

Coronal stop lenition in French and Spanish: Electropalatographic evidence

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Submitted: 14/10/2021; Accepted: 16/11/2021; Published on line: 25/10/2022

Citation / Cómo citar este artículo: Colantoni, L.; Kochetov, A.; S. Jeffrey (2021). Coronal stop lenition in French and Spanish: Electropalatographic evidence. *Loquens*, 8(1-2), e080. <https://doi.org/10.3989/loquens.2021.e080>.

ABSTRACT: Lenition of voiced and, to a lesser extent, voiceless stops is widely attested in Western Romance languages. In Spanish, utterance-initial voiced stops as well as those following nasals alternate with approximants in intervocalic position. Acoustic and articulatory studies have revealed factors that condition phonetic weakening. In contrast, very little is known about stop weakening in French. In this paper, using electropalatography, we provide articulatory evidence for the lenition of /t d/ in both Spanish and French. Data obtained from seven Spanish-speaking and four French-speaking participants reveal that, in both languages, /d/ is produced with less linguopalatal contact than /t/, and these differences are strongly conditioned by the position within the utterance or word. The languages differ, however, in the degree of /d/ lenition as well as in some of the contextual conditioning factors. Overall, our results, which should be interpreted with some caution given the number of speakers and the balance of the stimuli set, show that French resembles other Romance languages in its phonetic patterns of lenition, differing mainly in the degree of weakening.

Keywords: lenition, voiceless and voiced coronal stops, French, Spanish.

RESUMEN: *El debilitamiento de las oclusivas coronales en francés y en español: pruebas electropalatográficas.*- El debilitamiento de las oclusivas sonoras, y, en menor medida, el de las sordas, es un proceso frecuente en las lenguas románicas. En español, las oclusivas sonoras en posición inicial absoluta y después de nasal alternan con aproximantes en posición intervocálica. Aunque se han realizado estudios articulatorios y acústicos acerca del debilitamiento en español, poco se sabe acerca de los patrones de debilitamiento en francés. En este trabajo, se presenta evidencia sobre el debilitamiento de /t d/ en ambas lenguas, por medio de datos obtenidos de cuatro hablantes de francés y siete de español usando electropalatografía (EPG). Los resultados muestran que en ambas lenguas /d/ se articula con menos contacto linguo-palatal que /t/ y que las diferencias en los patrones de contacto están condicionadas por la posición en la palabra y en la frase. Ambas lenguas difieren en el grado de debilitamiento de /d/ y en algunos de los factores contextuales que lo afectan. En resumen, los resultados provenientes de esta pequeña muestra de hablantes revelan que el francés se asemeja a otras lenguas románicas en los patrones fonéticos de debilitamiento, aunque difiere en el grado de debilitamiento.

Palabras clave: lenición, oclusivas sordas y sonoras, francés, español.

1. INTRODUCTION

Lenition of voiced stops and, to a lesser extent, of voiceless stops is a widely attested process in Western Romance languages, both diachronically and synchronically. Of all these languages, the Spanish synchronic alternations have arguably received the most attention. In Spanish, phonologically voiced stops (see Mascaró, 1991, for discussion) are realized as approximants in all but absolute phrase-initial and post-nasal positions (/d/ is also realized as a stop after laterals) (Hualde, 2015). Variability is reported in word-final position with devoicing, fricativization, and deletion of /d/ in some varieties. Although devoicing and fricativization have been attested since the Middle Ages, deletion is a relatively more recent phenomenon, dating to the second half of the 15th century, and exhibiting lexical effects (Ariza, 2012, p. 154). Of these three processes, fricativization is only observed in Peninsular Spanish (Antón, 1998; García Mouton & Molina Martos, 2015; González, 2002; Hualde & Eager, 2016; Molina Martos, 2016; Navarro Tomás, 1977; Pérez Castillejos, 2012). Devoicing and deletion appear to be more geographically widespread and have been reported to be conditioned by speech style; in particular, deletion is present in informal speech (Hualde & Eager, 2016; Navarro Tomás, 1977, §102; see Molina Martos, 2016, for a distribution of variants in the province of Madrid) and seemingly absent from read speech (González, 2002; Pérez Castillejos, 2012). More importantly for the present study, two additional factors condition this process: deletion is more frequent in absolute word-final position than within a phrase (Navarro Tomás, 1977, §102; see Hualde & Eager, 2016, for experimental data), and conditioned by the specific lexical item. Frequent deletion of /d/ in words like *verdad* ‘truth’ and *virtud* ‘virtue’ has been reported since the 16th century, and this tendency is confirmed by recent experimental studies. As Hualde and Eager (2016) demonstrate, this is a lexical rather than a frequency effect, as words with very different frequencies exhibit similar processes.¹

Similar alternations are documented in Catalan (Bonet & Lloret, 1998), Galician (Regueira, 1999), and Portuguese (Cruz Ferreira, 1999). In contrast, relatively little is known about French. French differs from the other Western Romance languages in the evolution of its intervocalic voiceless stops from Latin. Whereas the bilabial voiceless stop became the labial fricative /v/, coronal and velar voiceless stops were lost (Sánchez Mirret, 2007). Very few studies have reported synchronic lenition of voiced stops in French. Duez (1995, p. 424), based on data obtained from two participants engaged in a spontaneous dialogue, observed instances of lenition of voiced stops to fricatives (i.e., /b/ realized as [v] or [w]) and approximants (i.e., /d/ > [l] or [ɟ]). These patterns, however, are very different from those reported in

other Western Romance languages. A more recent study (Sunara, 2011), based on the acoustic analysis of read speech obtained from four Quebec and European French speakers, showed that voiced consonants in French lenite more than voiceless ones. Sunara also reported a place-based asymmetry with coronal consonants weakening more than either labials or velars. While word-final stop deletion has not been reported for French, as with Spanish, devoicing does occur. Jatteau et al. (2019) report pre-pausal devoicing in 27 % of the voiced stops in their Standard French corpus. No effects were observed for place of articulation and the highest rate of complete devoicing occurred in semi-formal as compared to casual or formal speech; the authors caution that the effect of speech style may be a consequence of their semi-formal speech corpus involving overlapping speech that artificially raised F0 detection.

Torreira and Ernestus’ (2011) acoustic analysis of French and Spanish conversational speech reveals that French voiceless stops may also be lenited. These researchers studied the realization of intervocalic /p t k/ as produced by speakers from Central and Northern France. A small number (5.4 %) of productions involved incomplete closures particularly in word-medial as compared to word-final position, more often with /k/ than /p/, and less often in accented compared to unaccented syllables. Weakening via complete voicing of the stops also characterized 8.5 % of realizations.

Given the scarcity of studies on French, our first goal here is to contribute to our understanding of lenition in Romance languages by providing new data for this language and comparing the articulatory realization of /t d/ in both languages using electropalatography (EPG). Our second goal is to contextualize our findings in light of crosslinguistic patterns of consonant fortition and lenition documented in previous articulatory (Fougeron, 2001) and acoustic studies (Napoleão de Souza, 2019).

Previous acoustic and articulatory studies on lenition in Romance, based mainly on data from Spanish and Catalan, have uncovered a series of factors that favor the lenition of voiced and voiceless stops. As already mentioned, position in the phrase conditions the alternation between Spanish stops and approximants. Lavoie (2001), using acoustic and EPG data, claims that the most relevant variable (e.g., more important than stress) to characterize lenition patterns in Spanish is position in the utterance. Indeed, this researcher observed the lowest degree of contact in word-medial intervocalic position, the highest in word-initial, utterance-initial position. Parrell’s (2011, 2014) electromagnetic articulography (EMA) study confirms these findings for /p b/. Similar positional effects for French were found by Jatteau et al. (2019) for voiced stop devoicing and by Torreira and Ernestus (2011) for intervocalic voiceless stop lenition.

Whereas there is consensus that position in the utterance conditions lenition, mixed results have been obtained regarding the role of stress, stop place, and preceding segments. For Spanish, Cole, Hualde and Iskarous (1999), Ortega Llebaria (2004), and Colantoni and Marinescu

¹ García Mouton & Molina Martos (2015) found that sociolinguistic factors, such as the age of the speaker in addition to the specific lexical item, favored deletion.

(2010) reported a higher degree of lenition in unstressed than in stressed syllables, whereas Lavoie (2001) failed to find a significant difference in the maximum degree of contact in /t d/ in stressed versus unstressed syllables in different positions in the sentence. Place asymmetries have been documented as well. Coronals delete more often than labials or dorsals in Spanish (Bybee, 2001; Colantoni & Marinescu, 2010) and lenite 70% more often than the other stops in French (Sunara, 2011), which conflicts with the place-based lenition hierarchies (e.g., velars before labials and coronals) proposed by Escure (1997) and Wireback (1997). More recent studies (Jatteau et al., 2019; Torreira & Ernestus, 2011), however, found no effect for place of articulation on pre-pausal devoicing and voiceless stop lenition, respectively. These results are consistent with previous acoustic studies (Lewis, 2001; Recasens, 2015), and articulatory studies (Lavoie, 2001) have failed to observe any difference either in relative intensity or the percentage of maximum contact. As concerns the effect of preceding segments, both vowel type (Cole et al., 1999; Ortega Llebaria, 2004) and the constriction of the preceding consonant (Hualde, Shosted & Scarpace, 2011) appear to affect the degree of lenition in Spanish.

Finally, the degree of lenition may also vary across dialects of the same language. For example, Lewis (2001) observed a higher degree of lenition in Peninsular than in Colombian Spanish. Such dialectal variation might lead one to expect differences in the degree of lenition across languages. A more recent crossdialectal study (Butera, 2018) also reported different degrees of weakening as well as different contextual and social factors affecting weakening across seven varieties. In particular, Butera observed that, although voiced and voiceless stops differed significantly in the CV intensity ratio in all varieties, differences were the largest in Mexico and the Andean dialects and the lowest in the Caribbean region. Stress significantly affected the CV intensity ratio in the Andean region, the Canary Islands, Chile, and Spain but had no effect in the data from the Caribbean, Argentina or Mexico. Position in the phrase turned out to be significant in the Andean region, Chile, the Caribbean, and the Canary Islands but not in the remaining three regions. Finally, younger speakers and males showed an overall tendency to have less constricted consonants than the other groups. Based on this large degree of inter-dialectal variation, it is clear that the factors conditioning lenition within and between languages can only be determined empirically.

The goal of the present study is to compare lenition of French and Spanish /t d/ based on EPG data collected from 11 speakers, exploring possible similarities and differences in this process between the languages. Specifically, this will be done by comparing the overall degree of contact (Q) in Spanish (Peninsular, Cuban, and Argentine) and French (Quebec and European) /t/ and /d/, examining the effect of position in the utterance (initial, medial, final) in conditioning this variation as well as of stress (pretonic & tonic (both languages); posttonic (Spanish alone)).

2. METHODS

2.1. Participants

The data for the study come from a corpus of previously collected EPG recordings (Kochetov, Colantoni & Steele, 2017). The current sample includes 11 speakers – seven for Spanish and four for French.² All but one were female. Spanish speakers ranged in age between 23 and 42 years and had spent a mean of five years in Canada at the time of testing. The mean age of French participants was 27.8 years (range 25-29). Among the Spanish participants, five were from Buenos Aires, Argentina (SP_A1, SP_A2, SP_A3, SP_A4, and SP_A5, the latter being male), one from Havana, Cuba (SP_C1), and one from Madrid, Spain (SP_P1). Among the French speakers, all of whom were females, two were from France (FR_F1 from Cherbourg and FR_F2 from Clermont-Ferrand) and two from Quebec, Canada (FR1_Q1 from Chicoutimi and FR2_Q2 from St-Jean-sur Richelieu)³. All the participants lived in Canada at the time of testing and spoke English as a second language. However, they all continued to speak their L1 at home, at work (the majority of them were teachers of their native language or translators), and in social situations.

2.2. Materials

The target consonants /t/ and /d/ appeared in three positions in the word: word-initial, word-medial, and word-final as, for example, /d/ in the Spanish words *dama* ‘lady’, *adagio* ‘saying’, and *virtud* ‘virtue’, or the French words *demande* ‘I/s/he ask(s)’, *cadeau* ‘present’, and *commode* ‘convenient’. Each of these words was produced in two utterance-type conditions – as words in isolation (labelled ‘single’ here) and in a carrier phrase (‘carrier’). For Spanish, the carrier sentence was *Digo _____ otra vez* ‘I say _____ again’; for French it was *Dis _____ encore une fois* ‘Say _____ again’. As a result of combining Position and Type, when produced in isolated words, word-initial consonants were utterance-initial, word-final consonants were utterance-final. This resulted therefore in five possible prosodic contexts: utterance-initial word-initial, utterance-medial word-initial, utterance-medial word-medial, utterance-medial word-final, and utterance-final word-final.

In terms of their stress patterns, there were three contexts in which the target consonants could appear in Spanish: pretonic, tonic, and posttonic (e.g., *deshielo* /de'sjelo/ ‘thaw’, *adagio* /a'daxio/ ‘saying’, *bocado* /bo'kado/ ‘bite’). As French has word/phrase-final stress, only pre-

² Although the number of participants is small compared to acoustic studies, it is well above the median for EPG studies, which were published in major journals between 2000 and 2019 (Kochetov, 2020).

³ Whereas the particular French dialects present in our study result from these participants having been recruited via convenience sampling, in the case of Spanish, we selected speakers of dialects that rerepresented different patterns of palatalization and consonantal weakening in nasals and post-alveolar fricative based on a series of previous studies.

tonic and tonic contexts occurred in the French stimuli (e.g., *tendu* /tã'dy/ 'tense', *chandail* /ʃã'daj/ 'sweater'). All target phonemes appeared as single consonants or in consonant + glide clusters (e.g., Spanish *diente* /'djente/ 'tooth', French *patois* /pa'twa/ 'patois').

Tables 1 and 2 provide a breakdown of the Spanish and French stimuli, respectively, grouped by Position and Stress, while also presenting counts of different lexical items and tokens by Type. In total, there were 39 items & 2213 tokens for Spanish (on average, 316 tokens and 8 repetitions per item per speaker) and 32 items & 1344 tokens for French (on average, 336 tokens and 11 repetitions per item per speaker). Given that the materials were

drawn from an existing corpus, it was not possible to obtain equal numbers of items and tokens per condition. This is particularly true for consonants in final position and the pretonic stress context. The results for these data should therefore be considered with some caution.

2.3. Instrumentation and analysis

The recordings were made using the *WinEPG* system (Wrench et al., 2002) at a sampling rate of 100 Hz. Custom-made palates with 62 electrodes were made for each participant. All of the Spanish-speaking participants had the Reading-style palate, whereas the French participants had the newer Articulate model (Wrench, 2007). While the latter palate can have somewhat better coverage of dental and velar places, both devices are similar at measuring contact differences within places (Kochetov, Colantoni & Steele, 2017). The artificial palates used have a grid of 62 electrodes that can be represented with 8 columns and 8 rows (with the first row containing only 6 electrodes). The first four rows correspond to the denti-alveolar region where the consonants /t/ and /d/ are typically produced (Gibbon & Nicolaidis, 1999).

The data were annotated based on the waveform and spectrogram using the *Articulate Assistant* software (Wrench et al., 2002). Boundaries for /t/ and for stop realizations of /d/ were marked at the onset and offset of the closure. In absolute word-initial position, where the onset of (voiceless) stops cannot be determined, it was arbitrarily set to begin 70 ms before the release. To determine the onset and offset of approximant realizations of /d/, we used the intensity curve as well as formant transitions. Based on the assumption that more lenited consonants are shorter than non-lenited consonants, we compared the duration of /t d/ in all positions but absolute-word initial position in order to explore whether there was a relation between degree of contact and consonant duration. Figure 1 presents sample annotations of /t/ and /d/ for one of the Spanish speakers.

The small images at the bottom of each annotation present the point of maximum contact frames (PMC) during the annotated intervals. We can see that, at its maximum, /t/ was produced with a complete closure in the first three rows of the palate as well as substantial side contact. In contrast, there was only a partial constriction in the first few rows and reduced side contact for /d/, indicative of consonantal lenition.

Linguopalatal contact values were automatically extracted from the PMC frames. In general, lesser contact corresponds to greater lenition. As our focus is on coronal consonants, we chose to examine the amount of linguopalatal contact in the first four rows of the palate as measured by Q_{a4} (Quotient of maximum activation over the anterior four rows of the palate) or *anterior contact*. This measure also served to minimize the influence of adjacent high front vowels or glides, which tend to increase contact in the posterior portion of the palate. Q_{a4} was calculated as the number of contacts activated at PMC divided by the total number of contacts in the region (30). For example, the tokens of /t/ and /d/ in Figure 1 involve Q_{a4} values of 0.87 (26/30) and 0.37 (11/30), respectively.

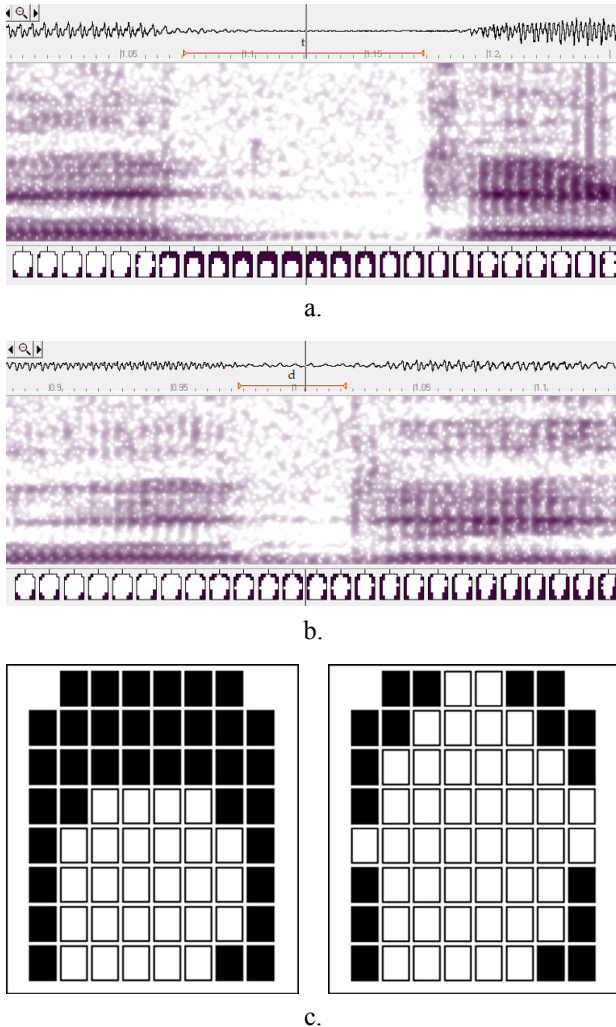
Table 1: Spanish stimuli by Type and (a) Position in the Word or (b) Stress, with counts of items and tokens.

	Position /Stress	Type	Items (N)		Tokens (N)	
			/t/	/d/	/t/	/d/
a.	initial	single	6	5	90	70
		carrier	6	5	282	209
	medial	single	12	12	163	139
		carrier	12	12	504	420
	final	single	1	3	14	70
		carrier	1	3	42	210
b.	pretonic	single	3	2	48	28
		carrier	3	2	156	83
	tonic	single	7	9	84	126
		carrier	7	9	264	378
	posttonic	single	9	9	135	125
		carrier	9	9	408	378

Table 2: French stimuli by Type and (a) Position in the Word or (b) Stress, with counts of items and tokens.

	Position /Stress	Type	Items (N)		Tokens (N)	
			/t/	/d/	/t/	/d/
a.	initial	single	4	3	96	73
		carrier	4	3	72	54
	medial	single	13	8	312	192
		carrier	13	8	234	144
	final	single	1	3	24	71
		carrier	1	3	18	54
b.	pretonic	single	3	4	96	336
		carrier	3	4	72	252
	tonic	single	14	11	73	263
		carrier	14	11	54	198

Figure 1: Examples of annotation of the EPG data: (a) a token of /t/ in Spanish *Digo termino otra vez* and (b) /d/ in *Digo deshielo otra vez* (SP_A4, 4th repetition); (c) the maximum contact palate frames for both tokens (/t/ left, /d/ right), with black cells indicating linguopalatal contact and the first four rows corresponding to the denti-alveolar region.



Q_{a4} values were analyzed using linear mixed effects models implemented with the lme4 package (Bates et al., 2017) using R (R Core Team, 2014). Since position and stress categories partly overlap, different analyses were conducted for Spanish and French. The first analysis included the fixed factors Consonant (/t/, /d/), Type (single, carrier), and Position (initial, medial, final). The second analysis included the fixed factors Consonant (/t/, /d/), Type (single, carrier), and Stress (pretonic, tonic, and – for Spanish – posttonic). Additional within-language analyses were conducted to explore potential dialectal differences. In the case of Spanish, two groups were created (Argentine Spanish versus others), whereas, for French, we compared the Quebec versus European speakers. Our final analysis involved the between-language comparison. To perform this analysis, we subsetted the Spanish data to exclude the

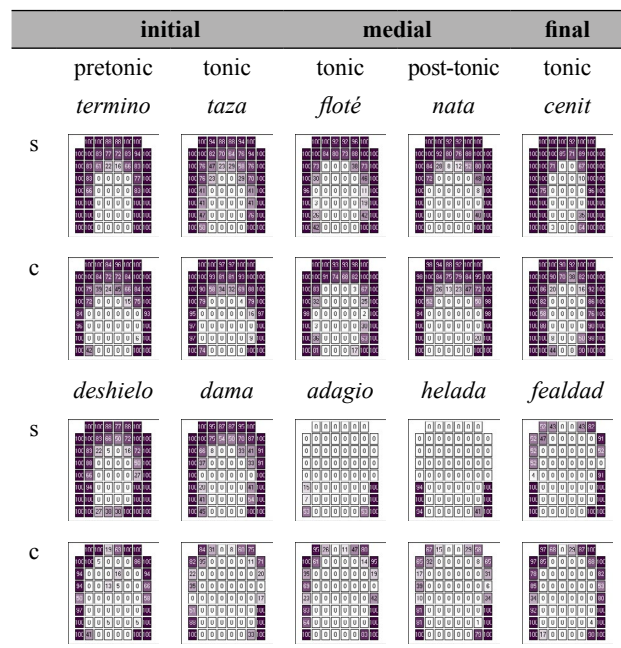
posttonic context, so as to have similar contexts in both languages. In all analyses, random intercepts were included for Speaker and Item. In each case, likelihood ratio tests were used to compare a full model to a nested model excluding the factor of interest, employing the Anova() function of the lmerTest package (Kuznetsova et al., 2017). Pairwise comparisons and posthoc tests (with a Bonferroni correction for multiple comparisons) were performed using thephia package (De Rosario-Martinez, 2015). Results were visualized using the package ggplot2 (Wickham, 2009).

3. RESULTS

3.1. Overview

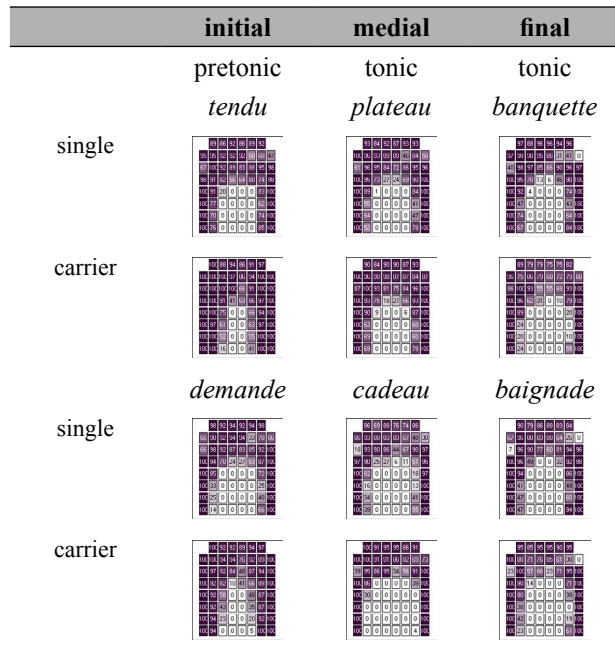
We will begin with an overview of linguopalatal contact differences across positions/stress contexts and utterance types as well as by considering between-language differences. Figures 2 and 3 present average linguopalatal contact profiles for selected Spanish and French speakers and items, respectively. Note that the figures differ in terms of the number of possible stress conditions illustrated (3 for Spanish, 2 for French). We can see in Figure 2 that SP_A4 produced /d/ with overall much lesser contact than for /t/. The contact for both consonants was reduced in medial position, especially for /d/, where the denti-alveolar region showed hardly any activation (especially for single words). Note also the considerably lesser contact for /d/ in the carrier phrase compared to the single word condition. In contrast to position, stress differences are not as apparent in these data.

Figure 2: Average linguopalatal contact profiles taken over the entire duration of Spanish /t/ and /d/ in selected words by speaker SP_A4; s = single, c = carrier.



Turning to the illustrative data from French speaker FR_F1 (Figure 3), we can see that the consonant- and position-based differences are considerably more subtle.

Figure 3: Average linguopalatal contact profiles taken over the entire duration of French /t/ and /d/ in selected words by speaker FR_F1; s = single, c = carrier.



Overall, /d/ is characterized by slightly less contact than /t/, at least word-medially; both consonants exhibit somewhat reduced contact word-medially and word-finally compared to word-initial position. As the stress patterns in the French data align with the position categories, /t/ and /d/ in stressed syllables (non-initial positions) show overall slightly less contact.

Below we continue by presenting analyses of the data – by Type and Position, then by Type and Stress – separately for each language, followed by a comparison of French and Spanish data.

3.2. Spanish

3.2.1. Type and Position Effects for /t/ and /d/

A linear mixed effects regression (LMER) model for the entire Spanish dataset revealed significant effects of Consonant, Type, Position, and significant interactions of these three factors. These results are summarized in Table 4; the full output of the model is presented in Table 1A in the Appendix. Given the significant 3-way interaction and distinct patterning for /t/ and /d/ (see Figure 2), we proceeded with separate analyses for each consonant. Due to space considerations, we will only present model comparison tables here and below.

Table 4: Model comparisons for Q_a4 for the entire Spanish dataset (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘***’ < .001, ‘**’ < .01, ‘*’ < .05).

Effect	χ^2	Df	Pr(> χ^2)	
C	973.18	1	<.001	***
Type	149.32	1	<.001	***
Position	105.73	2	<.001	***
C x Type	10.38	1	<.01	**
C x Position	51.77	2	<.001	***
Type x Position	240.92	2	<.001	***
C x Type x Position	194.39	2	<.001	***

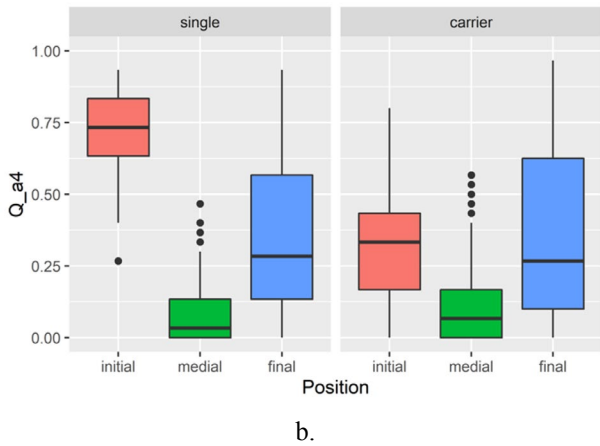
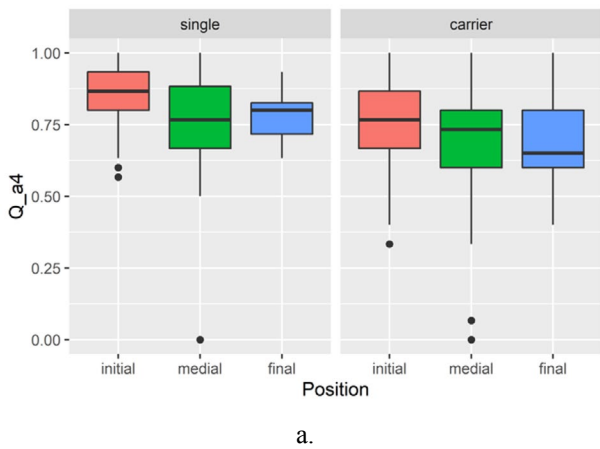
Table 5 presents results of separate LMER models for Spanish /t/ and /d/. Figure 4 illustrates differences by Type and Position for each consonant. As can be seen in Table 5 and Figure 4a, the anterior contact for /t/ was significantly affected by Type and Position. There was also a significant interaction of the two factors. Posthoc pairwise comparisons revealed that medial position was characterized by significantly less contact than initial position for both the single ($p < .0001$) and carrier conditions ($p < .01$). Words in carrier sentences also showed a marginal tendency towards lesser contact word-finally than word-initially ($p < .01$). /t/ was produced with greater contact in single words than in the carrier phrase regardless of the position (word-initial & word-medial $p < .0001$; word-final $p < .01$).

The anterior contact for /d/ also showed significant effects of Type, Position, and the interaction of these two factors (see Table 5 and Figure 4b). Position-based differences for /d/, however, were distinct from those for /t/ and varied by Type. Posthoc pairwise comparisons revealed that single words showed significantly less contact in word-medial and word-final compared to word-initial position (both $p < .0001$) as well as less contact for word-final compared to word-medial posi-

Table 5: Model comparisons for Q_a4 for Spanish /t/ and /d/ by Type and Position (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘***’ < .001, ‘**’ < .01, ‘*’ < .05).

C	Effect	χ^2	Df	Pr(> χ^2)	
/t/	Type	108.31	1	<.001	***
	Position	21.03	2	<.001	***
	Type x Position	8.95	2	.011	*
/d/	Type	77.09	1	<.001	***
	Position	90.97	2	<.001	***
	Type x Position	332.05	2	<.001	***

Figure 4: Boxplot of Q_a4 by Type and Position, separately for Spanish (a) /t/ and (b) /d/.



tion ($p < .0001$). Words in the carrier phrase showed less contact for word-medial compared to word-initial and word-final positions. The Type effect was limited to word-initial position: /d/ showed considerably less contact in carrier sentences than in single words. Viewed alternatively, word-initial /d/ showed reduction in contact when occurring utterance-medially compared to utterance-initially.

3.2.2. Type and Stress effects for /t/ and /d/

As the LMER model for Consonant, Type, and Stress showed a significant 3-way interaction of the kind observed above, here we will present only the results of separate analyses by consonant, focusing on stress. The results of these are summarized in Table 6 and illustrated in Figure 5.

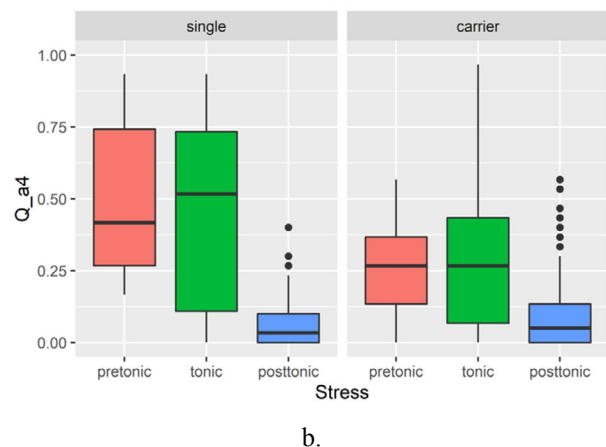
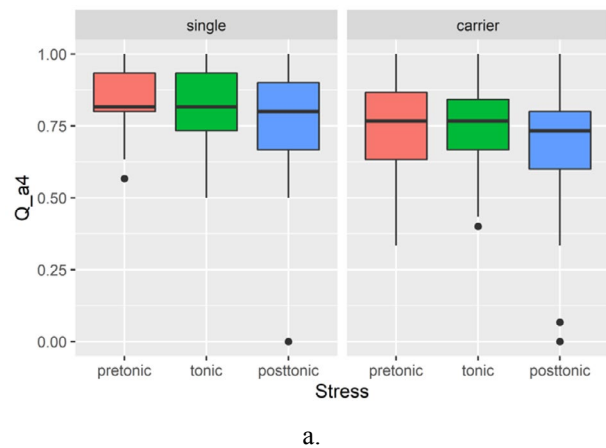
With /t/, anterior contact was significantly affected by Type and Stress. In terms of the latter difference, as revealed by posthoc pairwise comparisons, the amount of contact was reduced for posttonic compared to tonic position ($p < .0001$) but did not differ from pretonic position. For /d/, there were significant effects of Type,

Stress, and their interaction. Posthoc tests revealed that posttonic /d/ showed less contact than tonic /d/ in both the single ($p < .0001$) and carrier conditions ($p < .001$). In addition, single words also showed lesser contact for posttonic as compared to pretonic /d/ ($p < .0001$).

Table 6: Model comparisons for Q_a4 for Spanish /t/ and /d/ by Type and Stress (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘***’ $< .001$, ‘**’ $< .01$, ‘*’ $< .05$).

C	Effect	χ^2	Df	Pr(> χ^2)	
/t/	Type	110.81	1	<.001	***
	Stress	15.62	2	<.001	***
	Type: Stress	3.20	2	.202	
/d/	Type	63.98	1	<.001	***
	Stress	23.39	2	<.001	***
	Type: Stress	90.34	2	<.001	***

Figure 5: Boxplot of Q_a4 by Type and Stress, separately for Spanish (a) /t/ and (b) /d/.

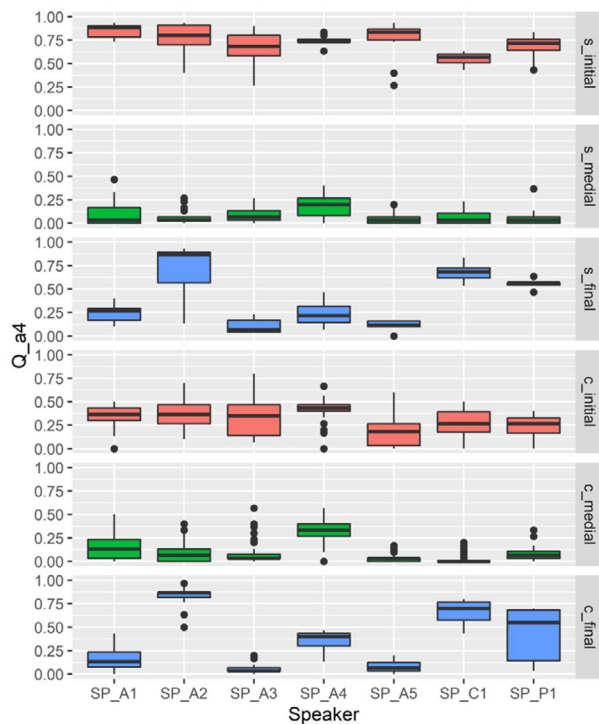


3.2.3. Dialect, Speaker, and Item Variation

To examine whether there were general dialectal differences between the Argentine versus other Spanish speakers, we performed an LMER model with Dialect included as a fixed factor with two levels (Argentina, Other). The results revealed significant 3-way interactions of Dialect with Consonant and Position ($p < .0001$) as well as with Type and Position ($p < .05$). The first interaction was due to different patterns in the realization of the final /d/: this consonant was more lenited by the Argentine speakers than the two other speakers, while the reverse was observed for this consonant initially and medially. The second interaction was partly due to the relatively greater contact for initial consonants in single words produced by the Argentine speakers. It was also due to the lesser contact shown by the Argentine speakers for initial consonants (of both types). These observations should be considered with caution, however, given the presence of only two speakers in the Other group.

An examination of individual data revealed that all speakers were relatively consistent in their realization of /t/ across positions and utterance types. There were, however, some individual differences in the realization of /d/ in certain contexts. As can be seen in Figure 6, SP_A2, SP_C1, and SP_P1 produced this consonant word-finally with little or no lenition at all, both in single words and in the carrier phrase. All other speakers, in contrast, lenited this consonant essentially to the same extent as medial /d/. It should be noted that final /d/ was produced by SP_P1

Figure 6: Boxplot of Q_a4 by Speaker and Type x Position for Spanish /d/.



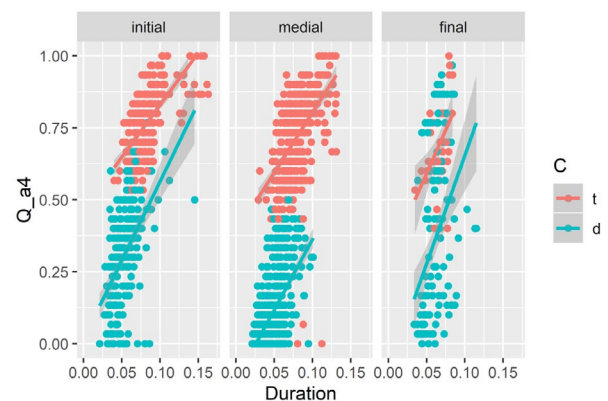
as a voiceless fricative, compared to the weak stop realization of SP_A2 and SP_C1. The fricativized realization of SP_P1, a speaker of Madrid Spanish, has been documented for this variety (Antón, 1998; González, 2002; Hualde & Eager, 2016; Navarro Tomás, 1977; Pérez Castillejos, 2012). Among other notable differences was the overall greater linguopalatal contact for SP_A4 in most positions/utterance types or utterances produced. This can be attributed to this individual’s generally slower and more careful speaking style (which was also reflected in on average longer duration of this speaker’s consonants: 88 ms compared to 53-69 ms for the other Spanish speakers).

Voiced /d/ also showed some item- or phonetic context-specific variation. While this consonant was characterized by considerable lenition in the words *dama* and *deshielo* in carrier phrases (utterance-medially), it also showed much lenition in *diente*, *dio*, and *diurno*, where it is followed by a palatal glide. This cannot, however, be attributed solely to coarticulation with the latter, as all words with initial /d/ showed relatively similar contact patterns utterance-initially. Furthermore, less lenition was observed for the medial /d/ in *videoclip* compared to other items (e.g., *bledo*, *enredar*). Finally, somewhat less contact was exhibited with final /d/ in the relatively less frequent words *abad* ‘abbot’ and *fealdad* ‘ugliness’, compared to the more frequent one *virtud* ‘virtue’.

3.2.4. Interaction of Duration and Lenition

To examine the potential relationship between the consonants’ anterior contact and duration, we plotted these variables by individual tokens in Figure 7. This was done for words in carrier sentences only, as duration measurements for word-initial and -final tokens in single words could not be always obtained reliably (see Method). Note also that the duration of fully lenited tokens of /d/ might not be reliable either, at least in cases where accurate segmentation was impeded by the lack of obvious intensity drops in the waveforms and spectrograms. Overall, we can see that there is a strong correlation between contact and duration:

Figure 7: Scatterplot for Q_a4 and Duration for Spanish /t/ and /d/ tokens in carrier sentences by Consonant and Position.



longer duration implies greater contact (and vice versa) for both consonants in all three positions. Note also that, compared to duration, Q_{a4} provides a better separation of the consonant categories for initial and medial positions.

3.2.5. Summary

To summarize, the results for the Spanish dataset showed robust between-consonant differences: voiced /d/ was characterized by much less anterior contact than voiceless /t/ (see Table 4). Differences between the two consonants were large in all contexts with the exception of utterance-initial position (word-medial single). /t/ was realized with weaker contact word-medially than word-initially, posttonically than tonically, and in carrier sentences than in single words. The magnitude of positional differences in the realization of /t/ was relatively small compared to the extensive /d/ variation observed. Specifically, the voiced stop showed less contact word-medially compared to the other two positions, as well as word-finally in single words compared to word-initially in the same type of utterances. In terms of stress, posttonic position involved less contact than tonic position and, for single words, pretonic position. Utterance-type differences for /d/ were limited to initial position, where less contact was observed for words in carrier sentences, similar to the pattern exhibited by /t/. The voiced stop also showed some variation in its realization across dialect, speakers and word items, while its voiceless counterpart was largely unaffected. Finally, for both consonants, there was a positive correlation between their relative amount of contact and constriction duration.

3.3. French

3.3.1. Type and Position Effects for /t/ and /d/

Turning to French, an LMER model for the entire dataset revealed significant effects of Consonant and Position (but not Type) as well as significant interactions of Consonant and Type, Consonant and Position, and Type and Position. These results are summarized in Table 7; the full output of the model is presented in Table 2A in the Appendix.

Table 7: Model comparisons for Q_{a4} for the entire French dataset (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘***’ <.001, ‘**’ <.01, ‘*’ <.05).

Effect	χ^2	Df	Pr(> χ^2)
C	22.49	1	<.001 ***
Type	0.25	1	0.615
Position	38.41	2	<.001 ***
C x Type	4.73	1	.030 *
C x Position	8.49	2	.014 *
Type x Position	10.97	2	.004 **
C x Type x Position	1.87	2	.3916

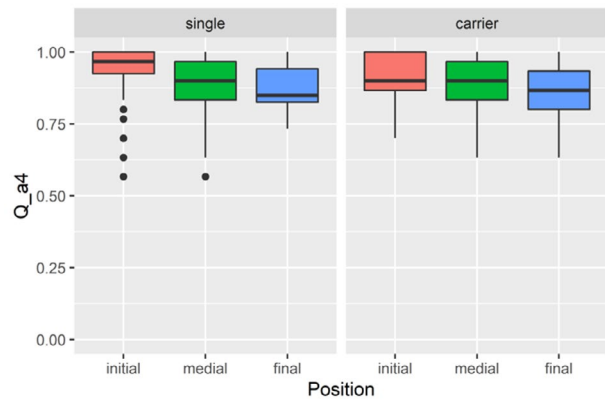
Given these interactions, and in parallel to our Spanish analysis, we proceeded with separate analyses for each consonant.

Table 8 presents results of separate LMER models for French /t/ and /d/. Figure 8 (a and b) illustrates differences by Type and Position for each consonant. The anterior contact for /t/ was affected by both Type and

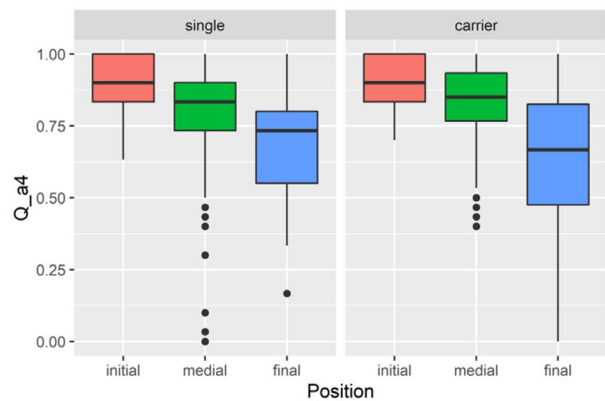
Table 8: Model comparisons for Q_{a4} for French /t/ and /d/ by Type and Position (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘***’ <.001, ‘**’ <.01, ‘*’ <.05).

C	Effect	χ^2	Df	Pr(> χ^2)
/t/	Type	4.36	1	.037 *
	Position	9.60	2	.008 **
	Type x Position	5.20	2	.074
/d/	Type	0.51	1	.475
	Position	22.32	2	<.001 ***
	Type x Position	6.37	2	.042 *

Figure 8: Boxplot of Q_{a4} by Type and Position, separately for French (a) /t/ and (b) /d/.



a.



b.

Position. The interaction between the two approached significance. Posthoc pairwise comparisons revealed that /t/ in word-medial position in single words was produced with significantly less contact ($p < .05$) than the same consonant word-initially (in single words). There were no significant differences involving word-final position, although values were on average lower than for the other two positions. There were also no significant positional differences in carrier sentences, even though the general trend was in the same direction (word-initial > word-medial > word-final; see Figure 8a). Significant Type differences were limited to initial position where /t/ in single words showed more contact than in carrier phrases ($p < .01$).

For /d/, anterior contact was affected by Position but not Type; there was also a significant Type-by-Position interaction (see Table 8b). Posthoc pairwise comparisons revealed that /d/ involved significantly lower contact in word-final than in word-initial and word-medial positions. This held for both single words ($p < .001$ and $p < .05$) and for words in carrier sentences (both $p < .001$). Interestingly, no significant results were observed for the word-initial versus word-medial contrast, despite the general tendency for lesser contact in the latter (see Figure 8b). Type differences were not significant regardless of the Position, with a non-significant reduction in contact for word-final /d/ in carrier sentences.

3.3.2. Type and Stress Effects for /t/ and /d/

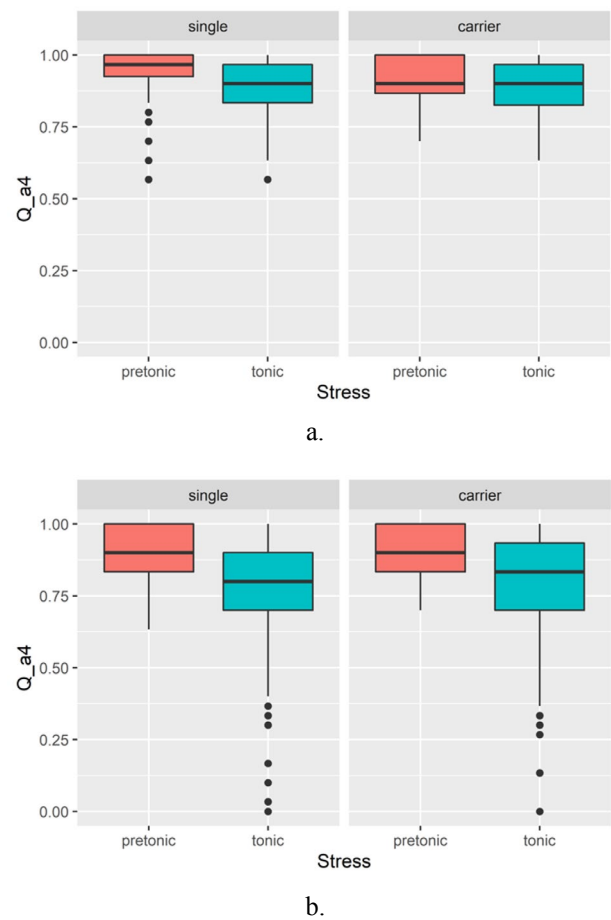
LMER models for Type and Stress for /t/ and /d/ are summarized in Table 9 and illustrated in Figure 9. Given the language’s fixed phrase-final stress, recall that only two stress contexts are possible in our French data – pretonic and tonic – and these partly correspond to the positional categories already discussed above.

For /t/, the model showed significant effects of Type, Stress, and their interaction. Posthoc pairwise comparisons revealed that contact was reduced in the tonic compared to the pretonic context but only in single words ($p < .001$). For /d/, there was also a significant effect of Stress (but not Type, and no interaction) with lesser contact in tonic position ($p < .001$).

Table 9: Model comparisons for Q_a4 for French /t/ and /d/ by Type and Stress (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘***’ < .001, ‘**’ < .01, ‘*’ < .05).

C	Effect	χ^2	Df	Pr(> χ^2)	
/t/	Type	4.37	1	.037	*
	Stress	9.35	1	.002	**
	Type: Stress	4.91	1	.027	*
/d/	Type	0.50	1	.478	
	Stress	4.67	1	.031	*
	Type: Stress	0.45	1	.502	

Figure 9: Boxplot of Q_a4 by Type and Stress, separately for French (a) /t/ and (b) /d/.

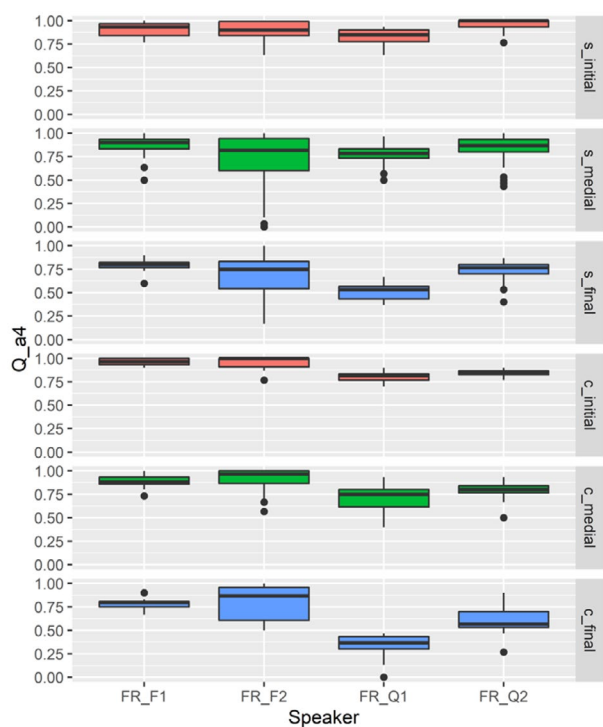


3.3.3. Dialect, Speaker, and Item Variation

To examine dialect-specific differences, we performed an LMER model with Dialect included as a fixed factor (with two levels: France versus Quebec). The results revealed significant 3-way interactions of Dialect with Consonant and Position ($p < .0001$) as well as with Consonant and Type ($p < .0001$). The first interaction was due to the significantly relatively lesser contact produced by the Quebecois speakers in the carrier phrase condition (but not in the single words). This effect was observed for both consonants but was overall greater for /d/ than /t/. The second interaction was due to the much lower contact produced by the Quebecois speakers in final position. Again, this was observed for both consonants but was greater for /d/ than /t/. Overall, our Quebec speakers showed greater lenition in carrier phrases and in final position, and this lenition was greater for the voiced stop. Whether these patterns are representative of Quebec French or simply individual speaker traits cannot be determined given the small speaker sample of this study.

As Quebec French is characterized by affrication of stops before high front vocoids (/i/, /y/, and /j/, /ɥ/; e.g.,

Figure 10: Boxplot of Q_a4 for French /d/ by Speaker and Type x Position.



Walker, 1984; Dumas, 1987), one may expect these differences to manifest in our results. Affrication of /t/ and /d/ was consistently present in the acoustic records for FR_Q1 and FR_Q2 but did not significantly affect our measure of contact. This was revealed by a follow-up LMER model with fixed factors Dialect, Consonant, and Vowel Context (high front versus other): contact values were in general lower for the Quebec speakers regardless the vowel context and consonant. The lack of the contextual effect can be attributed to contact having been measured during the consonant closure rather than its frication interval.

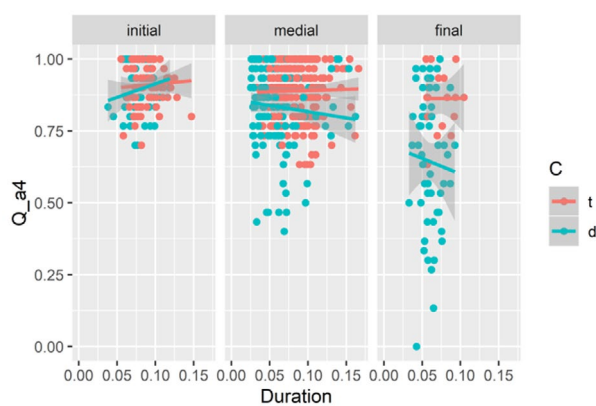
An examination of the individual data revealed rather similar Type and Position variation for each of the two consonants. Among some observed (yet relatively minor) differences were the generally lower contact for FR_Q1 as well as a somewhat greater reduction of final /t/ and, especially, /d/ by the two Quebec speakers. These similarities and differences can be observed in Figure 10. In contrast to Spanish, individual contact differences in the French data do not seem to correlate with speaking rate or style differences (with consonant duration for words in the carrier phrase being overall similar at 72 to 84 ms). No clear differences were observed either for the amount of contact among individual word items for either /t/ or /d/.

3.3.4. Interaction of Duration and Lenition

Finally, turning to the potential relationship between contact and duration, Figure 11 shows a scatterplot of all

French carrier sentence tokens plotted separately for Position. Note that word-initial position alone is characterized by some degree of positive correlation between the two variables (the longer the duration, the greater the contact) for both /t/ and /d/. No such relationship, however, is evident for the other two positions. This finding parallels that of Fougeron (2001) for word-initial strengthening where the amount of contact more consistently distinguished prosodic positions than duration.

Figure 11: Scatterplot for Q_a4 and Duration for French /t/ and /d/ tokens in carrier sentences by Consonant and Type.



3.3.5. Summary

Compared to Spanish, the results for French showed much subtler differences between the consonants as well as among positions and stress contexts. Some of the differences, however, were similar to those observed in Spanish. Specifically, both French /t/ and /d/ were realized with greater contact in word-initial compared to word-medial (for /t/ in single words) and word-final positions (for /d/ in both utterance types). For /t/ alone, single words exhibited greater contact than words produced in carrier sentences. Unlike Spanish, however, it was word-final rather than word-medial position where /d/ was most lenited. Also in contrast to Spanish, French showed more contact reduction in tonic compared to pretonic position. As tonic position in French coocurs with the final syllable, this indicates that word position is more important for French than stress for consonantal strength realization.

3.4. A comparison of Spanish and French patterns

To examine differences between the two language groups, we performed an LMER model across the two datasets, with the exception of the Spanish posttonic items (as this stress condition was absent in French). The model involved fixed factors Group (Spanish and French) as well as Consonant, Position, and Type as in the language-particular analyses above. Random factors were also the same, namely, Speaker and Item.

The results revealed a 4-way significant interaction (Group * Consonant * Position * Type; $p < .0001$). Follow-up analyses by Consonant (see Table 10) showed a significant 2-way interaction of Group and Type ($p < .0001$) for /t/, and a significant 3-way interaction of Group, Position, and Type ($p < .0001$) for /d/.

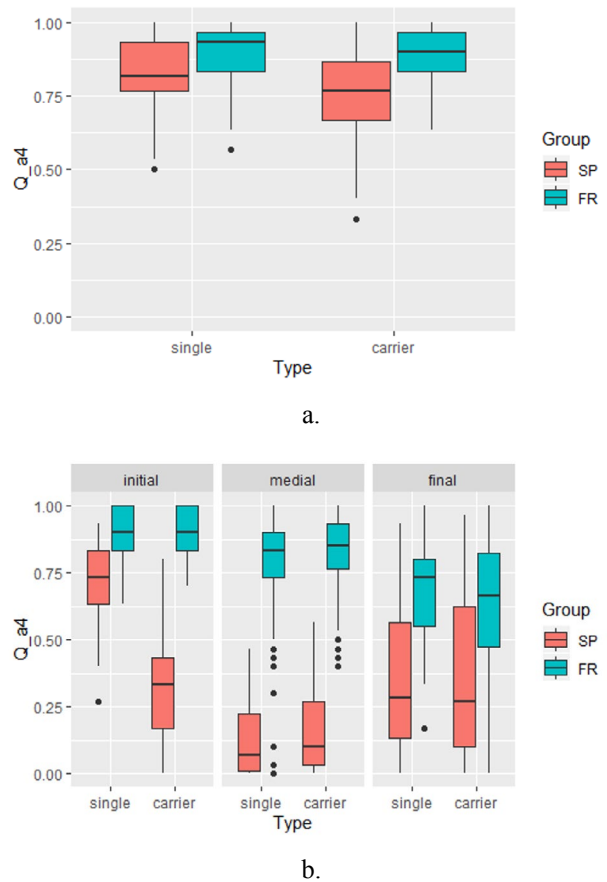
Table 10: Model comparisons for Q_a4 for the combined Spanish (subset) and French datasets, separately by Consonant (Analysis of Deviance Table, Type II Wald χ^2 tests, significance levels: ‘****’ $< .001$, ‘***’ $< .01$, ‘*’ $< .05$).

C	Effect	χ^2	Df	Pr(> χ^2)	
/t/	Group	5.76	1	0.022	*
	Position	14.54	2	<.001	***
	Type	50.00	1	<.001	***
	Group:Position	0.43	2	0.808	
	Group:Type	11.06	1	<.001	***
	Position:Type	17.62	2	<.001	***
	Group:Position:-Type	5.71	2	0.057	
/d/	Group	61.52	1	<.001	***
	Position	17.30	2	<.001	***
	Type	60.40	1	<.001	***
	Group:Position	24.81	2	<.001	***
	Group:Type	39.12	1	<.001	***
	Position:Type	114.69	2	<.001	***
	Group:Position:-Type	86.16	2	<.001	***

The first interaction was due to the significantly lower /t/ contact exhibited by Spanish speakers compared to their French counterparts in the carrier phrase condition. As shown in Figure 12a, a similar tendency was also observed in single words, albeit differences were not significant. The second interaction was due to the lack of significant Group difference in final position in the carrier sentence condition. Recall that this was the context of considerable inter-speaker/dialectal variation in both groups. In all other positions, Spanish speakers showed consistently lower contact compared to French speakers, albeit of different magnitude depending on the Position and Type. This is illustrated in Figure 12b.

Overall, these results reveal a greater lenition of stops in Spanish compared to French. The language group difference for /t/ is limited to carrier sentences, while the difference for /d/ is present in almost all utterance types and positions. The latter difference is largest word-medially and word-initially in carrier sentences – the contexts where Spanish exhibits allophonic lenition of /d/. While French does not have such an allophonic process, signifi-

Figure 12: Boxplot of Q_a4 by Type and Position, separately for French (a) /t/ and (b) /d/.



cant positional weakening is nonetheless observed in our data: French /d/ in word-medial and especially word-final position is characterized by much weaker contact than word-initially.

4. DISCUSSION AND CONCLUSIONS

While the extrapolation of our results to French and Spanish more generally must be done with some caution given the small number of speakers and certain imbalances in the stimuli set, they nonetheless show that, overall, the degree of linguopalatal contact is greater for /t/ than for /d/ in both languages with the difference being larger in Spanish. This is unsurprising given the extensive literature documenting allophonic alternations between voiced and voiceless stops. The other salient between-language difference is the lenition hierarchy. In French, there was a relatively greater amount of decreased contact moving from initial to word-medial to word-final position for both coronal stops. That lenition affects word-initial consonants less is in keeping with Fougeron’s (2001) finding of general domain-initial strengthening in French. In Spanish, the same hierarchy holds for /t/. As in previous studies, both languages differ in the degree of lenition of

/t/. In parallel to Torreira and Ernestus's (2011) findings, the degree of contact is lower in Spanish than in French (see Figure 4a versus Figure 8a). With /d/, in contrast, it is rather word-initial > word-final > word-medial. Finally, in both French and Spanish, less lenition was observed when the words were pronounced in isolation compared to carrier sentences. This effect was particularly pronounced for Spanish initial /d/. Thus, our overall results confirm previous acoustic analyses showing weakening in French voiced (Duez, 1995; Sunara, 2011) and voiceless stops (Torreira & Ernestus, 2011), and also confirm positional asymmetries reported in Spanish acoustic and articulatory studies. This includes lenition patterns of final /d/, which although less commonly documented than lenition in other positions, includes fricativization and fronting of the consonant and lexical effects. As in previous studies (e.g. Navarro Tomás, 1977; García Mouton & Molina Martos, 2015; Hualde & Eager, 2016), fricativization was observed in our Peninsular speaker and lenition was more frequent in some lexical items (e.g., *virtud*) than in others (e.g., *abad*) across participants.

Although the two languages are similar in the overall patterns, they clearly differ in the degree of lenition of both stops, especially of /d/, which is usually deleted in intervocalic position in Spanish but not in French. Additionally, Spanish voiceless stops also show clear signs of weakening with anterior contact values that resembled those obtained for French /d/. Some differences were also observed in the degree of lenition by context as mentioned in the previous paragraph.

As concerns stress, a significant but different effect was observed in both languages (pretonic > tonic in French versus tonic > posttonic in Spanish). We observed a clear asymmetry in the degree of lenition between stressed and unstressed syllables in Spanish. Contra Lavoie's (2001) findings, our results are consistent with previous studies that have found that lenition is affected by stress in different dialects (Colantoni & Marinescu, 2010; Cole et al., 1999; Ortega Llebaria, 2004). Although the results for French apparently contradict this tendency, with greater lenition found in tonic than in pretonic syllables, we argue that the factor that is relevant in French is position in the word: in this language, there is a clear asymmetry between strengthening in word-initial position versus weakening in word-final position.

Dialectal effects were observed in the Spanish and the French datasets. As concerns the former, we found differences in the degree of lenition of word-final /d/, which was larger for the Argentine speakers than for the other two participants, and in the realization of word-initial consonants, particularly in isolated words. Although our results support previous research regarding differences in the degree of lenition across Spanish varieties (Butera, 2018; Lewis, 2001), they are not completely consistent with differences reported in the only study which includes Argentine, Caribbean, and Peninsular speakers. As discussed in the introduction, Butera (2018) did not find significant stress-related differences in the Argentine data, neither reported significant differences for position in the

phrase. Our cross-dialectal comparison, however, needs to be interpreted with caution given that we had five Argentine participants but only one participant representing each of the other two varieties. Dialectal differences were also found for French. We observed a greater degree of lenition for /d/ in the two participants from Quebec. As concerns Spanish, the patterns seem to be more consistent with individual differences in articulatory precision than with dialectal differences, since the greater degree of constriction was found in the speaker with the slowest speaking rate.

In summary, our findings provide some initial insights into French's place on the Romance continuum of lenition. Specifically, we found evidence that French is moving in the direction of the other Romance languages, albeit at a slower pace and with a slightly different hierarchy (word-final > word-medial), which in turn is consistent with previous patterns of lenition documented in the language. This between-language difference could be due to diachronic factors. Since Latin intervocalic voiceless stops were either fricativized or deleted in French (Sánchez Miret, 2007) whereas they became voiced stops in other Western Romance varieties, we can assume that French is undergoing a second voicing cycle. In Spanish, as observed in previous studies, voiced stops, particularly /d/ (Bybee, 2001; Colantoni & Marinescu, 2010), are at the extreme of the lenition continuum even in read speech.

Some of the usual disclaimers apply to our study. We have an unbalanced number of stimuli per context and per language, and while efforts were made to control for vowel context by excluding tautosyllabic high front vowels from our stimuli, differences among stimuli existed. We believe, however, that our study constitutes a first step in providing articulatory evidence of the parallels in the weakening processes observed in these two Romance languages.

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APPENDIX

Table 1A: Summary of a linear mixed model for Consonant, Type, and Position fit for the Spanish data by maximum likelihood (formula: $\text{lmer}(Q_a4 \sim C * \text{Type} * \text{Position} + (1|\text{Speaker}) + (1|\text{Item}), \text{data_sp})$).

	Est.	SE	Df	t	Pr(> t)	
(Intercept)	0.85	0.04	15.20	22.20	<.001	***
C d	-0.14	0.04	56.19	-3.89	.001	**
Type carrier	-0.09	0.02	2163.00	-5.77	<.001	***
Position medial	-0.09	0.03	55.09	-2.99	.004	**
Position final	-0.08	0.06	56.85	-1.24	.221	
C d x Type carrier	-0.32	0.02	2163.00	-13.44	<.001	***
C d x Position medial	-0.54	0.04	56.20	-12.39	<.001	***
C d x Position final	-0.26	0.08	56.95	-3.36	.001	**
Type carrier x Position medial	0.04	0.02	2163.00	2.01	.045	*
Type carrier x Position final	0.00	0.04	2163.00	0.10	.920	
C d x Type carrier x Position medial	0.39	0.03	2163.00	13.69	<.001	***
C d x Type carrier x Position final	0.39	0.05	2163.00	7.62	<.001	***

Table 2A: Summary of a linear mixed model for Consonant, Type, and Position fit for the French data by maximum likelihood (formula: $\text{lmer}(Q_a4 \sim C * \text{Type} * \text{Position} + (1|\text{Speaker}) + (1|\text{Item}), \text{data_fr})$).

	Est.	SE	Df	t	Pr(> t)	
(Intercept)	0.94	0.04	7.56	25.26	<.001	***
C d	-0.04	0.04	31.65	-1.17	.251	
Type carrier	-0.03	0.02	1303.00	-2.04	.042	*
Position medial	-0.05	0.03	31.76	-1.95	.060	.
Position final	-0.06	0.05	31.76	-1.23	.227	
C d x Type carrier	0.03	0.03	1303.00	1.05	.294	
C d x Position medial	-0.05	0.04	31.68	-1.13	.266	
C d x Position final	-0.16	0.06	31.77	-2.43	.021	*
Type carrier x Position medial	0.03	0.02	1303.00	1.59	.112	
Type carrier x Position final	0.02	0.04	1303.00	0.46	.647	
C d x Type carrier x Position medial	0.01	0.03	1303.00	0.25	.804	
C d x Type carrier x Position final	-0.05	0.05	1303.00	-1.07	.286	