, the morpheme-final plosive is voiceless also when word-medial, showing that the alternations in (2a) are due to word-final devoicing (rather than word-medial voicing):

(2)   a.   *sap*   's/he knows'   *sabem*   'we know'   (Catalan)
              llop   'he-wolf'   *lloba*   'she-wolf'
              cantat   'sung, M.SG'   *cantada*   'sung, F.SG'
              amic   'friend, M.SG'   *amiga*   'friend, F.SG'

b.	*tip*	'full, M.SG'	*tipa*	'full, F.SG'
	gat	'cat, M.SG'	*gata*	'cat, F.SG'
	ric	'rich, M.SG'	*rica*	'rich, F.SG'

Word-final stops, thus, do not contrast in voice in Catalan. Whereas phonemically they are described as belonging to the voiceless series /p t k/, their realization as voiced or voiceless has been described as being context-dependent (Bonet & Lloret 1998, Wheeler 2005). Before a pause or a vowel-initial word, only voiceless plosives are said to be found, as in (3a, b). Before a consonant-initial word, on the other hand, word-final consonants assimilate in voice to the following consonant, being realized as voiced if the following consonant is voiced, as in (3c) (and as voiceless before voiceless consonants):

(3)   Word-final stops in Catalan
  a.   *sap*   [sap]   's/he knows'
  b.   *sap anar-hi*   [sapənaɾi]   's/he knows how to go there'
  c.   *sap vendre*   [sabbendrə]   's/he knows how to sell'
                                        (Bonet & Lloret 1998: 123)

In some Southern Valencian dialects, word-final plosives are also voiced (and spirantized) before a vowel (Jiménez & Lloret 2016), e.g. *m'ha impressiona<u>t</u>* [t] 'it has impressed me' but *m'ha impressiona<u>t</u>* [ð] *a mi* (same meaning). This pattern of intervocalic voicing of word-final plosives has not been described in phonological descriptions of the Central Catalan dialect that we investigate here. Nevertheless, Hualde and Nadeu (2020) report that 19% of tokens of word-final stops in VC#V were realized as fully voiced in a study of read speech in Central Catalan.

For Basque, where the voiced/voiceless contrast in plosives is also neutralized in favor of the voiceless series, as in Catalan, Hualde, Beristain, Icardo Isasa and Zhang (2019) found significantly weaker realizations of /t k/ in VC#V (which is the context of neutralization) than in V#CV or VCV, with data from conversational speech (labial plosives are not found word-finally in Basque). Furthermore, they found that 16% of word-final intervocalic tokens of /t/ and 32% of tokens of word-final /k/ were produced as fully voiced, whereas the rate of voicing of these segments was much lower in the other two intervocalic contexts. A more lenited articulation of stops in VC#V than in VCV and V#CV in Basque is consistent with the absence of a contrast between voiced and voiceless stops in word-final position. This is not, however, the only possible explanation, since it is not possible to separate the effect of phonological neutralization from the effect of position in the word (i.e., word-final position could induce greater weakening also in the absence of phonological neutralization).

A difference between Basque and Catalan is that, whereas in Catalan alternations like those in (2a) are common, in Basque they are marginal; in fact, they are essentially restricted to the 1.SG agreement marker, as in *dakit* 'I know', *dakid-ala* 'that I know' (vs *bat* 'one', *batean* 'in one').

As mentioned, Hualde and Prieto (2014) found that /s/ was weaker in their Castilian Spanish corpus than in their comparable Central Catalan corpus, which is consistent with the presence of a contrastive phoneme /z/ in Catalan and its absence in Spanish. These authors also report that, in their corpus, Castilian /s/ is weaker in Vs#V

than in VsV and V#sV. These results were replicated by Strycharczuk and Kohlberger (2016), with read speech. The explanation could thus be a difference in the CV coarticulatory patterns of sibilants that may obtain across word boundaries, in C#V, as compared with CV sequences within a single lexical item, as suggested by Hualde and Prieto (2014). In some studies, but not all, a difference has also been found between word-initial and word-medial consonants (see also Garcia 2015), suggesting additional motivations for positionally-conditioned differences in strength. In Hualde et al.'s (2019) study of Basque /t k/, a strength hierarchy V#CV >> VCV >> VC#V was in fact found, with word-initial consonants being the strongest and word-final consonants the weakest.

Torreira and Ernestus (2011) found a robust difference in strength between word-initial and word-medial voiceless stops in French, but much weaker effects in Spanish. These authors suggest that in French, but not in Spanish, word-initial consonant strengthening may be used to indicate word boundaries. Hualde, Simonet and Nadeu (2011) only found very small differences in Spanish related to word position. Carrasco, Hualde, and Simonet (2012) found word-initial voiced plosives to be more lenited than medial ones in Costa Rica Spanish, but not in Madrid Spanish. Broś, Żigis, Sikorski and Wołłejko (2021) also found somewhat inconsistent differences between word-initial and word-medial consonants in Gran Canaria Spanish.

Regarding Catalan, Hualde and Prieto (2014) confirmed the traditional view that the neutralization of /s/ and /z/ in word-final position in Catalan results in realizations of /s/ that fall within the range of /z/ in the Vs#V context. Notice that the patterns of phonological neutralization in word-final prevocalic position are different for fricatives and plosives in Catalan. In particular, whereas word-final plosives are neutralized in favor of the voiceless categories, word-final fricatives are said to be systematically voiced before a vowel, as in e.g. *més aigua* /z/ 'more water', *mateix amic* /ʒ/ 'same friend'. For the Central Catalan post-alveolar fricative /ʒ/ between two vowels, Hualde, Eager and Nadeu (2015) did not find an effect of word boundaries; that is, they report that the contexts /VʒV/ (as in *pluja* 'rain'), /V#ʒV/ (as in *la jove* 'the young woman'), and /Vʒ#V/ (as in *mateix amic* 'same friend') do not differ in the degree of constriction of the post-alveolar consonant. In other words, this study did not find an effect of phonological contrast versus neutralization.

Again, an important difference between word-final stops vs fricatives in Central Catalan is that before a vowel, stops are phonologically voiceless and fricatives are phonologically voiced. Summarizing, thus, this line of investigation on the effects of neutralization and word position on phonetic realization so far has produced the result that when word-final obstruents in VC#V have been analyzed as phonologically voiceless, they show greater reduction than other intervocalic instances of the same phoneme. This is what Hualde et al. (2019) found for Basque /t k/. Some effect in this direction has also been reported for /s/ in Spanish, although in this case one cannot speak of a phonological contrast being suspended in word-final position.

On the other hand, when word-final obstruents have been phonologically described as voiceless before a pause, but voiced before a vowel, as in the case of the Catalan alveolar and post-alveolar fricatives, no word-position-dependent pattern of reduction has been identified.

In the experiment reported in this paper, we further test the effect of phonological neutralization and word boundaries on the lenition of intervocalic

consonants in Catalan. In section 2, we formulate our research hypotheses and describe our experimental methods. The results are presented in section 3. Finally, the results are interpreted and discussed in section 4.

2. Research Hypotheses and methods

Here we are concerned with the possible effect of word boundaries on the lenition of intervocalic /p t k/ in Catalan as this relates to neutralization patterns. The hypothesis that we investigate is that word-final plosives before a vowel, VC#V, will show greater weakening than other intervocalic consonants, be they word-medial, VCV, or word-initial, V#CV. The reason for stating this hypothesis is that, in word-final position, the contrast between the voiced and the voiceless series is neutralized, so that maintenance of contrast would not play a role in constraining the lenition in this position. Support for this hypothesis was found by Hualde et al. (2019) based on a study of the realization of voiceless plosives in a corpus of Basque conversational data. As already mentioned, Basque, like Catalan, has a rule of word-final neutralization between voiced and voiceless plosives, in addition to sharing the "Iberian Spirantization" process (Mascaró 1991).

We note that the phonology of Basque and Catalan does not allow us to distinguish between word-finality and neutralization of contrast as separate factors.[1] Similarly, we are not including word stress in our analysis because Catalan words ending with a stop are overwhelmingly stressed on their last syllable.[2]

As explained immediately below in the Methods section, our Catalan corpus contains speech in two different styles. A second conditioning factor on lenition that we investigate here is speech style. The hypothesis is that there will be more lenition in conversational style than in fully-scripted read speech (see Lewis 2001, Hualde, Simonet & Nadeu 2011).

We define lenition as a reduction in consonantal gestures (including both supralaryngeal and laryngeal gestures). Acoustically, a reduction in the consonantal gesture of a voiceless plosive should be manifested in greater intensity, shorter duration and more voicing.

2.1. Methods
For this study we have analyzed data from the Catalan section of the *Glissando* corpus (Garrido et al. 2003). In particular, we have chosen two subcorpora: News (prosodic) and Task-based Dialogs. The News subcorpus consists of speech by professional radio announcers and advertising professionals instructed to read a news report as if they were on the air. This style of very fluent reading can perhaps be considered as intermediate between laboratory speech and unscripted speech. The Task-based Dialogs contain guided conversations between two speakers on a topic that is provided to them, where one speaker assumes the role of someone seeking information and the other one takes up the role of information provider, e.g., a customer of a travel agency

---

[1] The two effects could perhaps be separated in a comparative study of English (which does not have word-final neutralization) and German (which does).

[2] A reviewer suggests comparing alternating consonants (as in *llop, lloba*) with non-alternating ones (as in *tip, tipa*). Since we did not plan to examine this factor and did not develop a hypothesis beforehand, we leave this comparison for future research.

and the travel agent. In the Catalan Prosodic News subcorpus, we have analyzed the data from eight speakers (four female, four male). From the Task-based Dialogs, we have analyzed the speech of eight speakers (two female, two male) who also participated in the News reading. That is, for four speakers we have analyzed speech in both styles. The total number of tokens of /p t k/ analyzed for this study is 4875, distributed as shown in Table 1 (fc = word-final before a consonant, fv = word-final before a vowel, i = word-initial, m = word-medial). Word-final preconsonantal tokens (fc) were extracted for the sake of completeness (i.e., to get an initial impression of overall variation in word-final position), but they are not included in the statistical analysis, since the hypothesis that we investigate concerns only consonant tokens between two vowels. In the Glissando Praat TextGrids pauses are indicated. Word-final consonant tokens where a pause intervened before the next word were excluded.

Table 1. Distribution of observations of /p t k/ by context

	Number of observations: 4875			
	fc (VC#CV)	fv (VC#V)	i (V#CV)	m (VCV)
k	58	40	975	875
p	37	28	657	309
t	428	248	471	749

Although the Glissando corpus contains transcriptions of the audio recordings, the alignment between sound signal and text was performed automatically and was not hand-corrected. The first step in using this corpus for linguistic analysis thus involves checking the alignment for accuracy. After doing this, we created two tiers in the Praat TextGrids. On one tier, we segmented CV intervals by placing one boundary towards the beginning of the consonant to include the intensity minimum of the consonant and placing the other boundary after the intensity maximum in the following vowel. We used these intervals to calculate the difference in intensity in the CV sequence (in the case of word-final preconsonantal tokens the entire C#CV sequence was segmented). This was done automatically with a script that extracted the intensity minimum and maximum in each labeled interval. Examples of this measure of intensity difference are shown in Figure 1.

Figure 1. Examples of measures of intensity for the less lenited C#VC sequence *tot i* (left) and the more lenited VCV sequence in *petició* (right)
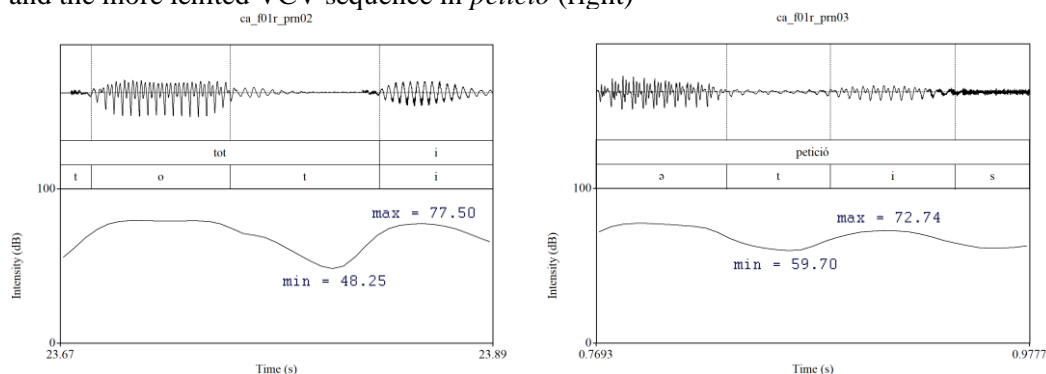
Measurements of intensity calculated as either a difference or a ratio between maximum and minimum value in a CV or VCV interval have been used in previous work on stop lenition in Spanish and other languages (Cole, Hualde & Iskarous 1999, Lewis 2001, Ortega-Llebaria 2004, Hualde, Simonet & Nadeu 2011, etc.). The reasoning is that a more lenited consonant is more vowel-like; this should result in greater aperture and, therefore, a smaller difference in intensity with respect to a following (or preceding) vowel. In some work using this methodology, a filter above a certain value in Hz is applied in order to separate energy due to voicing during the consonant from supralaryngeal energy. In the present study we have not filtered the energy, since we consider that the voicing of the consonant is an aspect of the lenition process that we are concerned with. That is, in Catalan the lenition of intervocalic /p t k/ involves their voicing and approximantization, unlike in other lenition paths where /p t k/ become voiceless fricatives or are debuccalized (Hock 1991: 80-86). In examining the lenition of voiced plosives (e.g., /b/ > [β]) it is sensible to exclude energy related to voicing; in the lenition of voiceless plosives that we are examining, however, voicing of the consonant is an integral part of the phenomenon (e.g., /p/ > [b] > [β]).

In some other work, it has been proposed to take the intensity of the consonant, without comparing it to that of flanking vowels as an index of lenition (Bouavichith & Davidson 2013). Here we also examine the results obtained by using the minimum intensity value during the consonant.

In addition, we have taken a third measurement from the intensity curve. Approximants differ from plosives in having a less abrupt transition into a following vowel. Kingston (2008) thus proposes using a measurement of the abruptness in the energy curve in CV (maximum velocity) to quantify lenition. In Hualde, Simonet and Nadeu (2011), the lenition of intervocalic /p t k/ in Spanish was analyzed by taking measurements of intensity difference in CV, intensity ratio, and maximum velocity in the same window, and highly correlated results were obtained with all methods. More recently Ennever, Meakins and Round (2017) have proposed using a unified methodology for quantifying lenition based on a calculation of maximum energy velocity (using an energy window between 400 Hz and 1200 Hz) that only requires placing a boundary towards the beginning of the consonant. We have also used the script that Ennever et al. (2017) provide for this calculation. The algorithm included in the script finds the moment of maximum intensity velocity after the manually-placed boundary. This script returns a calculation of the magnitude of change of intensity (delta_i) measured from the beginning of the consonant. A greater delta_i value indicates less lenition. The Ennever et al. (2017) script also provides an estimation of consonant gesture duration.

Regarding voicing, obtained from the voice report in Praat, we are primarily interested in the number of tokens where the consonant is fully voiced, as in these cases the intended phonological gesture score may not include a vocal fold abduction gesture (Browman & Goldstein 1992).

3. Results

3.1. Intensity

The boxplots in Figure 2 (obtained with the package ggplot2 (Wickham 2016) in RStudio (R Core Team 2021, R Studio Team 2021)) show intensity difference in CV (IntDiff) by Style (News reading or Task dialog) and Context (fc, fv, i, m). Something that is immediately clear from a visual inspection of the data is that Style has a much greater effect on IntDiff than Context. This effect is in the expected direction: IntDiff values are higher in the News style, indicating a more constricted realization of /p t k/ than in the Task dialog style. In Figure 3, we show the effect of Style for each of the four speakers for which we have data in both styles. As can be seen, the effect is present for all four speakers, although the magnitude of the effect appears to be greater for some speakers than for others.

Figure 2. IntDiff (in dB) by context
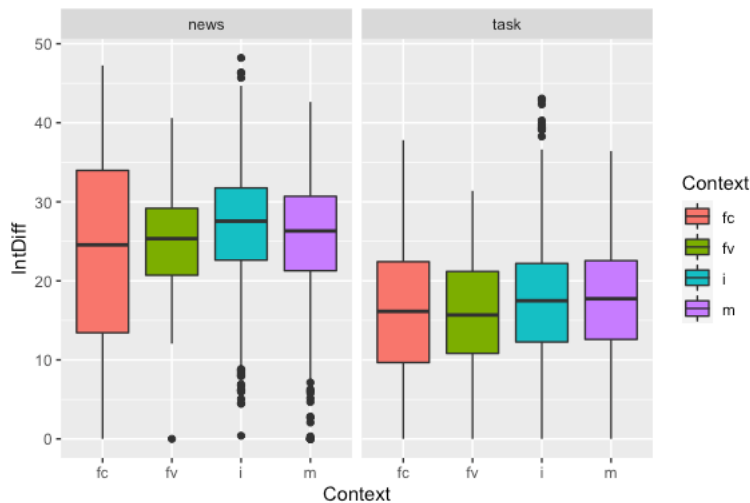
Figure 3. Effect of style on IntDiff (dB) for individual speakers (excluding preconsonantal tokens). In each panel: News reading (left box), Task dialog (right box)
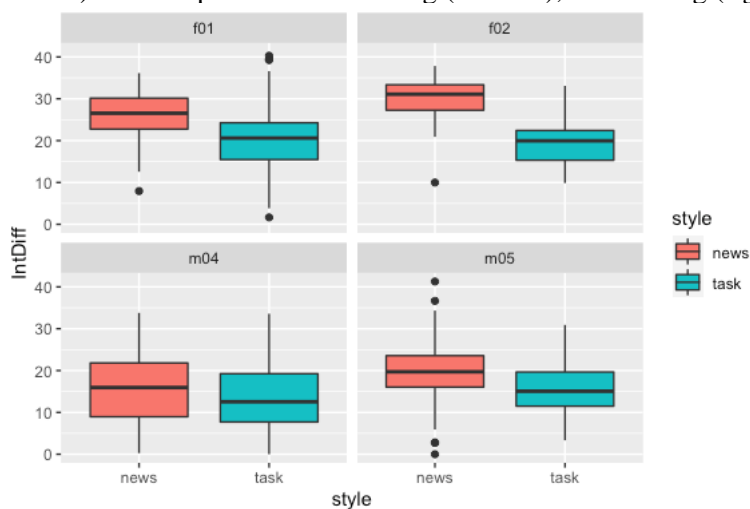
A second observation that we can make from Figure 2 is that in the word-final pre-consonantal context (fc) there is greater variability than in the two other contexts,

especially in the News style. It seems reasonable to attribute this to different following consonants having different effects on the realization of word-final consonants in C#C; that is, as mentioned before, we expect word-final consonants to be systematically voiced before voiced consonants and to be voiceless before voiceless consonants, with concomitant effects on degree of constriction. Comparing across the three intervocalic contexts (fv, i, m) in Figure 2, IntDiff values appear to be somewhat lower for word-final intervocalic consonants (fv) than for word-initial postvocalic consonants, which is consistent with our hypothesis. However, the difference between the VC#V (fv) and VCV (m) contexts is less obvious visually.

To determine statistical difference, we ran a mixed-effects regression analysis on IntDiff, using the packages *lm4* (Bates, Maechler, Bolker & Walker 2015) and *lmerTest* (Kuznetsova, Brockhoff & Christensen 2017) in R. The regression, which excluded pre-consonantal tokens (fc), had the structure in (4):

(4)   Linear mixed-effects regression on IntDiff:
       IntDiff ~ Context + Style+ (1|Speaker) + (1|Word)

This regression returned a significant effect of Style, with the Task style conditioning lower IntDiff values than the News style (Est. = -6.4, t = -22.4, $p < 0.0001$). Regarding Context, word-initial consonants have higher IntDiff values than word-final ones (Est = 1.86, t = 4.3, p < 0.0001), and a smaller significant different was also found in the comparison between word-final and word-medial consonants (Est. = 1.05, t = 2.5, $p < 0.05$). Since our research hypothesis concerns possible differences between contexts with and without neutralization of contrasts, the word-final context is the one with which the other two are compared in the regression, which precludes comparing the word-initial and the word-medial contexts with each other.

A regression on the intensity minimum during the consonant, with the same fixed and random factor structure as in (4), returned similar results: tokens produced in the Task style have higher intensity minima (i.e., are more lenited) than tokens in News style (Est. = 2.9, t = 10.7, $p < 0.0001$). Regarding word position, word-final consonants have higher minima than word-initial consonants (Est. = -1.5, t = -3.78, $p < 0.0001$), and than word-medial consonants (Est. = -0.7, t = -1.95, $p < 0.1$). A calculation of intensity difference in CV without filtering out low-frequency energy and the calculation of the intensity minimum during the consonant thus seem to be largely equivalent measurements. The two measurements are strongly correlated (r = -0.818), using Pearson's correlation.

Finally, a regression on the delta_i values using the Ennever et al. (2017) script, also with the same structure as in (4), returned a significant effect of Style (Est. = 3.06, t = 10.6, $p < 0.0001$) and, also a significant effect, but of a smaller magnitude, for the comparison across contexts between word-final and word-medial consonants (Est. = 1.02, t = 2.4, $p < 0.05$), but not for the comparison between word-final and word-initial consonants. As mentioned, this calculation focuses on the abruptness of the transition between consonant and vowel. It should be noticed that the delta_i script fails to return values for highly lenited tokens, which results in some data being excluded. Whereas the IntDiff and IntMin regressions include 4352 observations, the delta_i regression analysis includes only 4215 observations. Delta_i is only moderately correlated with our two other measurements, delta_i – Int Diff, r = -0.610; delta_i – IntMin, r = 0.567. This is not too surprising, since unfiltered IntDiff and

IntMin include low frequency energy from voicing, which is excluded in the delta_i calculation.

To summarize, all three measurements from the intensity curve detect an important effect of Style in the strength of the consonants. Effects due to word-position are much smaller and present only for one comparison in the delta_i analysis.

To get a better sense of the amount of intervocalic lenition for the voiceless series in our corpus (i.e., to explore whether the lenition of voiceless stops may produce neutralization with the voiced series), we have also analyzed 283 tokens of intervocalic /d/ in the Task-based dialogs from two of the speakers, f01 and f02, and have compared them with all tokens of /t/ in our corpus (the dentals were chosen because they are more frequent in the corpus than the labials and velars). As shown in Figure 4, although according to the IntDiff measurement the realization of intervocalic /t/ clearly differs according to style, there is very little overlap between phonemic /t/ and phonemic /d/. Even though /t/ is substantially weaker in the Task style than in the News style, it is still stronger (i.e., has greater IntDiff) than phonemic /d/.

Figure 4. IntDiff (in dB) for /t/ and /d/. Data from two speakers (f01, f02). /d/ = 283, /t/-news = 788 /t/-task = 1108
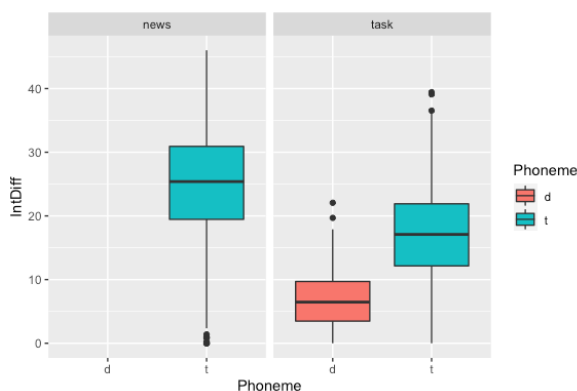

3.2. Duration

We have extracted duration values from the Ennever et al. (2017) script, which estimates the beginning and end of consonantal gestures based on changes in intensity. Differences in duration across contexts and across styles are very small, of only one or two milliseconds in the means, as shown in Table 2, where means, standard deviations and medians are offered. The distribution of consonant durations by Style and Context is shown in Figure 5.

The correlation between duration and delta_i is relatively strong (r = -0.7537), much higher than the correlation between duration and IntDiff (r = 0.4604) or IntMin (r = -0.5314), which is similar to the values obtained by Hualde, Simonet and Nadeu (2011: 310).

Table 2. Duration in ms.

	mean	s.d.	median
Word-final (VC#V)	69.40	16.7	66
Word-initial (V#CV)	70.69	19.1	68
Word-medial (VCV)	68.33	15.5	66
News	70.97	15.9	69
Task-based dialogs	68.43	18.5	65

Given the negligeable differences in the duration means across contexts and styles that we find, we may conclude that duration decrease does not appear to be driving the lenition of /p t k/ in our Catalan corpus, similar to the results from Broś et al. (2021) for Canary Island Spanish and unlike what has been found for other languages (see Ennever et al. 2017, Katz & Pitzanti 2019, Cohen Priva & Gleason 2020).

Figure 5. Duration (in seconds) of tokens in each context, separated by style
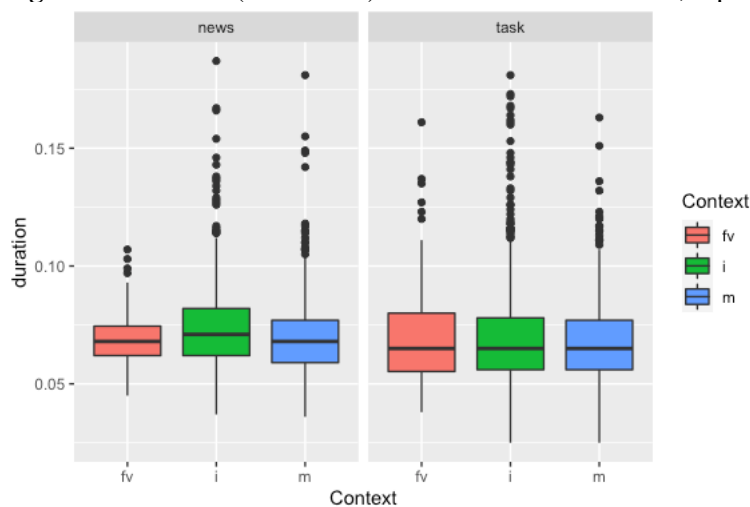
3.3. Voicing

From the CV intervals that we used to measure IntDiff, we have extracted the percentage of the interval that is voiced, using the voice report in Praat. The results are shown with density plots in Figure 6, where preconsonantal word-final tokens are also included. For these VC#CV tokens, we expected a bimodal distribution, corresponding to the nature of the second consonant, and this is what we see in the figure. But notice that in all contexts as well, there is a bimodal distribution with a peak at 100% voicing, meaning that the entire CV interval was produced with voicing. Since the interval where voicing was measured for intervocalic tokens includes the consonant and (part of) the following vowel, we could in principle expect a unimodal distribution reflecting the amount of the duration of the consonant that was voiced. This is, however, not

what we find. Fully voiced tokens stand apart from tokens with partial voicing, reflecting a different underlying mechanism. We are particularly interested in tokens that are fully voiced, as these seem to indicate that there is no vocal-fold abduction gesture (in Articulatory Phonology terms, see Browman & Goldstein 1992).

Figure 6. Density plots of voicing
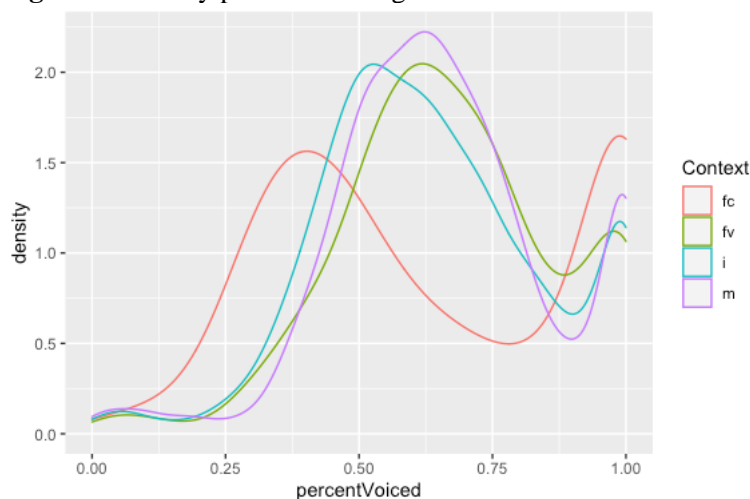
Excluding now preconsonantal tokens, in Table 3 we show the distribution of fully voiced tokens of /p t k/ by Context and Style. The effect of Style is also shown in the histograms in Figure 7. As can be seen in Table 3, the effect of Context is of negligeable magnitude. The context with the highest percentage of fully voiced tokens is the word-final prevocalic one and the one with the lowest percentage is the word-initial one, but the difference in number of tokens that are fully voiced is only about 2%. On the other hand, the effect of Style is much greater, with a much larger percentage of tokens being realized as fully voiced in the Task-based dialogs than in the News reading.

Table 3. Fully voiced tokens.

	All tokens	Fully voiced	Percentage fully voiced
Word-final (VC#V)	316	34	10.7% (34/316)
Word-initial (V#CV)	2103	179	8.5% (179/2013)
Word-medial (VCV)	1933	188	9.7% (188/1933)
News	2479	333	13.4% (333/2479)
Task-based dialogs	1873	68	3.6% (68/1873)

Figure 7. Histograms of fully voiced tokens.
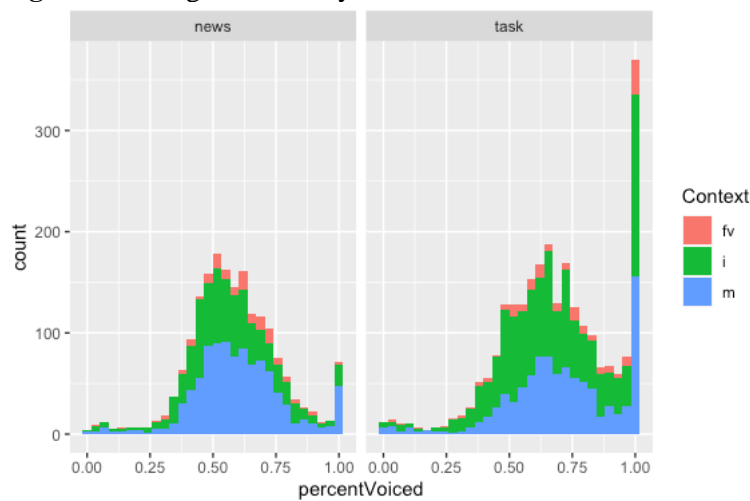
4. Discussion and Conclusions

Our analysis has revealed a strong effect of speaking style on the realization of intervocalic /p t k/ in our Central Catalan corpus. These consonants are significantly weaker in the guided conversation style, compared to the news reading style, according to the three intensity measurements that we have considered (IntDiff, IntMin and delta_i). In addition, they show a much greater propensity to be realized as fully voiced. Voicing and approximantization do not appear to be driven primarily by shortening in Catalan, since differences in consonant duration across styles are very small.

Regarding our main research question, we have found only weak evidence for the hypothesis that word-final voiceless plosives in VC#V are more lenited than other instances of /p t k/ in intervocalic position, using intensity, duration and voicing as correlates of lenition. In our regression analyses, our measurements based on the energy curve returned significant differences between VC#V and at least one of the other two intervocalic contexts, but the magnitude of the context-related differences are very small, much smaller than those conditioned by style. Differences in duration are also very small, and tokens are realized as fully voiced with very similar frequency in all three intervocalic contexts VCV, V#CV and VC#V.

The results that we have obtained regarding context are, thus, different for those reported for Azpeitia Basque by Hualde, Beristain, Icardo Isasa and Zhang (2019), which provided justification for our hypothesis. In that study, /t/ and /k/ (the only plosives that are found word-finally in Basque) were shown to be significantly more lenited in VC#V than in V#CV and VCV. A possible interpretation of this difference is that the two languages differ in the phonology of word-final consonants. Arguably, in Basque, word-final plosives are unspecified for voicing: /D G/ (see also Hualde, Beristain, Icardo Isasa and Zhang 2019 [2021] for consonant clusters across word boundaries). In Central Catalan, on the other hand, phonologically we have word-final /p t k/ (morphophonologically there is a voicing contrast, as shown in (2) above), which undergo different amounts of lenition when placed in intervocalic position within the phrase. The phonology of Southern Valencian Catalan may also differ from Central Catalan in this respect (Jiménez & Lloret 2016).

There is also a difference in the type of speech analyzed in this study and in Hualde 2019, 2021). In this paper, we have analyzed a corpus of Catalan speech produced by speech professionals, including news reporters and advertisement professionals. In Hualde et al. (2019, 2021) the Basque speech that was analyzed was free conversation produced by regular speakers of the language without any special training. Professional speakers can be expected to have more careful diction, perhaps even when engaging in conversation. Nevertheless, there is no expectation that this effect would interact with the position of consonants in words. The difference in the magnitude of the word-position effect that we find between the two studies is thus more likely to be due to a phonological difference between Basque and Central Catalan in the nature of word-final plosives.

In this respect, it is also interesting to compare the results of this study with those of Hualde and Eager (2016), which is based on the analysis of the (Valladolid) Castilian Spanish part of the Glissando corpus. In Spanish, the only word-final plosive that is found with any frequency is /d/. Hualde and Eager (2016) report that, before pause, this consonant is usually deleted or realized as the voiceless fricative [θ], phonetically identical to the independent phoneme /θ/, with only 9% of the tokens being realized as stops and only 2% as approximants. In the VC#V context, about 38% of the tokens were elided, 46% were voiceless fricatives, 15% voiced approximants and 2% voiced stops. What the authors propose, both as a diachronic evolution and as a synchronic analysis, is that word-final /d/ systematically reduces to [ð], which undergoes one of two additional transformations, with different frequency depending on the specific lexical item: deletion (e.g., *verdad* /beɾdád/ > [beɾðáð] > [beɾðá] 'truth') or devoicing and neutralization with the interdental fricative (e.g., *abad* /abád/ > [aβáð] > [aβáθ] 'abbot').

In contrast, for the Spanish spoken in Catalonia (including both Catalan-dominant and Spanish-dominant speakers), Hualde and Nadeu (2020) report that 78% of tokens of orthographic *-d* were realized as voiceless stops, that is, as in accordance with the Catalan pattern. It is clear, thus, that we find different final-neutralization rules in different languages and geographical dialects of the same language, resulting in different phonetic effects.

To summarize, the results obtained from our acoustic analysis are consistent with the standard view that in Central Catalan the neutralization of the /p t k/ and /b d g/ series in word-final position produces a single series that is phonologically voiceless. These consonants can be lenited when followed by a vowel, that is, in the VC#V context, but not to a substantially greater effect than intervocalic instances of /p t k/ that are not word-final. We have pointed out that our acoustic analysis has revealed a lenition pattern that is quite different from the one reported for Basque in a recent study where the same methodology was used as in the present paper. We have suggested that this phonetic difference has phonological roots: Even though both languages have a process of final neutralization of the two oral stop series, the phonological outcome of the neutralization is different in each of them.

Acknowledgments

References

Bates, Douglas, Maechler, Martin, Bolker, Ben, & Steve Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1): 1-48. http://dx.doi.org/10.18637/jss.v067.i01

Bonet, Eulàlia & Maria-Rosa Lloret. 1998. *Fonologia catalana*. Barcelona: Ariel. https://doi.org/10.1484/j.rph.2.304489

Bouavichith, Dominique & Lisa Davidson. 2013. Segmental and prosodic effects on intervocalic voiced stop reduction in connected speech. *Phonetica* 70, 182–206. https://doi.org/10.1159/000355635

Broś, Karolina, Żygis, Marzena, Sikorski, Adam & Jan Wołłejko. 2021. Phonological contrasts and gradient effects in ongoing lenition in the Spanish of Gran Canaria. *Phonology* 38(1): 1-40. https://doi.org/10.1017/S0952675721000038

Browman, Catherine & Louis Goldstein. 1992. Articulatory Phonology: An overview. *Phonetica* 49(3-4): 155-180. https://doi.org/10.1159/000261913

Carrasco, Patricio, Hualde, José Ignacio, & Miquel Simonet. 2012. Dialectal differences in Spanish voiced obstruent allophony: Costa Rican vs. Iberian Spanish. *Phonetica* 69: 149–179. https://doi.org/10.1159/000345199

Chodroff, Eleanor & Colin Wilson. 2017. Structure in talker-specific phonetic realization: Covariation of stop consonant VOT in American English. *Journal of Phonetics* 61: 30–47. https://doi.org/10.1016/j.wocn.2017.01.001

Cohen Priva, Uriel & Emily Gleason. 2020. The causal structure of lenition. A case for the causal precedence of durational shortening. *Language* 96.2: 413-448. https://doi.org/10.1353/lan.2020.0025

Colantoni, Laura & Irina Marinescu. 2010. The scope of stop weakening in Argentine Spanish. In: Ortega-Llebaria, Marta (ed.), *Sel. Proc. 4th Conference on Laboratory Approaches to Spanish Phonology*, 100–114. http://www.lingref.com/cpp/lasp/4/paper2371.pdf

Cole, Jennifer, Hualde, José Ignacio, & Khalil Iskarous. 1999. Effects of prosodic and segmental context on /g/-lenition in Spanish. In: Fujimura, Osama, Joseph, Brian D. and Palek, B. (eds.),. *Proc 4th International Linguistics and Phonetics Conference*. Prague: The Karolinium Press 2: 575–589.

Eager, Christopher D. 2017. Contrast preservation and constraints on individual phonetic variation. PhD diss. Urbana-Champaign, IL: UIUC.
Eddington, David. 2011. What are the contextual phonetic variants of /β ɣ/ in colloquial Spanish? *Probus* 23, 1–19. https://doi.org/10.1515/prbs.2011.001

Ennever, Thomas, Meakins, Felicity, & Erich R. Round. 2017. A replicable acoustic measure of lenition and the nature of variability in Gurindji stops. *Laboratory Phonology*: 8(1), 20. http://doi.org/10.5334/labphon.18

Garcia, Christina. 2015. Gradience and Variability of Intervocalic /s/ Voicing in Highland Ecuadorian Spanish. Doctoral dissertation, Ohio State University. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=osu1437154659

Garrido, Juan María, Escudero, David, Aguilar, Lourdes, Cardeñoso, Valentín, Rodero, Emma, de-la-Mota, Carme, González, César, Vivaracho, Carlos, Rustullet, Sílvia, Larrea, Olatz, Laplaza, Yesika, Vizcaíno, Francisco, Estebas, Eva, Cabrera, Mercedes, & Antonio Bonafonte. 2013. Glissando: a corpus for multidisciplinary prosodic studies in Spanish and Catalan. *Language resources and evaluation* 47(4), 945-971. https://doi.org/10.1007/s10579-012-9213-0

Harris, James. 1969. *Spanish phonology*. Cambridge, Mass.: MIT.

Hock, Hans Henrich. 1991. *Principles of historical linguistics*, 2nd ed. Berlin: Mouton de Gruyter. https://doi.org/10.1515/9783110219135

Hualde, José Ignacio, Beristain, Ander, Icardo Isasa, Ana & Jennifer Zhang. 2019. Lenition of word-final plosives in Basque. In Calhoun, Sarah, Escudero, Paola, Tabain, Marija & Paul Warren (eds.) *Proc of the 19th ICPhS, Melbourne, Australia*, 642-646.

Hualde, José Ignacio, Beristain, Ander, Icardo Isasa, Ane, & Jennifer Zhang. 2021. Hitz-bukaerako herskariak: kontsonante talkak. *ASJU* 53 (1-2): 83-106. https://doi.org/10.1387/asju.22412

Hualde, José Ignacio & Christopher D. Eager. 2016. Final devoicing and deletion of /-d/ in Castilian Spanish. *Studies in Hispanic and Lusophone Linguistics* 9(2): 329–353. https://doi.org/10.1515/shll-2016-0014

Hualde, José Ignacio, Eager, Christopher D., & Marianna Nadeu. 2015. Catalan voiced prepalatals: Effects of nonphonetic factors on phonetic variation? *Journal of the International Phonetic Association* 45: 243-267. https://doi.org/10.1017/s0025100315000031

Hualde, José Ignacio & Marianna Nadeu. 2020. Oclusives finals en català i en castellà de Catalunya. In C. Gabriel, A. Peskova & M. Selig (eds.), *Contact, variation and change in Romance and beyond: Studies in honor of Trudel Meisenburg*, 23-38. Berlin: Erich Schmidt.

Hualde, José Ignacio, Nadeu, Marianna & Miquel Simonet. 2010. Lenition and phonemic contrast in Majorcan Catalan. In S. Colina, A. Olarrea & A. Carvalho (eds.) *Romance Linguistics 2009: Selected Papers from the 39th Linguistic Symposium on Romance Languages (LSRL) Tucson, Arizona, 26–28 March 2009*, 63-80. Amsterdam: Benjamins.

Hualde, José Ignacio & Pilar Prieto. 2014. Lenition of intervocalic fricatives in Catalan and Spanish. *Phonetica* 71: 109-117.

Hualde, José Ignacio, Shosted, Ryan, & Daniel Scarpace. 2011. Acoustics and articulation of Spanish /d/ spirantization. In W.-S. Lee and E. Zee (Eds.), *Proceedings of the ICPhS XVII,* 906-909. Hong Kong: City University of Hong Kong. http://icphs2011.hk.lt.cityu.edu.hk/resources/OnlineProceedings/RegularSession/Hualde/Hualde.pdf

Hualde, José Ignacio, Simonet, Miquel, & Marianna Nadeu. 2011. Consonant lenition and phonological recategorization. *Laboratory Phonology* 2: 301–329. https://doi.org/10.1515/labphon.2011.011

Jiménez, Jesús & Maria-Rosa Lloret. 2016. Paral.lelism vs serialisme en teoria de l'optimitat: interacció entre sonorització i espirantització. In Fernández Planas, ed., *53 reflexiones sobre aspectos de la fonética y otros temas de lingüística*, 59-66. Barcelona.

Katz, Jonah, & Gianmarco Pitzanti. 2019. The phonetics and phonology of lenition: A Campidanese Sardinian case study. *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, *10*(1): 16. http://doi.org/10.5334/labphon.184

Kingston, John. 2008. Lenition. In Laura Colantoni & Jeffrey Steele (eds.), *Selected proceedings of the 3rd conference on laboratory approaches to Spanish phonology*, 1–31. Somerville, MA.: Cascadilla Proceedings Project.

Kuznetsova, Alexandra, Brockhoff, Per B., & Rune H. B. Christensen. 2017. lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software* 82(13): 1-26. http://doi.org/10.18637/jss.v082.i13

Lewis, Anthony M. 2001. *Weakening of intervocalic /p, t, k/ in two Spanish dialects: Toward the quantification of lenition processes.* Doctoral dissertation. University of Illinois at Urbana-Champaign.

Mascaró, Joan. 1991. Iberian spirantization and continuant spreading. *Catalan Working Papers in Linguistics* 1, 167–179.

Melero-García, Fernando. 2021. Lenition of syllable-initial /p t k/ in a variety of Andalusian Spanish: Effects of linguistic factors and speech rate. *Estudios de Fonética Experimental* 30: 169-187.

O'Neill, Paul. 2010. Variación y cambio en las consonantes oclusivas del español de Andalucía. *Estudios de Fonética Experimental*, 19: 11-41.

Ortega-Llebaria, Marta. 2004. Interplay between phonetic and inventory constraints in the degree of spirantization of voiced stops: comparing intervocalic /b/ and

intervocalic /g/ in Spanish and English. In Face, T.L. (ed.) *Laboratory Approaches to Spanish Phonology*, 237–253. Berlin: Mouton de Gruyter, Berlin.

Parrell, Benjamins. 2014. *Dynamics of consonant reduction*. Doctoral dissertation. University of Southern California.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

RStudio Team. 2021. RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

Rafel, Joaquim. 1976. Fonologia diacrònica catalana: aspectes metodològics. *Problemes de llengua i literatura catalanes: Actes del II col.loqui internacional sobre el català*, 47-65. Montserrat: Publicacions de l'Abadia de Montserrat.

Recasens, Daniel. 1991. *Fonètica descriptiva del català (Assaig de caracterització de la pronúncia del vocalisme i consonantisme el català al segle XX)*. Barcelona: Institut d'Estudis Catalans.

Recasens, Daniel. 2017. The effect of contextual consonants on voiced stop lenition: Evidence from Catalan. *Language and Speech* 59(1): 139-161. https://doi.org/10.1177/0023830915581720

Rogers, Brandon M. A., & Mirisis, Christina A. 2018. Voiceless stop lenition and reduction as linguistic and social phenomena in Concepción, Chile. *Borealis: An International Journal of Hispanic Linguistics*, 7(2): 187-215.

Simonet, Miquel, Hualde, José Ignacio, & Marianna Nadeu. 2012. Lenition of /d/ in spontaneous Spanish and Catalan" *Proceedings of the 13th Annual Conference of the International Speech Communication Association (InterSpeech)*. Portland, Oregon. September 9-13, 2012. https://www.isca-speech.org/archive/archive_papers/interspeech_2012/i12_1416.pdf

Strycharczuk, Patrycja & Martin Kohlberger. 2016. Resyllabification Reconsidered: On the Durational Properties of Word-Final /s/ in Spanish. *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, 7(1), 3. http://doi.org/10.5334/labphon.5

Tetzloff, Katerina. 2020. On the gradient lenition of Spanish voiced obstruents: A look at onset clusters. *Studies in Hispanic and Lusophone Linguistics* 13(3): 419-449. https://doi.org/10.1515/shll-2020-2036/html

Torreira, Francisco & Mirjam Ernestus. 2011. Realization of voiceless stops and vowels in conversational French and Spanish. *Journal of Laboratory Phonology* 2: 331-353.

Wheeler, Max. 2005. *The phonology of Catalan*. Oxford: OUP.

Wickham, Hadley. 2016. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. https://ggplot2.tidyverse.org