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EXCEPTIONALITY IN SPANISH ONSET CLUSTERS*

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ABSTRACT. Spanish complex onsets have been traditionally described as consisting of a stop (/p, t, k, b, d, g/) or the fricative /f/ plus a liquid. Given that all Spanish varieties have other fricatives (/x, s/), the obstruents that can form part of an onset cluster do not straightforwardly compose a natural class. As such, past studies have argued that /f/ is exceptional in its ability as a fricative to pattern with stops in onset clusters. This paper presents empirical data from a nonce word judgment task that challenges this claim and shows that Spanish listeners rate unattested /xɾ/ clusters as more acceptable than ungrammatical /sɾ/ clusters. These results suggest that /s/, and not /f/, is exceptional in its inability to form complex onsets in Spanish. As /s/ is the sole sibilant in the Spanish consonant inventory and is uniquely characterized by the feature [strident], this generalization is easily capturable in a theoretical framework. This analysis further predicts that other non-sibilant fricatives should also be acceptable in onset cluster position, such as /θ/, which is supported by data from a follow-up study with speakers of Peninsular Spanish, who have this phoneme in their dialect. This analysis also predicts that other sibilants should be unacceptable in onset clusters. This is supported by data from the related languages Portuguese and Catalan, which have other sibilant phonemes (/s, z, ʃ, ʒ/) yet also have similar onset cluster phonotactics as Spanish, disallowing all sibilants from being in an onset cluster.

Keywords: Spanish, phonology, phonotactics, attestedness, grammaticality

RESUMEN. Los grupos de ataque en español tradicionalmente se describen como una oclusiva (/p, t, k, b, d, g/) o la fricativa /f/ seguida de una líquida. Dado que todas la variedades del español tienen otras fricativas (/x, s/), las obstruyentes que pueden formar parte de un grupo de ataque no conforman directamente una clase natural. Así anteriores estudios han señalado la excepcionalidad de /f/ como fricativa por su capacidad para alinearse con las oclusivas en los grupos de ataque. El presente estudio cuestiona esta afirmación y demuestra que oyentes hispanohablantes califican el grupo de ataque no atestiguado /xɾ/ como más aceptable que el grupo agramatical /sr/. Estos resultados sugieren que /s/, y no /f/, es excepcional en su incapacidad para formar un grupo de ataque en español. Como /s/ es la única sibilante en el inventario de consonantes del español y se caracteriza particularmente por el rasgo [estridente], esta generalización se captura fácilmente en un marco teorético. Además este análisis predice que otras fricativas no-sibilantes como /θ/ pueden formar parte de un grupo de ataque. Esta hipótesis se apoya en un estudio adicional con hablantes del español peninsular que tienen este fonema en su dialecto. Este análisis también predice que otras sibilantes no serán aceptables en los grupos de ataque. Esto se apoya en datos de otras lenguas relacionadas, como el portugués y el catalán, que tienen otros fonemas

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sibilantes (/s, z, ʃ, ʒ/) pero comparten las mismas restricciones fonotácticas que el español, es decir, no permiten que las sibilantes estén en un grupo de ataque.

Palabras clave: español, fonología, fonotáctica, atestabilidad, gramaticalidad

1. Introduction

Many languages allow clusters of two or more sounds to appear at the beginning of a syllable. Different languages have different restrictions on what consonants can occur in this position. For example, English allows onset clusters like /pl/, /dɹ/, and

/sm/ but disallows onset clusters like /bd/ and /lb/; other languages, such as Polish, are much less restrictive in this domain. In Spanish, onset clusters can consist of a stop consonant (/p, t, k, b, d, g/) or /f/, but not /s/, plus a liquid. This group of consonants allowed in the first part of an onset cluster does not constitute a natural class based on traditional phonological features. Because of this, this phenomenon has been the source of much debate in the literature, which tries to explain why /f/ is exceptional in that it patterns with stops.

This paper presents empirical data that challenges the claim that /f/ is exceptional in its ability as a fricative to form part of a complex onset in Spanish by investigating whether it is /f/ that is exceptional or if it is actually /s/ that is exceptional in its inability as a fricative to form part of a complex onset in Spanish. This question is tested by gathering acceptability judgments of nonce words beginning with /fɾ/ (grammatical because of attestedness in the lexicon), /sɾ/ (ungrammatical because of unattestedness in the lexicon and an active repair rule for loan words), and /xɾ/ (unattested in the lexicon, grammaticality unknown). The results of the experimental task are then used to propose a novel analysis of Spanish onset cluster phonotactics, which is phonetically-grounded and follows the current, standard ideas of phonological theory. Ultimately, this study of onset clusters in Spanish allows for a deeper understanding of the grammatical constraints that can affect the phonotactics of complex onsets in Spanish, other related languages with similar patterns, and beyond.

2. Background

2.1. Spanish onset clusters

Although Spanish varieties can differ in their realization of some phonemes, all varieties include voiced and voiceless labial, coronal, and velar stops, along with the lenited variants of the voiced stops ([p, t, k, b, d, g, β, ð, ɣ]). They all also include voiceless labial, coronal, and velar fricatives ([f, s, x]), as well as the liquids ([l, ɾ]). Most of these obstruent phonemes can be combined with the liquids to form complex onset clusters.

The canonical description of licit onset clusters in Spanish has been described as being maximally composed of a voiced or voiceless stop or /f/ plus a liquid (/l, ɾ/) (Harris 1983). Examples of these licit complex onsets can be seen in Table 1, with Latin American Spanish transcriptions.[1] It should be noted that the rhotic is always realized as an apicoalveolar tap [ɾ] in onset cluster contexts.

[1] /tl/ is an exception to this in most varieties of Spanish and /dl/ is an exception to this in all varieties of Spanish (Harris 1983; Bradley 2006a; Tobin 2002), but these clusters are also prohibited in other languages that allow stop plus liquid clusters (e.g., English and Italian, among others). This suggests that there is an

Table 1: Licit onset clusters in Spanish

Onset Cluster	Transcription	Gloss	Onset Cluster	Transcription	Gloss
/pl/	[**pl**a.ta]	'silver'	/pɾ/	[**pɾ**e.sjo]	'price'
	----------		/tɾ/	[**tɾ**a.xe]	'suit'
/kl/	[**kl**a.βo]	'nail'	/kɾ/	[**kɾ**e.a.sjon]	'creation'
/bl/	[**bl**u.sa]	'blouse'	/bɾ/	[**bɾ**u.xa]	'witch'
	[la **βl**u.sa]	'the blouse'		[la **βɾ**u.xa]	'the witch'
	----------		/dɾ/	[**dɾ**o.gas]	'drugs'
/gl/	[**gl**o.sa]	'gloss'	/gɾ/	[**gɾ**an.xa]	'farmer'
	[la **ɣl**o.sa]	'the gloss'		[la **ɣɾ**an.xa]	'the farmer'
/fl/	[**fl**u.xo]	'flow'	/fɾ/	[**fɾ**u.ta]	'fruit'

Although /f/ and /s/ are both voiceless fricatives, they behave differently. /s/ does not pattern with the other obstruents that appear in complex onsets. This segment is illicit when combined with a liquid in this position and is repaired with a prothetic intrusive vowel in both seemingly-native and loan words. Examples of this are shown in Table 2. In Peninsular Spanish, the /s/ tends to assimilate entirely in these contexts, such that a word like 'Israel' would be realized as [i.ra.el] (Navaro-Tómas, 1980). However, in Latin and South American Spanish dialects, this is not the case, and the realization of /s/ can alternate between [s] and [z] (as in Table 2) because of regressive voicing assimilation and possibly gestural overlap (Bradley, 2006b).

Table 2: Illicit onset clusters in Spanish

Onset Cluster	Transcription	Gloss
/sl/	[e**z.l**oɾa]	'length'
	[e**z.l**a.βon]	'link'
	[e**z.l**o.βa.ko]	'Slav'
/sɾ/	[e**z.ɾ**i.laŋ.kes]	'Sri Lankan'
	[i**z.ɾ**a.el]	'Israel'

Regarding the third Spanish voiceless fricative, /x/, Harris (1983: 34) suggests that this segment may be grammatical in onset clusters, but there is no empirical evidence regarding how this segment behaves in this position, as there are no instances of this segment in onset clusters in the lexicon and there is no known active repair rule.

The above description of onset clusters in Spanish, where all obstruents can cluster with liquids except /s/ and /x/, is uncontroversial, but the underlying reason as to why this

independent and perceptually-motivated constraint that disprefers this combination of sounds due to the perceptual similarity between /tl/ and /kl/ and between /dl/ and /gl/ (Flemming, 2007 2013; Parker 2012). Spanish varieties that do allow tautosyllabic /tl/ clusters have contact with Nahuatl, which allows these clusters. Because these exceptions are distinct from those at hand (/xɾ, sɾ/), further discussion of /tl/ and /dl/ will be omitted from this paper, but an analysis of this restriction can be seen in (Bradley 2006a).

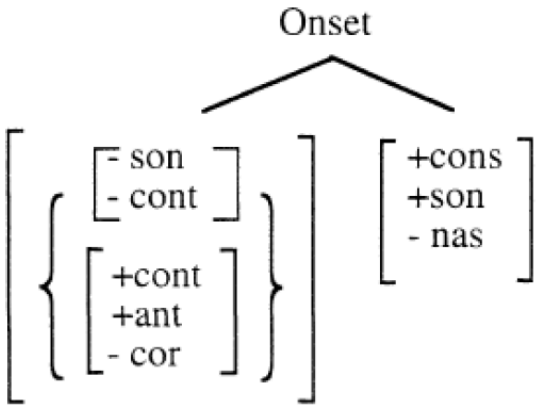
peculiar class of obstruents can precede liquids in onset clusters has been the source of much debate (Harris 1983; Martínez-Gil 2001; Colina 2009, 2016; among others). Naturally, the question arises as to why /f/ is seemingly exceptional in that it patterns with stops and not the other voiceless fricatives, /s/ and /x/. This generalization is not easily translated into formal terms in a transparent way, due to the fact that the set of consonants that are licit as the first consonant do not form any exclusive, natural phonological class based on articulation, perception, or phonological features. Because of this, it has been of interest to past researchers, but no analysis to date has been able to capture the Spanish onset cluster generalization in an accurate and theoretically-motivated way.

2.2. Previous work

2.2.1. Place

Harris (1983) proposed the structure, shown in Figure 1, as an account for the seemingly unnatural group of sounds that are allowed to be the first segment in Spanish complex onsets (i.e., stops plus /f/). Here, /f/ is distinct from /s/ because it is specified as [-coronal, +anterior]. However, this merely represents the generalization presented above in features without providing any insight as to why /f/ patterns differently from the other fricatives and instead patterns with stops.

Figure 1: Harris' (1983) description of Spanish complex onset phonotactics



2.2.2. Sonority

It is often the case that syllable structure phonotactics are explained through constraints placed on languages by the Sonority Sequencing Principle (henceforth, SSP). The SSP is a scale that characterizes cross-linguistic well-formedness in syllables (Selkirk 1984; Clements 1990; among others). Simply stated, the SSP prefers syllables whose nucleus, or peak, is the most sonorous, and the syllable margins whose consonants create a unidirectional sonority slope that rises towards the peak. Although there has been much debate about whether or not there is a single phonetic correlate of sonority, it seems to correlate both with relative intensity compared to surrounding segments and the degree of articulatory stricture, which is also a relative property (Price 1980; Keating 1983;

Ladefoged 1993; Parker 2002, 2008). Cross-linguistically, the sonority hierarchy gives segments the following relative ranking: vowels > glides > liquids > nasals > obstruents. This broad classification has shown to be overwhelmingly consistent between languages, but beyond this, it has been proposed that further sonority subdivisions within classes of sounds can be made depending on the language; for example, it has been argued that voiced obstruents can be more sonorous than their voiceless counterparts, or that fricatives or sibilants can be more sonorous than stops, despite their similar classification as obstruents (Lloret & Jiménez, 2001; Jany et al. 2007; Parker 2008).

Reported data and analyses of Egyptian Arabic, Malayalam, and Catalan propose that sibilants are in fact more sonorous than other fricatives (Jany et al. 2007; Lloret & Jiménez, 2001). Given this argument for Catalan, a language closely related to Spanish, it is worthwhile to consider that /f/ is allowed to pattern with the stops in Spanish because it is less sonorous than the sibilant /s/; this view has been adopted in past work (Harris 1983, 1989; Hualde 2004; Colina 2009; Sheperd 2003). In order to differentiate /s/, which is not allowed in this position, from the other fricatives, /s/ would have to be more sonorous than the other fricatives in the Spanish inventory. This would indicate that the sonority difference between non-/s/ obstruents versus liquids would be greater than that of /s/ versus liquids, yielding better phonotactic well-formedness (Selkirk 1984).

Because relative intensity is one of the most reliable phonetic correlates of sonority, to explain the ungrammaticality of Spanish /s/ in complex onsets, /s/ would necessarily have a higher relative intensity than the other fricatives in the same prosodic context in Spanish, as this could explain the difference between the behavior of Spanish /s/. However, Parker (2002) quantitatively showed that Spanish /s/ does not have a higher but actually a lower relative intensity than /f/ and other fricatives in multiple contexts, and therefore, it is not more sonorous if it is assumed that phonology is phonetically-grounded. Subsequently, this would rule out the possibility of a strict sonority explanation for the apparent ungrammaticality of /s/ in Spanish complex onsets, while other segments of the same class are licit.

If, on the other hand, it is not necessary that phonological properties have direct phonetic correspondents, as proponents of emergentist or substance free phonology would argue (Mielke 2005, 2008; Odden 2006; Blaho 2008; Iosad 2017; among others), then the fact that the relative intensity of Spanish /s/ is not greater than that of /f/, is less important. /f/ having a sonority profile intermediary between the other obstruents and /s/ is plausible, and some feature denoting this would need to emerge in order to account for this pattern. Even under this approach though, it is unknown how /x/ would pattern. It could pattern with the other obstruents and be licit in onset clusters or it could pattern with /s/ and be prohibited in this context, but knowing this is still important in order to understand how the segments group in order to propose an emergent feature that can account for those groupings. Therefore, regardless of one's view on the role of phonetics in phonology, the question stands as to how /x/ patterns in Spanish compared to other fricatives in onset cluster contexts.

2.2.3. Underspecification of continuancy

Martínez-Gil (2001) and Colina (2016) abandoned the idea that onset restrictions are determined by place of articulation or sonority and instead proposed that manner of articulation is what is important for Spanish phonotactics. They claimed that /f/ patterns

with the stops because it is underspecified for the feature [continuant]. Because the voiceless coronal and dorsal stops (/t, k/) are phonemically contrastive with respective fricatives (/s, x/), they must hold a [continuant] specification. As there is no stop counterpart to /f/, they argue that it is redundant for it to be marked as [+continuant] because there is no contrast with this feature at the labiodental place of articulation. Therefore, they propose that the set of consonants that can constitute the first segment of an onset cluster in Spanish are those that do not have a specification for [+continuant] (e.g., all stops and /f/). These proposals thus imply that /x/ is not permitted in onset cluster position, since this segment would have a [+ continuant] specification.

This account is problematic for a number of reasons. If place features are what define the natural classes, then /f/ is in fact contrastive with stops because there is no feature specifically for labiodental sounds: just as /s/ versus /t/ and /k/ versus /x/ are defined by the place features [coronal] and [dorsal], respectively, /f/ and /p/ are both defined by the place feature [labial]. Hualde (2005: 150) and Lipski (2016: 248) state that some dialects of Spanish actually do have a voiceless bilabial fricative [ɸ] in lieu of [f]. As such, a specification of [continuant] would be necessary to distinguish a word like *pino* [pino] 'pine' from *fino* [ɸino] 'fine'. Having a bilabial fricative that is specified for the feature [continuant], which is necessary in these dialects, should mean that the bilabial obstruents pattern with coronal obstruents. This would result in both [s] and [ɸ] being illicit in complex onsets in these dialects, but this is not the case.

Furthermore, Colina (2016) acknowledges the relevant allophonic variation of voiced obstruents in Spanish: Spanish voiced stops are produced as fricatives or approximants when following [+continuant, +sonorant] segments, and this realization holds even when produced as the first segment of an onset cluster. So, as previously mentioned, the set of consonants allowed in the first slot of Spanish complex onsets in phonetic output forms includes [p, t, k, b, d, g, f, β, ð, ɣ]. /s/ is still prohibited in this position. She argues that these consonants can only form this class if voiced obstruents, along with /f/, are all underspecified for the feature [continuant] and if this underspecification persists in the output forms. This analysis results in a three-way continuancy contrast in the Spanish consonant inventory: [+continuant] segments (voiceless fricatives except for /f/, which do not alternate with voiceless stops in the same way that their voiced counterparts do), [-continuant] segments (voiceless stops), and segments that are underspecified for the [continuant] feature (voiced obstruents and /f/). Segments that do not hold a [+continuant] specification (i.e., segments that are [-continuant] and segments that are underspecified for [continuant] can hold the first position in an onset cluster.

This account of Spanish onset clusters is problematic for a variety of reasons. As mentioned in Section 2.2.2, substance free phonology posits that features do not have phonetic correlates and that they emerge in order to group segments and account for various phonological patterns within languages. In Colina's (2016) account, she seems to subscribe to this theory, positing that what groups together these consonants is the lack of a [+continuant] specification. This is at odds though with her motivation for the proposal, which was to account for the group of output forms that appear in onset cluster contexts, which include gradient variations of the voiced stops. A substance free feature theory would not need to or aim to account for this variation, as that is outside their scope of phonology. If her goal is to account for this variation, then the features used to group sounds together should be phonetically-grounded. If voiced obstruents and /f/ are naturally

grouped together because they are underspecified for continuancy so that the different phonetic forms of the voiced obstruents can be accounted for underspecification allows for the different phonetic forms of the voiced obstruents, variable pronunciations of this /f/ should also be expected in similar contexts. This type of variation is unattested, as there is no anecdotal or quantitative evidence that /f/ ever behaves in a stop-like manner or has variable pronunciations similar to the voiced obstruents in Spanish.

Finally, underspecification is incompatible with a constraint based analysis that assumes Richness of the Base (henceforth, ROTB), which rules out any restrictions on the forms of inputs, including leaving features unspecified. The principle of ROTB is that, in a constraint-based framework such as Optimality Theory (henceforth, OT) (Prince & Smolensky 1993/2004), all phonological alternations are generated by the same constraints that are responsible for unchanging phonotactic generalizations. Thus, ROTB states that a language's constraint ranking should yield the correct, well-formed outputs for all possible inputs regardless of the input form. For the case of Spanish voiced obstruent alternations, leaving the [continuant] feature underspecified violates ROTB, as it is restricting what the input can be. /f/ must be able to have some feature specification and still be able to be grouped via the correct Spanish constraint ranking with [p, t, k, b, d, g, β, ð, ɣ] and crucially not with /s/ in order to account for the segments that are allowed as the first consonant in Spanish onset clusters.

3. This study

The question that past researchers have tried to answer is 'Why is /f/ exceptional?' However, the question that should be asked instead is not 'Why is /f/ exceptional?' but rather 'Is it /f/ or is it /s/ that is exceptional?' The Spanish data clearly show that /f/ can form part of an onset cluster while /s/ cannot, but there is no data to support or refute the grammaticality of the third voiceless fricative, /x/ in this context, as there is no evidence in Spanish that /x/ plus liquid complex onsets are acceptable or unacceptable, and no empirical study has investigated this.

The goal of the following experiment is to test whether or not native Spanish listeners accept the velar fricative in an onset cluster. In aiming to discover how

/x/ behaves in Spanish onset clusters, participants in this experiment were asked to first identify sequences of two sounds, including /xɾ/, /fɾ/, and /sɾ/, in order to confirm that they could recognize the initial fricative in each of these three target onset clusters. If they achieved high accuracy in identifying these clusters, they then continued to a nonce word judgment task. The nonce words of interest began with these same three complex onsets. If there is evidence that /x/ plus liquid clusters are more acceptable than those with /s/, then it can be concluded that it is /s/ that is exceptional in its inability to form part of a complex onset, rather than /f/ because of its unacceptability compared with other unattested clusters. This is because it has been previously shown that listeners' phonological judgments of nonce words often show gradience, meaning they are rarely black and white (Anttila 2008; Albright 2009; Coetzee 2008, 2009; White & Chiu 2016, 2017; among others). With this type of task, whereby listeners are asked to rate how much a word form sounds like it could be a word of their language, it is typically the case that attested, or real words, which listeners have experience with, are consistently rated as being better than unattested, or novel word forms. However, within unattested forms, listeners' ratings tend to show sensitivity to the phonotactic restrictions of their language. If an unattested form is

phonotactically licit, it is likely to be rated as better than an unattested form containing phonotactic violations of that language. If, on the other hand, there is evidence that /x/ plus liquid clusters are equally as unacceptable as /s/ plus liquid clusters, then it can be concluded that /f/ is in fact exceptional in its ability as a fricative to form complex onsets in Spanish.

4. Methods

The grammaticality judgments of /xɾ/ clusters were compared against those of /sɾ/, which are ungrammatical, and /fɾ/, which are grammatical, in order to shed light on the phonotactic constraints that apply to onset clusters in Spanish.[2] This section presents the hypotheses, participant demographics, stimuli characteristics, design of the experiment, and a description of the statistical tests used.

4.1. Participants

There were 123 participants in this study, all of whom gave their consent to participate in the study, which was approved by the Institutional Review Board. Participants were asked to provide information on their demographics and language background through an online form at the start of the experiment. They were asked to provide their age, gender, languages spoken, first language, dialect of Spanish, and which language they use the majority of the time.

4.2. Stimuli

The target stimuli for the nonce word judgment experiment included 20 made-up words of Spanish for each /xɾ, fɾ/, and /sɾ/ onsets, totaling 60 target tokens. These were randomized with 172 nonce words beginning with /pɾ, tɾ, kɾ, *pn, *tn, *kn, *sl/, and /*tl/. All tokens had -VCV tails, which is a common word shape in Spanish. For each onset cluster, there were four stimuli with each of the five vowels of Spanish (/i, e, a, o, u/) for the initial vowel, and the medial consonant was randomized from all possible Spanish consonants; both of these measures were taken in order to minimize other phonotactic confounds of the stimuli. Finally, the final vowel consisted of either /a, o, e/, as to conform to morphological patterns of the vast majority of Spanish non-verbs, chosen to prevent negative judgments due to parts of the word forms not at interest in this study (i.e., the tails). A list of stimuli can be found in the Appendix.

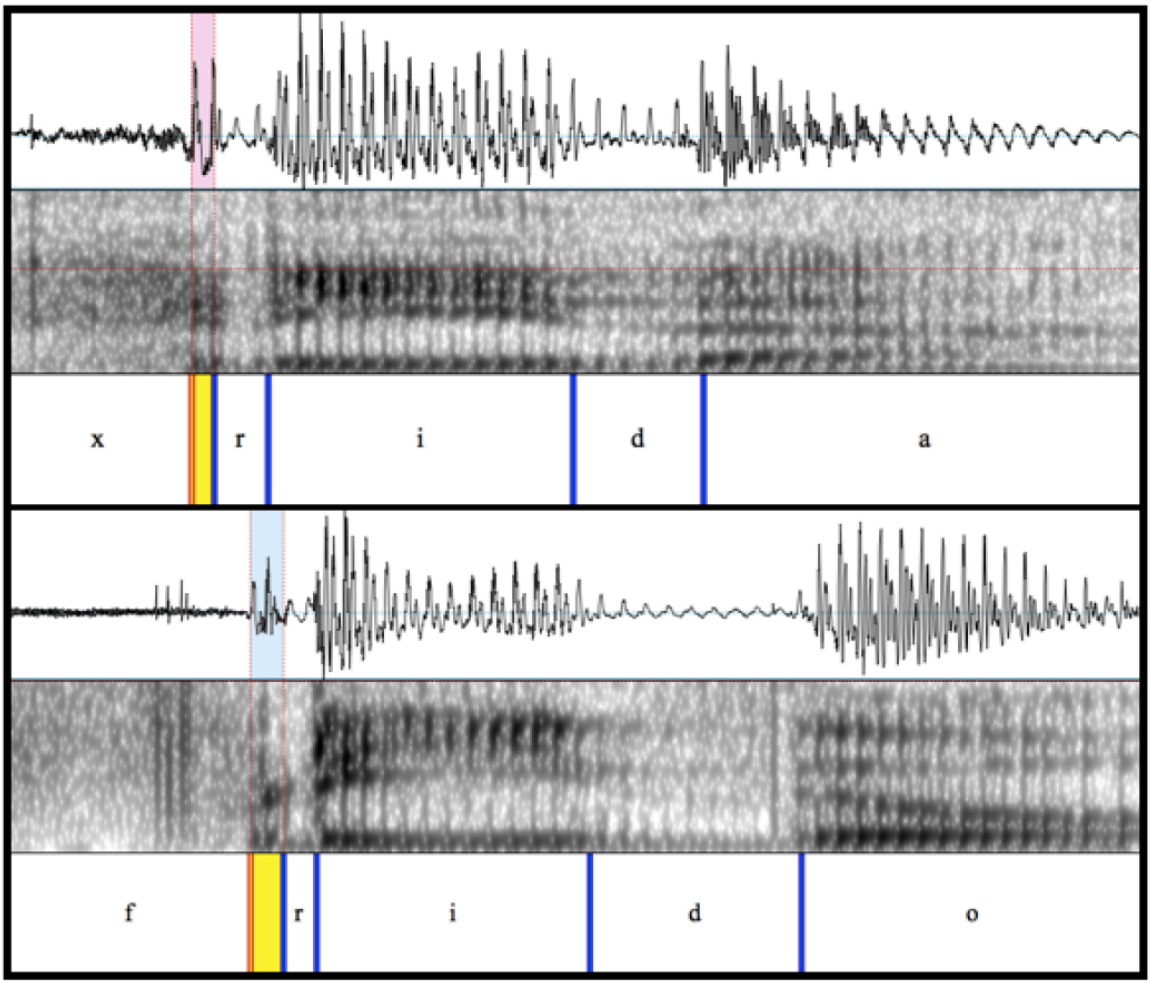
Each stimulus token was recorded by a 30 year old male who is a trained phonetician and a native speaker of Spanish from Bogotá, Colombia; a speaker of this dialect was chosen because Spanish of Bogotá has been characterized as having well-maintained articulatory precision with significantly less consonant lenition than other dialects (Canfield 1981: 5, 36; Carreira 1998: 146; Izquierdo et al., 2010: 72; Chávez & Romero 2017: 29; among others). By trying to ensure clearly articulated stimuli, any potential unwanted effects from lenited or non-standard production were minimized. This was important for this perception study, as non-standard pronunciations could affect listeners' of other dialects judgments and distract from the onset cluster portion of the word.

Although intrusive (i.e., Svarabhakti) vowels have been reported in licit Spanish onset clusters (e.g., [tᵊɾaxe] 'suit') (Gili 1921; Bradley & Schmeiser 2003; Bradley 2006c), they

[2] It should be noted that not all C+/l/ clusters were included solely so that the experiment duration was not excessive for the participants.

were not acoustically salient in the stimuli recorded, and therefore, no modifications were made. The /xɾ/ stimuli did not have notable intrusive vowels present either, unlike the other unattested onset clusters, and thus were not modified in this way. Figure 2 shows example spectrograms of /xɾ/ and /fɾ/ onset cluster words. From these, it is clear that the intrusive vowel produced in both the /xɾ/ and /fɾ/ words was minimal.

Figure 2: Target and grammatical nonce word stimuli spectrograms. The top image shows a nonce /xɾ/ stimulus; the short intrusive vowel is highlighted. The bottom image shows a nonce word with an attested /fr/ complex onset; the short intrusive vowel is again highlighted. These and other attested and /xɾ/ stimuli were not edited, as the amount of vocalization present in the onset cluster is not uncommon for Spanish complex onsets.

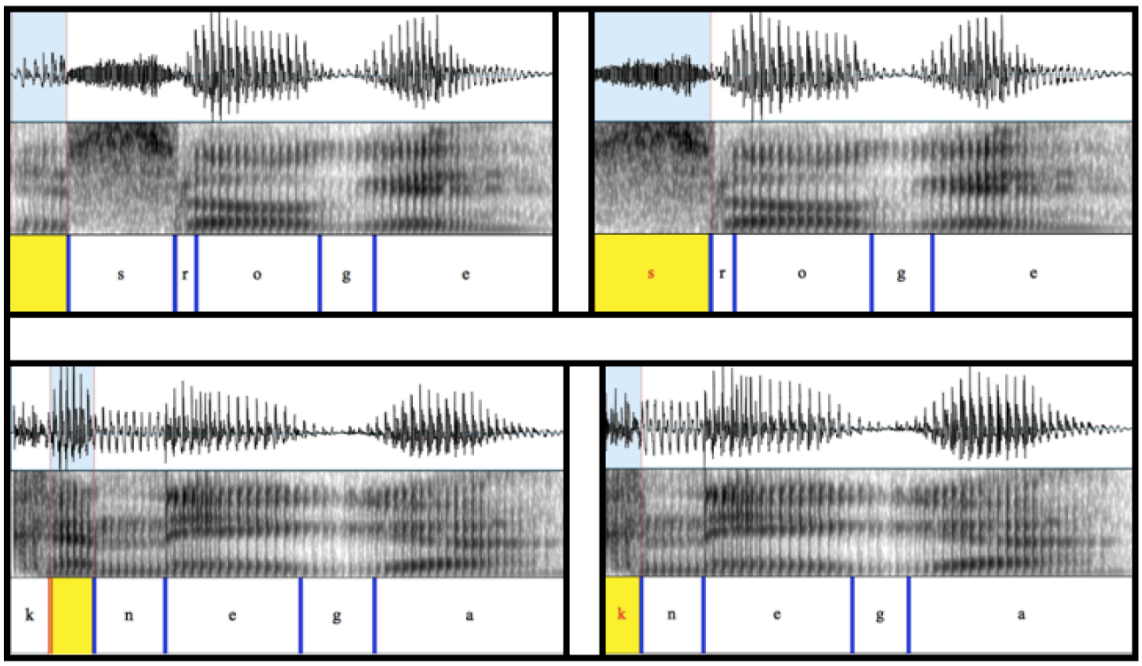


A much longer prothetic intrusive vowel, up to 120ms, in the /sɾ/ word was manually edited out and can be seen in Figure 3. Similarly, unattested and ungrammatical onsets like /pn/ and /kn/, for example, had intrusive vowels comparable to or longer than the initial intrusive one observed for /sr/ clusters, around 120ms, which were also manually removed in PRAAT Phonetics Software (Boersma 2006). A representative example of a /kn/ word is shown also in Figure 3, both before and after editing. All tokens were also normalized for amplitude to the mean across stimuli in PRAAT. It should be noted that the following /ɾ/ in the clusters never strengthened to a trill [r] in these stimuli, as has been reported in

words like Israel [i.ra.el] where the /s/ assimilates to the following segment, resulting in a trill (Navaro-Tomás 1980; Solé 1999); Along these same lines, the /s/ was always realized as an [s] or [z] and was never aspirated.

No significant differences were found between stimuli regarding word duration and mean fundamental frequency of the stressed vowel. This was determined with mixed effect linear regressions, for both mean F0 and duration, whereby the quality of the stressed vowel was included as a random intercept. Because there were no significant differences between groups of stimuli with differing onset clusters with respect to mean F0 and duration, after correcting for the variation caused by differing vowel qualities as a fixed effect, the stimuli were not manipulated in any way to normalize these factors.

Figure 3: Ungrammatical nonce word stimuli spectrograms before and after editing. The two leftmost images show spectrograms of example unattested/ungrammatical nonce word stimuli before manual removal of vocalization; the intrusive vowels are highlighted. The rightmost two images show spectrograms of these same stimuli after the manual removal of the vocalization that affects the complex onset.



The first syllable of these nonce words was then extracted for use in the identification task. These manipulated stimuli were normalized for duration and were given gradual fadeouts to minimize their sounding overly-abrupt and unnatural due to their being segmented from a longer word. The onset and offset ramps for these fadeouts were created using a raised cosine window, with the onset ramp duration set at 0.0001 and the offset at 0.05 seconds.

4.3. Task

The experiment was hosted on the online IbexFarm platform (Drummond 2013). Participants were first asked to give their consent to participate in the study. Subjects were then presented with a sound check that only allowed them to proceed if they were wearing headphones (Woods et al. 2017). This was performed to help control the sound

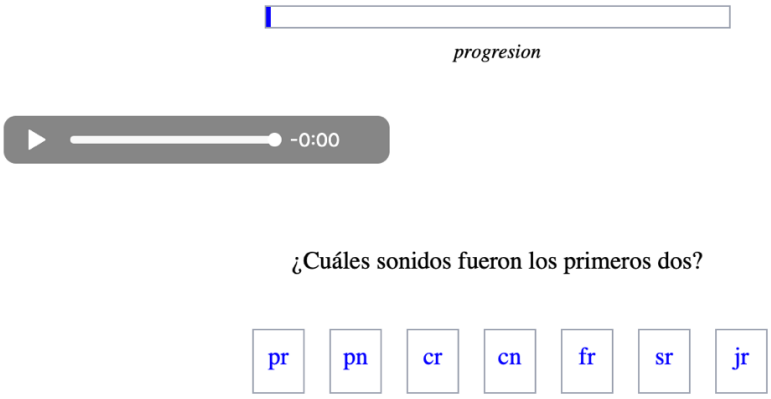
presentation, which is important for a perception task involving fricatives that are characterized by high amount of acoustic noise. Listeners heard three sounds, of which one of the tones was presented 180◦ out of phase across the stereo channels. They had to judge which of three tones was the quietest. Hearing the softest tone is simple when wearing headphones but difficult when listening over speakers due to phase cancellation. Participants were asked to select the softest of three tones six times. In order to continue to the language experiment they were required to correctly select the quietest tone five of six times.

4.3.1. Identification task

After successfully passing the headphone check, participants were prompted to begin a sound identification task. They were presented with the following complex onsets:/ʔxɾ, *sɾ, fɾ, kɾ, pɾ, *kn, *pn, *tl/. After being able to listen to two examples of each

onset followed by a random vowel (i.e., CCV syllables), they were prompted to begin the identification task. A syllable with one of the aforementioned onset clusters was presented aurally, and each of the onsets was written in standard Spanish orthography below; all of the consonant clusters in Spanish orthography match their corresponding phonemic transcription, with the exception of the /xɾ/ cluster, which is represented with the letters 'jr'. Although both of these segments and their corresponding orthographic representations are possible in onset position, Spanish listeners would not have previously seen these segments adjacent, even word internally; the same is true for /pn/ and /kn/ as well. Upon listening to the stimulus, participants were required to select which sounds were the first two that were played. Seven tokens of each /xɾ, sɾ, fɾ/ were presented, while the other onsets were presented only three times each. These were presented in a randomized order, and a sample of what participants saw during this task is shown in Figure 4. A forced decision task was implemented in order to inform the participants of the possibility of unattested clusters, such as /xɾ, pn/, etc., rather than allowing for an open-ended response.

Figure 4: Sample screen of what participants saw during the identification task



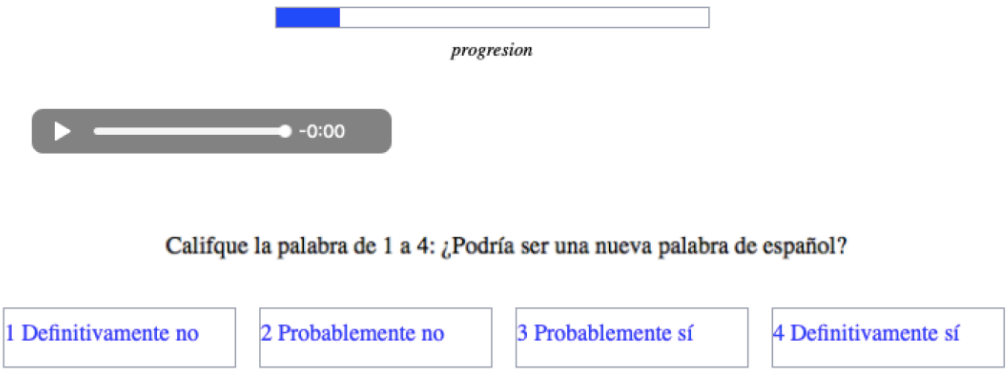
The purpose of the identification task was to ensure that Spanish listeners could in fact discriminate between /xɾ/ and other clusters that are acoustically similar, such as /kɾ/ and /fɾ/. The reason for this was to help ensure that in the nonce word judgment task participants were perceiving /xɾ/ as /xɾ/ and responding accordingly, rather than perceiving /xɾ/ as /kɾ/ or /fɾ/, which could falsely yield high acceptability of these words. Only the participants who could reliably discriminate /xɾ/ from the other clusters with 71.4% accuracy (five of the seven /xɾ/ stimuli presented had to be correct) and correctly identify /sɾ/, /fɾ/, and /kɾ/ clusters with 87.5% accuracy (six of the seven stimuli presented for /sɾ/ and /fɾ/ correct) were assumed to be able to perceptually distinguish this unattested /xɾ/ cluster. The results of participants who did not meet this criterion based on the identification task were excluded from the analysis of nonce word judgments. The results of this identification task are presented below in Section 5.1.

4.3.2. Nonce word judgment task

For the nonce word judgment task, the set of previously described target stimuli were presented aurally in a randomized order. Listeners were presented with an isolated nonce word and were asked to give the form a score on a scale of 1-4 for how likely the stimulus could be a new word of Spanish, with 1 meaning it could never be a word of Spanish, 2 meaning it probably could not be a word of Spanish, 3 meaning it probably could be a word of Spanish, and 4 meaning it definitely could be a word of Spanish. This gradient scale was chosen for assessment of the novel forms due to the gradient nature of phonological judgments, which extend being simply "grammatical" or "ungrammatical" in terms of acceptability. Intermediate levels of acceptability are often reported for nonce words based both on lexical frequency statistics and native phonotactic constraints, meaning that nonce words that are more similar to existing lexical items and that show fewer phonotactic violations tend to receive better ratings than those that are completely foreign (Albright 2009; Berent et al. 2007; Coetzee 2008, 2009; among others). Figure 5 shows a screenshot of what participants would have seen for each of the 232 nonce words that was presented to them.

The first two tokens presented were practice trials; these responses were not included. During the remaining experimental trials, participants were given two breaks throughout task, where they were given the option to watch Pixar short films. The whole experiment lasted roughly 45 minutes, and participants were offered seven dollars to compensate them for their time.

Figure 5: Sample screen of what participants saw during the nonce word judgment task



4.4. Statistics

The dependent variable, the one-to-four rating from the nonce word judgment task, was analyzed using a mixed effects ordinal regression in R (R Core Team, 2013) with the integrated development environment RStudio (RStudio Team 2015); the packages utilized were 'lme4' (Bates et al. 2014) and 'ordinal' (Christensen 2015). An ordinal regression was chosen due to the fact that participant responses were on an arbitrary scale from one to four, whereby only the relative ordering between the different values on this scale were relevant, as compared to a non-arbitrary continuous scale with linear regressions. With the ordinal regression, the rating responses of /xɾ/ clusters, the reference level, were compared to those of /fɾ/ and /sɾ/ clusters, with onset cluster as a fixed effect and the individual subjects and tokens as random intercepts using the default polynomial trends contrast. The definition of the model is shown below in example 1. This mixed effects model accounted for the variation introduced by individual subjects and items, providing a better estimate of how much of the variation in responses was attributed to the factors that were manipulated in a controlled way, the onset cluster and the stressed vowel. A maximal model that included random effects of subject and token on the slopes of the fixed effect, Onset Cluster, was also run but did not converge.

(1) **Ord<– clmm(Response~OnsetCluster+(1|Subject)+(1|Token))**
The dependent variable is the participant response. The fixed predictor is the Onset Cluster type. Subject and Token are random intercepts.

5. Results

5.1. Identification task

123 participants completed the identification task. 100 of them were ultimately included in the study, as the remaining 23 failed to meet the minimum accuracy to be included in the second part of the study. The criteria were set at correctly identifying at least 71.4% (or

five of seven) /xɾ/ clusters and 85.7% or higher accuracy on the other fricative clusters. The criterion for /xɾ/ clusters was set slightly lower than that for

/fɾ/ and /kɾ/ clusters because it is unattested and subjects have less, if any, familiarity with this sound combination. Of these 100 participants who met the cut-off point for being able to correctly identify /xɾ/ from other acoustically similar sound sequences, most of the participants performed better than this cutoff: the mean accuracy across listeners was 91.5%; 34 achieved 100% accuracy in identifying /xɾ/ onsets. These subjects also achieved high accuracy in correctly identifying the /fɾ/ and /sɾ/ clusters at or above 85.7% correct, with all but one participant correctly identifying all /fr/ and /sr/ onsets.

Of the 100 participants who passed the identification task, 49 (49%) were female. Though the ages of these subjects spanned 18-63, the mean age was 26.45 with a median and first and third quartile (M(Q1,Q3)) of 25(23,29). There was one speaker from Chile, one from Argentina, one from Bolivia, seven from Mexico, eight from Colombia, ten from Spain, 13 from Ecuador, and 57 from Venezuela. Most speakers also reported some proficiency in English, and some speakers had some knowledge of French and/or German.

There were no demographic differences that separated the subjects who passed the identification task from those who failed to do so. 10 of the 23 participants in the cohort that did not pass were female (43%), and their ages ranged from 18-75 with a mean of 28 and a M(Q1, Q3) of 25(20.5,30.25). They represented Ecuador (n=2), Spain (n=2), Mexico (n=2), Peru (n=2), Colombia (n=3), and Venezuela (n=12). Many of them also reported some knowledge of English, French, and/or German.

Those who performed poorly on the identification task, achieved a group accuracy of 40.3% on /xɾ/ cluster identification, which was significantly worse than those who passed this task as determined by a two-tailed t-test. Across all participants, incorrect responses to /xr/ clusters varied: 40.9% were identified as /fɾ/, 37.0% were identified as /kɾ/, and 22.1% were identified as /pɾ/.

It should be noted that there did not seem to be any negative effect of unfamiliarity with the orthography, as the unattested clusters and /xɾ/ clusters (written ‘jr’) are not present even word-internally in Spanish. The passing 100 participants all displayed equally high accuracy (85.7%, or at least six out of seven correct) for /pn/ and /kn/ clusters, indicating that the lack of attestedness and orthographic unfamiliarity did not interfere with their perception.

5.2. Nonce word judgment task

The results of the 100 participants, who all achieved at least 71.4% accuracy in identifying /xɾ/ clusters from other acoustically similar clusters and achieved at least

85.7% accuracy in identifying /fɾ/ and /sɾ/ clusters, were included in the analysis of the nonce word judgment task.

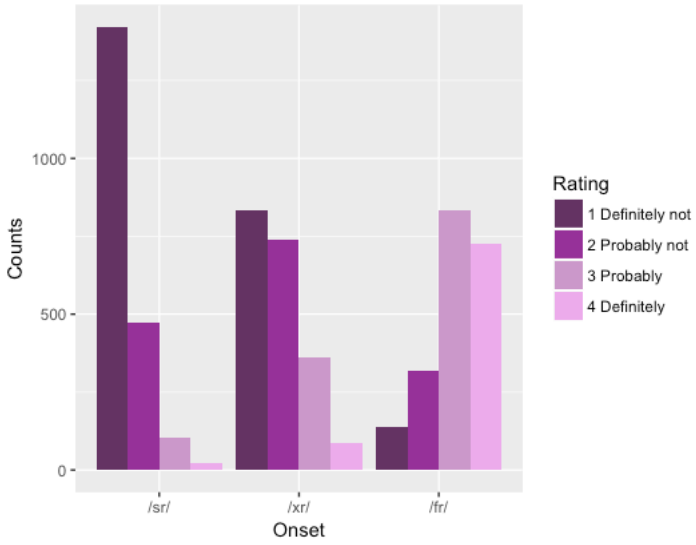
Overall, participants rated the test /xɾ/ clusters as more acceptable than the ungrammatical /sɾ/ clusters, but less acceptable than the grammatical /fɾ/ clusters. This is demonstrated by the data in Table 3. It is clear that /fɾ/ clusters were rated to be very Spanish-like, given the high percentage of ‘good’ judgments (3-4) and the small amount of variation shown by the interquartile range. On the contrary, /sɾ/ clusters were judged to be non-Spanish like, with the majority of responses as 1, or definitely not Spanish-like. /xɾ/ clusters, of most importance here, fell in between the scores of the grammatical and ungrammatical fricative-initial onset clusters, with the majority of responses being 2-3.

Table 3: Mean and inter-quartile range of responses for the fricative-initial onset clusters

Cluster	Mean (SD)	Median (Q1, Q3)	Percent of each response			
			1	2	3	4
/sɾ/	1.37 (0.63)	1 (1, 2)	70.4%	23.4%	5.1%	1.1%
/xɾ/	1.85 (0.86)	2 (1, 1)	41.3%	36.6%	17.9%	4.2%
/fɾ/	3.06 (0.89)	3 (3, 4)	6.9%	15.7%	41.3%	36.0%

These results are also shown in Figure 6. From this plot, it is clear that /fɾ/ clusters, shown in the rightmost column, were given the highest ratings in this task, due to the higher number of 3 and 4 responses. The responses for /sɾ/ clusters, in the leftmost column, are mainly 1, which is the worst of the four ratings. The data in the middle indicate the responses for /xɾ/ words, which is more variable than for the other two groups. Although many /xɾ/ words were given lower ratings, there appear to be fewer responses with a rating of 1 and more responses in the 3-4 range than for the /sɾ/ clusters, suggesting that these are preferred over or are more Spanish-like than the ungrammatical /sɾ/ clusters.

Figure 6: Grammaticality judgments of onset clusters in Spanish. Graph showing number of each response type per onset cluster



In order to confirm the tendencies revealed with the descriptive statistics above, the results from the mixed effects ordinal regression analysis, described in Section 4.4 are presented in Table 4. Grammaticality judgments from the /xɾ/ clusters were used as the reference level to which the judgments on the other clusters were compared. After accounting for within-subject and within-item variation, the trends shown with the descriptive statistics above achieved statistical significance: /fɾ/ clusters were reliably rated as being more Spanish-like than the /xɾ/ clusters ($p<0.0001$), while /sɾ/ clusters were reliably rated as less Spanish-like than the /xɾ/ clusters ($p<0.0001$).

Table 4: Results of ordinal regression comparing judgments on nonce words with fricative-initial onset clusters

Contrast against /xɾ/	β-Estimate	Standard Error	z-value	p-value
/fɾ/	2.96	0.18	16.11	p<0.0001
/sɾ/	-1.51	0.18	-8.30	p<0.0001

Because /fɾ/ and /sɾ/ clusters were used as controls to which /xɾ/ judgments were compared, the responses for the other grammatical and ungrammatical clusters presented are also of import in order to confirm that /fɾ/ and /sɾ/ serve as good grammatical and ungrammatical controls, respectively. Figure 7 shows the responses per onset cluster of the grammatical, attested Spanish onset clusters /kɾ, pɾ, fɾ/. An identical non-maximal mixed effects ordinal regression, as presented below, was run on the response data from these onsets, with subject and token included as random intercepts. This model revealed that there were no significant differences between responses for /fɾ/, /pɾ/, or /kɾ/.

Figure 7: Grammaticality judgments of attested onset clusters in Spanish. Graph showing number of each response type per onset cluster, showing that grammatical /fr/ onset clusters behave similarly to other grammatical onset clusters, given the distribution of rating responses

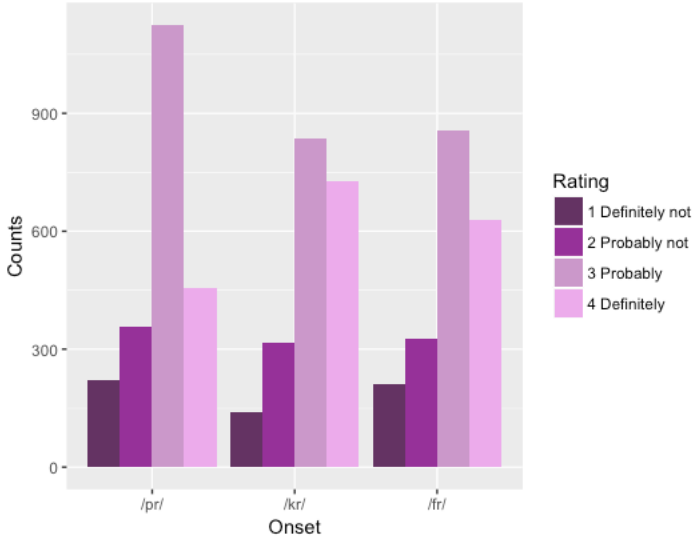
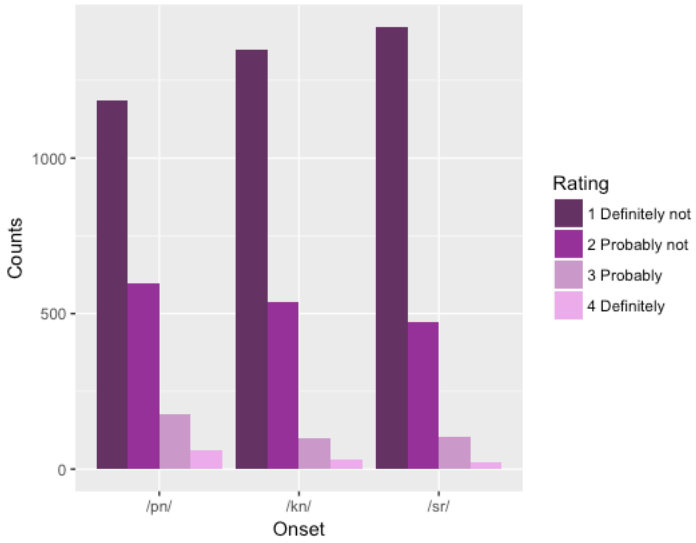


Figure 8 shows the responses per onset cluster of the ungrammatical, unattested Spanish onset clusters /sɾ, pn, kn/. Again, a non-maximal mixed effects ordinal regression, as shown in Section 4.4, was run on these responses. The results of this model showed that /sɾ/ responses did not differ from /kn/ responses, but /pn/ responses were significantly higher than those of /sɾ/ and /kn/.

Figure 8: Grammaticality judgments of unattested onset clusters in Spanish. Graph showing number of each response type per onset cluster, showing that ungrammatical /sr/ onset clusters behave similarly to other ungrammatical onset clusters, given the distribution of rating responses



It is unclear why judgments for /pn/ nonce words were significantly higher than for the other ungrammatical onset clusters, especially since the gradient nature of sonority distance in onset clusters would predict /pn/ to be worse than /sr/ (and /sl/ and /tl/). It is possible that there is some familiarity with words of Greek origin that are spelled with 'pn' in Spanish, such as 'pneumático' (pneumatic), which could have led to slightly higher acceptability for this ungrammatical onset cluster. Nonetheless, this graph does still show that the vast majority of responses to /pn/ were still 1 and 2. Nonetheless, /pn/ nonce words were still rated as being significantly worse than /xɾ/ nonce words, providing further support for the argument that /xɾ/ is a possible grammatical onset in Spanish.

These additional tests revealed that /fɾ/ and /sɾ/ do not behave differently than other licit and illicit clusters, respectively.

6. Discussion

The empirical results of the present experiment suggest that, overall, native Spanish listeners rate /xɾ/ clusters as being more acceptable than the ungrammatical /sɾ/ clusters, which suggests that /s/ is exceptional in its inability to form complex onsets in Spanish; this differs from past proposals that argued that /f/ is exceptional in that in can form complex onsets in Spanish. If the /xɾ/ clusters were phonotactically illicit, their ratings would not have differed from those of the ungrammatical /sɾ/ clusters, both of which are unattested. Because this was not the case, it can be concluded that /xɾ/ clusters are marginally acceptable, as they yield acceptability ratings greater than those for ungrammatical /sɾ/ clusters but are not rated as well as the attested /fɾ/ clusters.

The results of this study provide evidence that ultimately support Harris' (1983: 34) original prediction regarding /x/ plus liquid clusters. They contradict more recent previous analyses on Spanish onset cluster phonotactics, summarized in Section 2, which more or less argue that stops and /f/ plus a liquid are the only licit complex onsets. This experiment suggests that /xɾ/ clusters are also phonotactically licit, despite their unattestedness. Thus, /f/ is not unique in its phonotactic behavior.

6.1. Gradient acceptability and variability

The observed gradient acceptability (Albright 2008, 2009; Coetzee 2008, 2009) of /xɾ/ clusters is evidence that this sequence is not systematically prohibited by the Spanish grammar. It has been previously shown that acceptability judgments for unattested sequences or nonce words that are grammatical are lower than those for attested forms but higher than those for other unattested, ungrammatical (Albright 2008, 2009; Coetzee 2008, 2009), particularly for phonotactic judgments (Daland et al. 2001; Frisch & Zawaydeh 2001; White & Chu 2016, 2017; among others). The fact that /xɾ/ were given acceptability ratings between those of /fɾ/ and /sɾ/ clusters suggests that this onset cluster is in fact grammatical, despite its unattestedness.

Spanish listeners have sufficient experience with /fɾ/ clusters to know they are grammatical, hence the high acceptability judgments. Even so, some speakers judged the novel /fɾ/ words as un-Spanish-like, likely because the words themselves were unattested. The novel /sɾ/ clusters were given low ratings because they are ungrammatical, which is further evidenced by the presence of an active repair strategy (i.e., /sC/ → [es.C]). However, the Spanish listeners have no prior experience of /xɾ/ clusters, and no participant had exposure to a language like Greek where this cluster is present. If they believed this complex onset to be ungrammatical, the ratings would have matched those of the ungrammatical /sɾ/ clusters.

This result was not a result of a bimodal distribution in the acceptability of /xɾ/ clusters, with some participants consistently rating these tokens poorly and others doing the opposite. The vast majority of the participants actually did rate /xɾ/ clusters an intermediate acceptability between that of /sɾ/ and /fɾ/. There were, however, a few individuals who deviated from this trend. Three subjects completely rejected /xɾ/ as being acceptable, likely basing their judgments solely on attestedness of the onset clusters. On the other hand, two other participants completely accepted /xɾ/ clusters, consistently giving them the highest possible rating.

In Spanish, /s/+stop clusters are also illegal and are repaired with the same vowel prothesis. The Spanish listeners' experience with these different yet still prohibited /s/ clusters may have contributed to the observed low /sɾ/ ratings, making the difference between the /sɾ/ and the /xɾ/ onsets more extreme. However, the fact that all /s/ clusters in Spanish are illegal and that participants rated the /sɾ/ clusters accordingly, which are less frequently encountered than repaired /s/+stop clusters, reaffirms the ungrammaticality of this consonant in this context. Given the compelling evidence that Spanish listeners reject this cluster but rate the /xɾ/ clusters as more acceptable, it suggests that there is no comparable restriction on /x/ in this position, or if there were, it would be remarkably weaker than that against /s/.

Another possible explanation for the gradient acceptability of /xɾ/ clusters could be that this sound sequence is not as unattested as one might expect. It is well known that voiced stops show consistent variation in their realizations as either stops or fricatives, depending on the preceding segment; /b, d, g/ are realized as their respective fricatives [β, ð, ɣ] when preceded by segments that are both sonorant and continuant. However, it has also been reported that voiceless stops can lenite similarly but to a lesser extent in some dialects (Romero-Gallego 1995; Lewis 2001). Thus, /p, t, k/ can be realized as /ɸ, θ, x/, respectively, when following continuant segments. The Spanish listeners who participated in this study may have had some exposure to lenited /k/ (i.e., /x/-like) in onset cluster environments, even though the identification task pre-screening determined that they could clearly

distinguish between /x/ and /k/ in this context. If this were the case, the /xɾ/ clusters may have been rated better than the ungrammatical /sɾ/ clusters because they are not entirely unattested. Nonetheless, the results of the present study still suggest that it is /s/ that is exceptional in its inability as a fricative to form part of a complex onset in Spanish.

Furthermore, it is possible that, although listeners were required to pass a pre-screening identification task in which they had to reliably indicate /xɾ/ clusters and /kɾ/ clusters, that in the nonce word judgment task itself, they mapped /xɾ/ onto /kɾ/, failing to perceive this as a novel onset cluster. This sort of misperception could have accounted for some of the variation seen within responses to /xɾ/ stimuli, as some speakers consistently gave /xɾ/ very high ratings. The presence of the identification task prior to the nonce word judgment task aimed to provide evidence that misperception would not occur in this context, and /xɾ/ stimuli that were mis-identified were not consistently mis-identified as one specific cluster. If nearly all mis-identifications were marked as /kɾ/, this would suggest a possible mapping of /xɾ/ onto /kɾ/. This was not the case, and thus these results instead suggest that /xɾ/ is marginally acceptable in complex onsets in Spanish, where as the ungrammatical /sɾ/ is highly unacceptable.

6.2. How /s/ is distinct phonetically and phonologically

As these results have shown that /s/ is exceptional in its inability to form part of an onset cluster, it is important to consider what makes /s/ exceptional and distinct from /f/ and /x/.

6.2.1 Phonetic distinctions between sibilants and other fricatives

From a phonetic perspective, /s/, along with the other members of the sibilant class (i.e., /s, z, ʃ, ʒ/) is acoustically different from other, non-sibilant fricatives. Sibilants tend to have higher spectral means and higher amplitudes relative to their surrounding segments than non-sibilant fricatives do (Hughes & Halle 1956; Behrens & Blumstein 1988; Shadle & Mair 1996; Jongman et al. 2000; among others). It has been previously shown that Spanish /s/ does not have a higher relative amplitude (Parker 2002), but it is the case with the current stimuli that the spectral means of /s/ are higher than other segments. As /s/ is the sole sibilant in the Spanish consonant inventory, its perceptual distinctness separates it from the other fricatives, which could contribute to its exceptionality in onset cluster contexts.

In addition to perceptual distinctness, it has been argued that sibilants require a tighter articulatory constriction than other fricatives involving particular tongue configurations that are necessary to produce the right kind of air flow for strident features (Keating 1991). These phonetic features required for stridency could make articulation more difficult in onset clusters, as the tongue body and blade position, as well as the stricture and resulting airflow, differ between strident and other segments.

Of particular importance to the /sɾ/ clusters that were used in this study, it has been shown that rhotics, cross-linguistically, require very specific articulatory and aerodynamic gestures; in sibilant + rhotic clusters, like /sɾ/, the rhotic gesture can hinder the articulations and aerodynamic conditions that are necessary to realize the preceding sibilant (Solé 2002; Ohala & Solé 2010). As such, the sibilant often is produced with voicing or completely assimilates to the following rhotic. The fact that this cluster is ‘difficult’ to produce could partially explain its ungrammaticality in Spanish. However, this cannot be the whole story because, as previously mentioned, Spanish prohibits all /s/ clusters. In the present study, /sl/ clusters were also judged by participants, but they were used as fillers. A post-hoc

regression of these clusters, similar to that presented in Section 4.4, revealed that the /sl/ clusters were also rated very poorly, being significantly less acceptable than the target /xɾ/ clusters (Mean (SD) = 1.46 (0.70); Median (Q1, Q3) = 1 (1, 2); β = -1.17; p <0.0001). This suggests that the dispreference of /s/ in onset clusters is due to the stridency of /s/, rather than its particular combination with a liquid, but its combination with a liquid definitely could have contributed to the low ratings.

6.2.2 A feature defining sibilants and phonetically-grounded phonology

The results of the present experiment provide support for the phonological differentiation of /s/ from the other obstruents. A substance free phonologist might propose some abstract feature for /s/ that the other obstruents, which pattern differently, lack. However, given the compelling evidence that /s/ and the other sibilants are phonetically distinct from other obstruents highlights the logic behind phonetically-grounded phonological features. The perceptual and articulatory features that are distinct to the sibilant family can be captured by the feature [+strident] (Keating 1991: 45; Hayes 2001: 95).

Because /s/ is the only sibilant in Spanish, it is both phonetically and phonologically distinct from the other obstruents. Following the assumption that features cannot be left unspecified, it is the case that all [-sonorant, -strident] segments can grammatically be the first consonant in a Spanish complex onset. This substantively-grounded proposal allows for the natural grouping of segments that pattern together phonologically. Furthermore, this proposal does not rely on underspecification of input or output features and does not predict stop-like or variable realizations of [f], as past proposals have done, making it all the more substantively-grounded (i.e., nothing in the phonology predicts /f/ to have similar variation as the voiced obstruents).

Additionally, this generalization, of [-sonorant, -strident] segments exclusively being allowed in onset clusters could be easily captured in any phonological framework, including Optimality Theory. A constraint that is violated by segments in the first slot of a complex onset that are either [+sonorant] or [+strident] (e.g., *$_{\sigma}$[sC) would be violated by all clusters beginning with /s/ in Spanish, but it would still correctly predict and permit the full range of remaining stops and fricatives to exist in this context in Spanish and other related languages.

This constraint is substantively grounded, as explained in Section 6.2.1. It is important that phonological features, such as the use of [strident] in Spanish obstruents, be substantively-grounded because if they are not, then there are no real restrictions on how different segments can be grouped together, and the concept of natural classes, by which many phonological rules and constraints are defined, is diminished. Phonetics not only describes the physical properties of the segments, from the articulations to the acoustics, but it also helps in defining the distinctive features (Archangeli & Pulleyblank 1994; Scoobie 2005; Kingston 2007). Furthermore, ignoring the relationship between phonetics and phonological features is not well-motivated on articulatory, perceptual, or typological grounds (Hayes 1966).

6.3 Typological implications

The results of the present experiment show that Spanish prohibits sibilants from forming the first part of an onset cluster. Spanish has only one sibilant, /s/, but this analysis makes

the prediction that other members of the sibilant class of sounds (e.g., /ʃ, z, ʒ/), which are also characterized by the feature [+strident], would also be illicit in onset clusters if they were present in the phonological inventory. These additional sibilant segments were not tested in the present study due to the fact that they are not in the phonological inventory of Spanish. Although these other sibilants in similar onset clusters are expected to be illicit given the present analysis, testing them with speakers of Spanish would be challenging because it would be difficult to determine if low acceptability ratings were due to the unattested, illicit clusters or due to the non-native segments themselves.

That being said, although Spanish only has one sibilant, /s/, the typologically related languages of Portuguese and Catalan have /s, z, ʃ, ʒ/ in their consonantal inventories, and data from these languages shows that the other sibilants do in fact pattern with /s/ in not forming complex onsets. This follows what is predicted and provides support for the present analysis. It also shows that a constraint against [+sonorant] [+strident] features in onset clusters is not specific to Spanish but also extends to other related languages within the Western Romance language family.

Sibilants tend to behave differently than other fricatives even beyond Western Romance languages. For example, English allows /st, sp, sk, sn, sl/ onset clusters, even though other clusters with comparable sonority differences are prohibited (e.g., */fp/); additionally, English prohibits surface /sɹ/ clusters, but it is likely that this underlying cluster surfaces as [ʃɹ] (e.g., in the word "shrimp"), as it does in German and Dutch (Grijzenhout, 1998).

Although other languages that show sibilants behaving uniquely in onset clusters may not abide by a constraint that strictly prohibits sibilants in this position, like Spanish seems to do, it is important to note the wide-spread exceptionality of /s/ in this context cross-linguistically.

7. Follow-up experiment

In many varieties of Peninsular Spanish, there is an additional voiceless fricative, /θ/, which is like /f/ and /x/ in that it is not a sibilant or strident sound. Like /x/, it is unattested in onset cluster contexts. However, the above analysis predicts that, because this voiceless dental fricative is not a sibilant, that it too should not be ungrammatical in complex onsets. Hualde (1991: 483) provides anecdotal evidence that this is indeed the case; speakers of Peninsular Spanish with whom he consulted stated that they would not be surprised if they encountered a nonce word like Alazraque [a.la.θɾa.ke]. Therefore, it is predicted that /θ/ would pattern with /x/ in acceptability judgments in onset clusters, as it does not meet the proposed criteria of stridency to be ungrammatical but is also unattested in this environment.

To test this prediction, a smaller-scale follow-up experiment was performed, which aimed to provide evidence that /θɾ/ clusters pattern with /xɾ/ clusters and not with ungrammatical /sɾ/ clusters in speakers of Peninsular Spanish. These results will ultimately shed light on the formal analysis proposed above.

7.1. Methods

The methods for this second experiment are largely the same as those used in the first experiment. Grammaticality judgments of /θɾ/ onset clusters were collected and compared with those of /sɾ/, /fɾ/, and /xɾ/ clusters in order to determine if this unattested cluster is

marginally acceptable, like /xɾ/, due to its phonological status in Peninsular Spanish as a non-sibilant voiceless fricative.

7.1.1. Participants

There were 10 participants in this second experiment who all gave their consent to participate. None of these 10 subjects had participated in the first experiment. Demographic information such as age, gender, languages spoken, and the region where they live in Spain was collected.

7.1.2. Stimuli

Stimuli included a subset of those used in the first experiment, along with the addition of nonce words composed of the /θɾ/ cluster. All words were bisyllabic trochees. The same 20 nonce words were used for /xɾ/, /fɾ/, and /sɾ/ clusters. An additional 20 /θɾ/ clusters were created, again with four tokens having each of the five Spanish vowels, and a randomly assigned CV tail that complied with Spanish phonotactics. These additional words can also be found in the Appendix. These 80 target tokens were randomized with 320 nonce words beginning with /pɾ, tɾ, kɾ, *pn, *tn, *kn, *sl/ and /*tl/ tokens.

The /θɾ/ stimuli were recorded by the same 30 year old, male speaker of Colombian Spanish; due to his experience as a phonetician and his proficiency in English, he was able to produce the /θɾ/ without issue. No intrusive vowels were detected in these new stimuli, and they did not significantly differ in mean F0 or duration. As such, they were not modified or normalized.

Again, the first syllable of the /θɾ/ nonce words were manually cut out for use in a nearly identical identification task, described below. As was done with the other extracted onset clusters, they were normalized for duration and were given gradual fadeouts using the same standards as described in Section 4.2.

7.1.3. Task

The task of this follow-up experiment was identical to that of the first experiment, described in Section 4.3, with the only difference being that /θɾ/ clusters were included in the identification and rating judgment tasks.

The new 10 participants performed the identification task, which now included syllables that began with /θr/ clusters as well as the original /xɾ, θɾ, *sɾ, kɾ, pɾ, *kn, *pn/ and /*tl/ clusters. A syllable with one of these complex onsets was played, and subjects were asked to choose which combination of letters matched the first two sounds that were played. These were written in standard Spanish orthography, with /θɾ/ written as ‘zr’. The same cut-off criteria were used for the identification task: 71.4% accuracy (five of seven) for the unattested /xɾ/ and /θɾ/ clusters, and 87.5% accuracy (six of seven) for /sɾ, fɾ/, and /kɾ/ clusters.

Participants who met the identification task criteria were included in the nonce word judgment task, where they were asked to rate the nonce stimuli on a scale from

1-4, with 1 meaning it could never be a word of Spanish, 2 meaning it probably could not be a word of Spanish, 3 meaning it probably could be a word of Spanish, and 4 meaning it definitely could be a word of Spanish.

7.1.4. Statistics

Responses to /θɾ, fɾ/, and /*sɾ/ clusters were compared with those of /xɾ/ clusters. These results of the nonce word judgment task were analyzed in an identical ordinal mixed effects regression model, as in Section 4.4.

7.2. Results

7.2.1. Identification task

Of the 10 Peninsular Spanish speakers who completed the identification task, nine of them met the accuracy criteria for identifying the attested and unattested onset clusters. Of these nine participants who passed the identification task, six (66.7%) were female. The ages of participants ranged from 24-40, with a mean age of 29.33 and a median and first and third quartile (M(Q1,Q3)) of 29(26,30). Participants' home dialects varied but, importantly, all were from regions that have /θ/ as a phoneme; participants were from Barcelona (n=3), Oviedo (n=3), Madrid (n=2), and Lugo (n=1). Their language backgrounds varied. Most participants had some knowledge of English, and some also reported proficiency in Italian and French, but some also noted fluency in other languages spoken in Spain, such as Catalan, Galician, and Asturian.

The mean accuracy of these participants in identifying /xɾ/ and /θɾ/ clusters was 92.1% and 80.9%, respectively. They all achieved high accuracy in identifying the /fɾ/ and /*sɾ/ clusters as well, with mean accuracies equaling 97.8% and 92.1%, respectively.

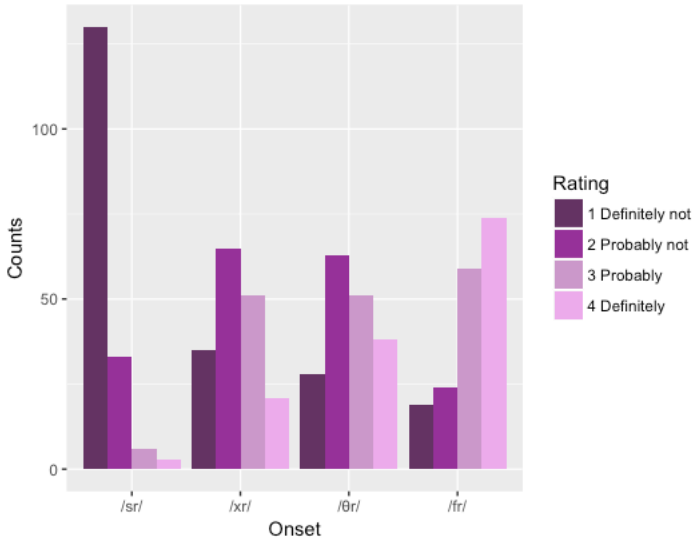
7.2.2. Nonce word judgment task

The nine Peninsular Spanish speakers who participated in this follow-up experiment and passed the identification task pre-screening tended to rate both /xɾ/ and /θɾ/ unattested clusters as more acceptable than the ungrammatical /sɾ/ clusters but as less acceptable than the grammatical and attested /fɾ/ clusters. These results can be seen in Table 5 and in Figure 9.

Table 5: Mean and inter-quartile range of responses for the fricative-initial onset clusters

Cluster	Mean (SD)	Median (Q1, Q3)	Percent of each response			
			1	2	3	4
/sɾ/	1.31 (0.62)	1 (1, 1)	75.6%	19.2%	3.5%	1.7%
/xɾ/	2.34 (0.94)	2 (2, 3)	20.3%	37.8%	29.7%	12.2%
/θɾ/	2.55 (0.99)	2 (2, 3)	15.6%	35.0%	28.3%	21.1%
/fɾ/	3.09 (0.99)	3 (3, 4)	10.8%	13.6%	33.5%	42.0%

Figure 9: Grammaticality judgments of onset clusters in Peninsular Spanish. Graph showing number of each response type per onset cluster



These data show that /fɾ/ clusters, again, are rated as highly acceptable. Likewise, /sɾ/ clusters are rated as highly unacceptable. /xɾ/ and /θɾ/ clusters are given intermediate ratings, with responses being much more variable than for the other two clusters. Nonetheless, these two unattested clusters are clearly rated as more acceptable than the ungrammatical /sɾ/ clusters, as they were given many more 3-4 responses and fewer responses of 1.

The results of the ordinal mixed effects regression confirmed the trends observed in the descriptive statistics. As the novel onset cluster in this follow-up experiment is the /θɾ/ cluster, this was set as the reference level to which the judgments of the other onset clusters were compared. These, shown in Table 6, show that the grammatical /fɾ/ onsets were rated as significantly more acceptable than the unattested /θɾ/ onsets ($p<0.0001$), and that ungrammatical /sɾ/ onsets were rated as significantly less acceptable than the target /θɾ/ onsets ($p<0.0001$). When compared to /xɾ/ clusters, which were hypothesized to have the same acceptability as /θɾ/ clusters due to their unattestedness but equivocal grammaticality, there was no significant difference in the rates of participant responses ($p=0.12$).

Table 6: Results of ordinal regression comparing judgments on /θɾ/ nonce words with other fricative-initial onset clusters

Contrast against /θɾ/	β-Estimate	Standard Error	z-value	p-value
/fɾ/	1.35	0.26	5.28	p<0.0001
/sɾ/	-3.44	0.31	-10.93	p<0.0001
/xɾ/	-0.39	0.25	-1.55	p=0.12

7.3. Discussion of the follow-up experiment

The results of the primary experiment, presented in Section 3 – Section 6 showed that Spanish speakers rate unattested /xɾ/ clusters as being more acceptable than known ungrammatical clusters (e.g., /sɾ/) but less acceptable than known grammatical clusters

(e.g., /fɾ/). This gradient acceptability was interpreted in a way such that /xɾ/ clusters are not ungrammatical in the Spanish grammar but that the lower ratings are a result of unattestedness or unfamiliarity. Because of this, it was proposed that all non-sibilant obstruents can form part of a complex onset in Spanish. Because the phonological inventory of Peninsular Spanish has an additional voiceless, non-sibilant fricative, /θ/, the experiment was replicated in a smaller-scale follow-up study with just speakers of this variety of Spanish. This was done to test if /θɾ/ clusters also behave like /xɾ/ clusters, which ultimately would provide support in favor of or against the proposed analysis of Spanish onset clusters.

There were nine speakers from Spain who participated in the follow-up experiment. Their results patterned with those of the first experiment, whereby both /xɾ/ and /θɾ/ onset clusters were shown to have an intermediate acceptability. This supports the constraint proposed in Section 6.2, which distinguishes grammatical from ungrammatical obstruents in onset clusters via the phonological feature [strident], which is a feature of sibilant sounds. Thus, non-sibilant fricatives can form the first part of an onset cluster in Spanish.

Although the results of this follow-up experiment were largely compatible with those of the first experiment, the target onset clusters /xɾ/ and /θɾ/ seemed to be rated as more acceptable than in the first experiment. This is evidenced by the mean and median statistics, which were higher in the second study. It is unclear at this time why this difference would exist, but it could be due to the much smaller data set. Another possible source of this difference could be that the first experiment included participants from all over the Spanish speaking world, where as the follow-up experiment was restricted just to Spain. There is a high degree of phonetic variation between Spanish dialects, which could influence their acceptability of these unattested sound sequences. It could be both valuable and interesting to collect additional data from more speakers of various regions and see if dialect affects this, although this is outside the scope of the present study.

Like the first experiment, the follow-up experiment also did not include other sibilants that are non-native to Spanish (/z, ʃ, ʒ/). One could argue that without these controls, it cannot be certain that the gradient acceptability of /xɾ/ and /θɾ/ are a result of their satisfying the constraint against sibilants in onset cluster position because it could be a result of the Spanish listeners simply not knowing what to do with these onsets because they don't occur in their language. However, including these additional onset clusters may not resolve this uncertainty, because if they, too, received poor ratings like /sɾ/, it would be difficult to decipher if the low ratings were due to unattested onset clusters or unattested segments. As suggested in Section 6.3, a better way to resolve this would be to conduct a similar study using related languages with larger sibilant inventories like Portuguese or Catalan.

8. Conclusions

This paper has provided empirical evidence to support a new analysis of Spanish onset cluster phonotactics. Previous analyses of this phenomenon have relied on nonstandard use of underspecification of features, using underspecification to unify an unnatural group of segments, to claim that /f/ is exceptional in its ability to pattern with stop consonants in onset cluster contexts. This hypothesis is not substantively-grounded, cannot be extended to other languages with similar phonotactic patterns, and has not been supported with empirical data.

In order to remedy these problems, this paper tested the claim that /f/ behaves like a stop and is therefore exceptional because it can form part of a complex onset while other fricatives cannot. The results of a nonce word phonotactic judgment task revealed that this is not the case. Native Spanish listeners show gradient acceptability for the unattested onset cluster /xɾ/. Though the acceptability of the /xɾ/ clusters did not reach the same status as those with the attested and grammatical /fɾ/ clusters, they were rated as significantly better than the ungrammatical /sɾ/ Spanish clusters. This suggests that /s/ is exceptional in the fact that it is the only obstruent that cannot form part of a complex onset. This is likely due to /s/ being strident, as well as to various acoustic properties, such as spectral peak and amplitude, which differentiate it from other members of its class.

Given that /s/ is a sibilant, it can be uniquely characterized in Spanish with the phonological feature [+strident]. Therefore, only segments that are [+strident] or [+sonorous] are prohibited from being in the first slot in Spanish complex onsets. By using this feature, this generalization is easily capturable in many formal frameworks of phonology, including OT. Importantly, the proposed analysis solves the past problem of leaving both input and output forms underspecified, and it is substantively-grounded on the phonetic differences between sibilants and other obstruents. This highlights the importance of phonetically-grounded phonological features, as the only logical way to phonologically group together this set of obstruents is based on their phonetic properties.

This novel analysis of Spanish onset clusters also extends to typologically-related languages that exhibit the same phonotactic patterns, which past analyses have not been able to do. This analysis then resulted in the prediction that other non-sibilant fricatives should also be accepted in this context. Because Peninsular Spanish has an additional voiceless fricative, /θ/, the experiment was replicated with speakers from Spain, including /θɾ/ cluster nonce words as well. The results of the follow-up study similarly showed gradient acceptability of this unattested cluster. To provide further support for this analysis, it would be worthwhile to replicate this study with speakers of Portuguese or Catalan, which seem to show the same phonotactics in onset cluster contexts but whose sibilant inventories are richer; this would allow other sibilants to also be tested in onset cluster position without the methodological confound of including non-native segments.

Nevertheless, the results of this study ultimately show that /f/ is not exceptional in that it patterns with stop consonants and is therefore able to form part of a complex onset cluster in Spanish, contrary to what past proposals have hypothesized. Instead, it is /s/ that is exceptional in its inability to form part of an onset cluster in Spanish because of its phonetic properties as a sibilant, which are phonologically represented with the [+strident] feature.

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Appendix

Nonce words from judgment task by onset cluster

/xr/	• jrako	• jrebo	• jrepe	• jrino
• jrabe	• jrana	• jrelo	• jreso	• jripo
• jrago	• jrata	• jrena	• jrida	• jrite

• jrile
• jrocha
• jrogo
• jromo
• jroso
• jrote
• jrubo
• jruke
• jruma
• jrupo
• jrusa

/θr/

• zrame
• zrado
• zrala
• zrache
• zraso
• zreta
• zreje
• zrebo
• zrena
• zrefe
• zrogo
• zrola
• zroque
• zrojo
• zrota
• zrugue
• zrubo
• zruna
• zruche
• zrupo
• zrida
• zrite
• zrico
• zrisa
• zrime

/sr/

• srabe
• srafe
• srado
• sraque
• srapa
• srebo
• srecha
• sreja
• srere
• srimo
• srija
• srile
• srine
• srite
• srico
• sroda
• srofa
• sroge
• sroje
• srote
• srube
• sruma
• srusa
• srute
• srupa

/fr/

• fraba
• frade
• frajo
• fralo
• frase
• frepe
• frejo
• frecha
• frefa
• frege
• fripe
• frido
• frigo
• frila
• fribo
• frodo
• froga
• frole
• fropo
• frota
• frula
• fruko
• fruto
• fruba
• frusa

/tr/

• traba
• trabo
• trana
• trapa
• traso
• trete
• trecha
• treco
• tremo
• tresa
• tribo
• trika
• trile
• trime
• tripo
• troba
• trobo
• tromo
• tropa
• trote
• trubo
• trule
• truso
• trute

• trupe

/pr/

• prabe

• praba

• prafe

• prajo

• pralo

• precho

• predo

• prega

• prena

• presa

• pricho

• pride

• prija

• prira

• priba

• probo

• proda

• prora

• prose

• prota

• pruje

• pruso

• prune

• pruba

• pruche

/kr/

• craba

• cracha

• crafo

• crara

• craba

• crefa

• crega

• crela

• cremo

• crebe

• criba

• cricho

• crife

• crigo

• crije

• croda

• crojo

• croko

• crone

• crose

• crucha

• crufa

• cruge

• crula

• crupo

/pn/

• pnafe

• pnalo

• pnare

• pnase

• pnaso

• pneja

• pneke

• pneko

• pnela

• pnero

• pnicha

• pnifo

• pnijo

• pnimo

• pniso

• pnocho

• pnofa

• pnole

• pnome

• pnobe

• pnube

• pnudo

• pnufe

• pnure

• pnuta

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• tnata

• tnano

• tnabe

• tnaje

• tnalo

• tnecho

• tnelo

• tnega

• tnesa

• tnere

• tnicha

• tnife

• tniba

• tnira

• tnine

• tnobo

• tnofa

• tnofe

• tnole

• tnoga

• tnube

• tnule

• tnuma

• tnubo

• tnuge

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• tlare

• tlale

• tlake

• tlajo

• tlako

• tlecho

• tlera

• tlede

• tlepa

• tlego

- tlira
- tlibo
- tlige
- tliso
- tlida
- tlofo
- tlose
- tlola
- tlomo
- tlope
- tlune
- tludo
- tlura
- tluto
- tlusa

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- slare
- slape
- slaro
- slato
- slage
- sleko
- slemo
- sleno
- slecho
- sleje
- slino
- slipo
- slira
- slise
- slida
- sloka
- slome
- slopa
- sloba
- sloche
- sluje
- slume
- slune
- sluso
- slucha

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- knado
- knako
- kanje
- knasa
- knafo
- knega
- knese
- knele
- kneso
- knefo
- knipo
- knicho
- knira
- knilo
- knite
- knoka
- knome
- knoga
- knofo
- knoto
- knula
- knumo
- knosa
- knubo
- knuge