Coarticulatory Effects on Spanish Trill Production

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1. Introduction

The class of speech sounds known as trills, in comparison with other types of manner classes, demonstrates a relatively high level of articulatory instability, in all likelihood due to the high level of complexity associated with their mechanism of production. The apico-alveolar trill of Spanish is among the last types of segments to be successfully produced in the acquisition of that language (Jiménez, 1987; Vihman, 1996). In addition, it is a well known fact that apical trills often present great difficulty to second language learners, and even native speakers often never learn to properly "roll their 'r's". Nevertheless, trills are by no means uncommon segments: Typological surveys of the world's languages reveal that well over one third have apical trills in their phonological inventories, and among languages that contain rhotics, nearly half of these r-sounds are trills (Maddieson, 1984).

Primarily, apical trills are the result of tongue tip vibration brought about by aerodynamic conditions while other rhotics (i.e., taps, flaps and approximants) involve active muscular contraction of the tongue (Ladefoged & Maddieson, 1996). At least two conditions must be met for the successful production of a sustained trill: First, the tongue must first assume the proper shape, position and pliability, and second, a sufficient amount of oropharyngeal pressure must build behind the stricture to set the tongue apex into motion. Once set into motion, the tongue tip is involved in a series of opening and closing phases.

In Spanish, a phonemic contrast exists between the alveolar tap /ɾ/ and the alveolar trill /r/, but the two phones contrast only in intervocalic position word-internally, while in word and syllable-final positions, the tap and trill are in free variation. Of particular interest to the present study is the implementation of /ɾ/ in word-initial position. In this context the norms of the Royal Spanish Academy (1924, 1979) require that the voiced apical trill /r/ surface allophonically, as is the case after the consonants /n, l, s/ word-internally or across word boundaries. Examples are provided in Table 1.

/ɾepito/	→	[repito]	*[ɾepito]	'I repeat'
/ɾoto/	→	[roto]	*[ɾoto]	'broken'
/onɾa/	→	[onra]	*[onɾa]	'honor'
/unɾegalo/	→	[un#reɣalo]	*[un#ɾeɣalo]	'a gift'
/alɾededor/	→	[alreðeðor]	*[alɾeðeðor]	'around'
/elɾekurso/	→	[el#rekurso]	*[el#ɾekurso]	'the resource'
/isɾael/	→	[israel]	*[isɾael]	'Israel'
/lasɾokas/	→	[las#rokas]	*[las#ɾokas]	'the rocks'
/miɾisa/	→	[mi#risa]	*[mi#ɾisa]	'my laughter'
/laɾama/	→	[la#rama]	*[la#ɾama]	'the branch'

Table 1. Examples of the distribution of contexts in which [r] surfaces allophonically word-internally and across word boundaries according to the Spanish Royal Academy.

Nevertheless, it is a well documented fact that a significant percentage of trills fail to be realized in the environments prescribed by the Royal Academy (Hammond, 1999; Harris, 1983; Navarro-Tómas, 1980). While the occurrence (or non-occurrence) of voiced alveolar trills may be influenced by a number of external factors, such as dialectal variation, speech style and prosodic position, the

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present study focuses on how the aerodynamic conditions required for the successful production of trills may be influenced by the articulatory quality of adjacent segments- namely, the degree of stricture associated with segments immediately preceding the rhotic. The present study builds on recent work by Solé (2002) in which catheters of varying diameters were placed in the oral cavity to bleed oropharyngeal pressure behind the site of the lingual constriction in an effort to determine the critical limits within which voiced and voiceless trills are initiated and sustained. The present study differs from Solé (2002) in at least two regards: First, instead of using an artificial method of manipulating oropharyngeal pressure, actual articulatory gestures distinguished by distinct degrees of stricture are employed. Second, the conclusions drawn in the previous study are based upon the researcher's and a colleague's attempts to sustain trills in isolation, as well as in detached utterances of the disyllabic frames [iri] and [ara]. The current study aims to better our understanding of coarticulatory effects on the production of Spanish trills resulting from varying degrees of stricture associated with the pre-rhotic segment, and is based upon the most natural speech attainable.

2. Experimental Design

Three females and one male ranging in age from 25-36 years participated in the study. All were native Spanish speakers representing dialects spoken in Argentina, Chile, Mexico and Spain. Each produced ten sequences of /a##ɾ/, /i##ɾ/, /s##ɾ/, /l##ɾ/, /n##ɾ/ and /##ɾ/ nested in a carrier phrase, establishing (in ascending order) six distinct degrees of oral stricture associated with the pre-rhotic segments. The ranking of segments loosely reflects values associated with each for the phonological feature [continuant] in the sense that /a, ɪ, s/ are [+cont], /l/ may be [+cont] or [-cont], and /n/ is [-cont]. Rhotics in absolute-initial position were read from a list of isolated words and are considered to be produced in the most highly constricted environment, post-pausal position. One may conceive of the pre-rhotic segments (or environment, in the case of /##ɾ/) as occupying distinct points along a continuum of continuancy as illustrated in Figure 1.

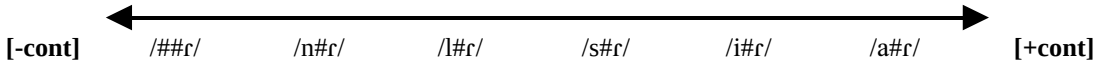


Figure 1. Pre-rhotic segments/environments as points along an (ascending) continuum of continuancy.

The post-rhotic vowel was consistently varied and tokens of /ɾ/ were equally divided between those forming onsets to stressed and unstressed syllables. Approximately 75% of the carrier phrases contained non-rhotic-initial distracters to avoid the identification of a pattern on the part of the participants. Sample sentences extracted from the list of carrier phrases are given in Table 2.

a) Diga la frase la rosa para mí.
b) Diga la frase mi ruta para mí.
c) Diga la frase las rejas para mí.
d) Diga la frase el rabo para mí.
e) Diga la frase un río para mí.

Table 2. Sample extractions from the list of carrier phrases illustrating the variation of the pre-rhotic segments and post-rhotic vowels.

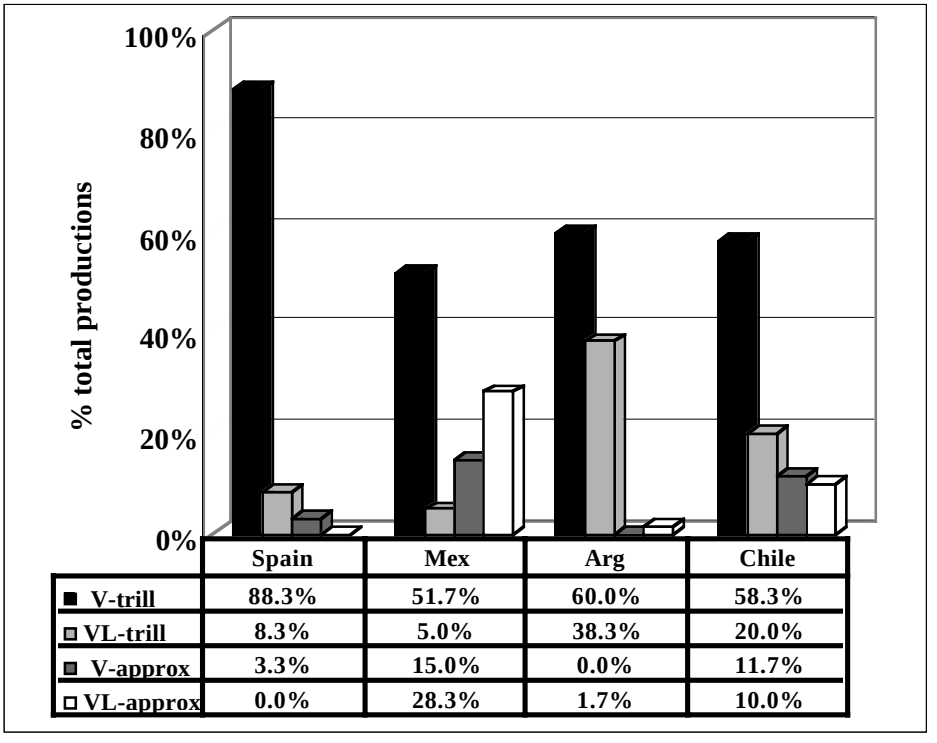
Three measurements were taken to evaluate the magnitude of each rhotic production. Wide-band spectrograms and corresponding acoustic waveforms were visually inspected to identify the duration of the segment and the number of apico-alveolar contacts. Root mean square (RMS) energy (converted into decibels) was calculated to determine the difference in relative intensity between the peak (i.e., point of highest amplitude) of the rhotic and the valley (point of lowest amplitude) of the preceding segment.

3. Results

In this section results are presented indicating the extent to which subjects' productions of trills were influenced by segmental context (the degree of stricture associated with the pre-rhotic segment). Dialectal variation and linguistic stress are also considered. Data were submitted to single factor analyses of variance (ANOVA), and results reported to be significant reflect that a value of $p<0.001$ was obtained.

3.1 Variability in the allophony of /ɾ/

Productions of the Spanish trill are often characterized by a wide range of allophonic variation. Over the years, a significant body of work has been assembled documenting the numerous realizations of /ɾ/, which often serve to identify populations of speakers (Canfield, 1981; Harris, 1983; Lipski, 1994). While variability of /ɾ/-production across dialects was not of primary concern in the present study, it was interesting to note that the vast majority of /ɾ/-allophones produced by the participants fell into one of four categories: voiced and voiceless trills and approximants, as illustrated in figure 2.



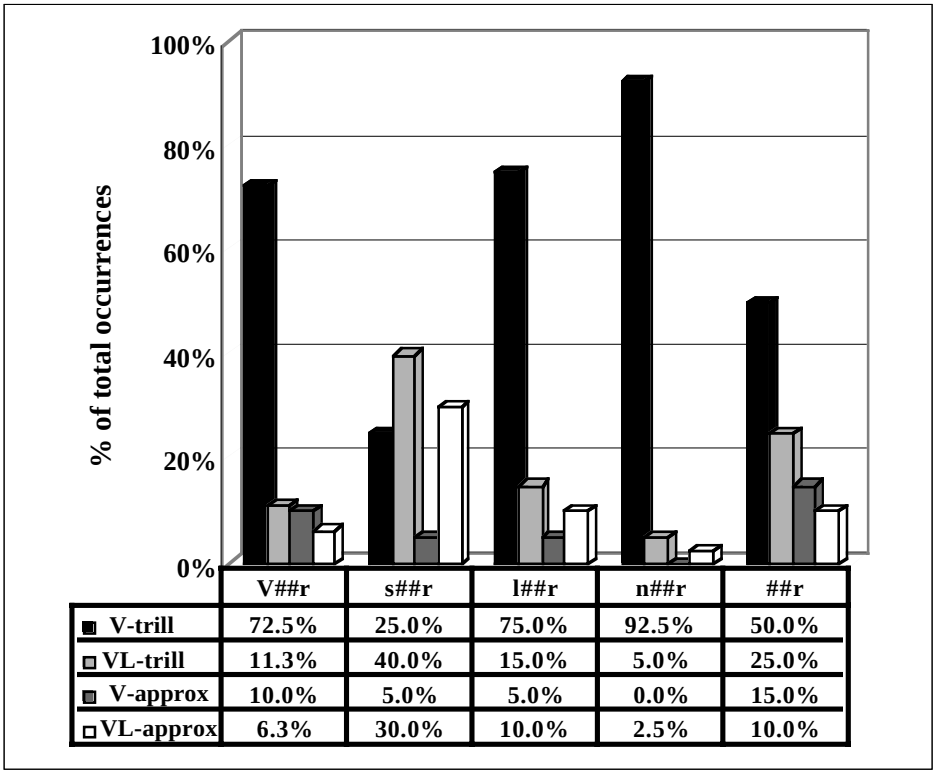
	Spain	Mex	Arg	Chile
V-trill	88.3%	51.7%	60.0%	58.3%
VL-trill	8.3%	5.0%	38.3%	20.0%
V-approx	3.3%	15.0%	0.0%	11.7%
VL-approx	0.0%	28.3%	1.7%	10.0%

Figure 2. Distribution of /ɾ/ allophones as produced by speakers from four different dialects of Spanish.

The voiced trill was clearly the most frequent allophone for all participants, regardless of dialectal affiliation. Consistent with previous research, the South Americans demonstrated the strongest tendency to devoice trills, while approximants, both voiced and voiceless, occurred most frequently in the speech of the Mexican and Chilean subjects.

3.2 Coarticulatory effects

The distribution of /ɾ/ variants grouped by pre-rhotic segment is illustrated in Figure 3.



	V##r	s##r	l##r	n##r	##r
V-trill	72.5%	25.0%	75.0%	92.5%	50.0%
VL-trill	11.3%	40.0%	15.0%	5.0%	25.0%
V-approx	10.0%	5.0%	5.0%	0.0%	15.0%
VL-approx	6.3%	30.0%	10.0%	2.5%	10.0%

Figure 3. The percentage of total productions for each segmental context based upon the combined productions of all speakers.

A positive correlation exists between the degree of stricture associated with the pre-rhotic segment and the frequency with which voiced trills occur, but only in the post-consonantal contexts. That is, as the degree of the pre-rhotic stricture increases from /s##ɾ/ → /n##ɾ/, so increases the likelyhood of a voiced trill production. The post-vocalic and absolute-initial contexts do not seem to participate in this trend, a point we will return to momentarily. Figure 3 illustrates the comparison of successful trills (both voiced and voiceless) with failed trills (approximant productions, voiced and voiceless) across segmental contexts.

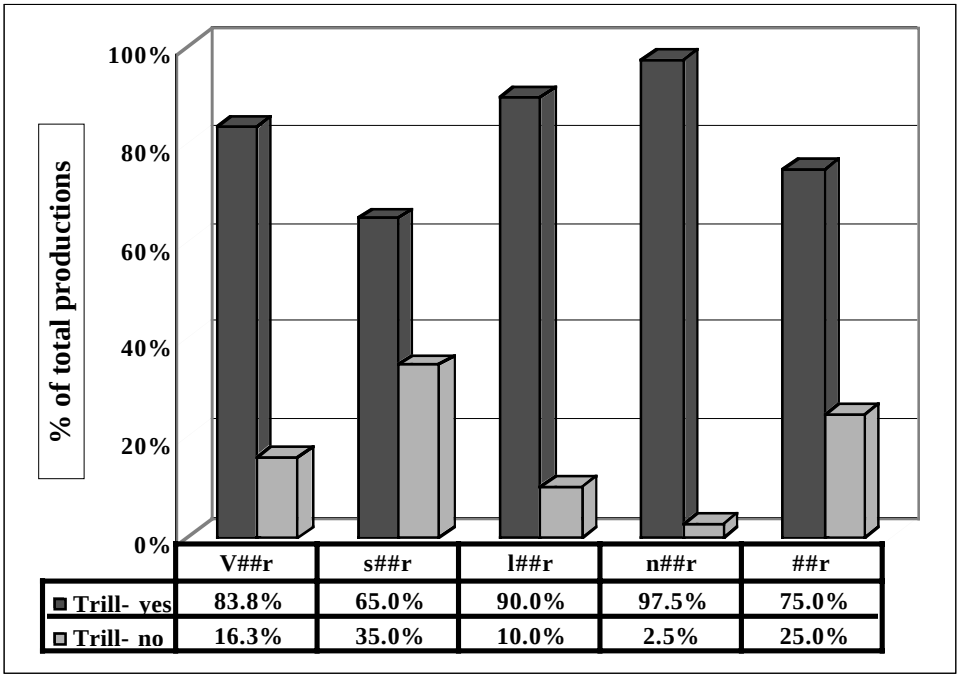


Figure 4. Percentages of total productions resulting in successful vs. failed trills for each segmental context.

As mentioned in the previous section, as the degree of the stricture among the pre-rhotic consonants increases from /s##ɾ/ → /n##ɾ/, so increases the likelyhood of a trilled production. Remaining to be accounted for however is the fact that a relatively high percentage of successful trills occur post-vocalically and in absolute-initial position. A possible explanation hinges on the fact that virtually no demands are placed on the tongue in either of the non-consonantal pre-rhotic environments thus affording speakers the opportunity to properly posture and brace the tongue body and apex, often leading to productions within the critical limits for initiating and sustaining trills.

A final observation to be made here is that the largest percentage of voiceless trills were noted to occur in the two post-voiceless contexts (i.e., following [s] and in post-pausal position, when the vocal folds are at rest) suggesting a strong tendency toward voicing agreement between the pre-rhotic segments and the corresponding /ɾ/-allophones.

3.3 Linguistic stress and trills

Voiced and voiceless trills are grouped together in Figure 5, which compares the percentages of successful as opposed to unsuccessful trills produced when /ɾ/ forms the onset to stressed versus unstressed syllables.

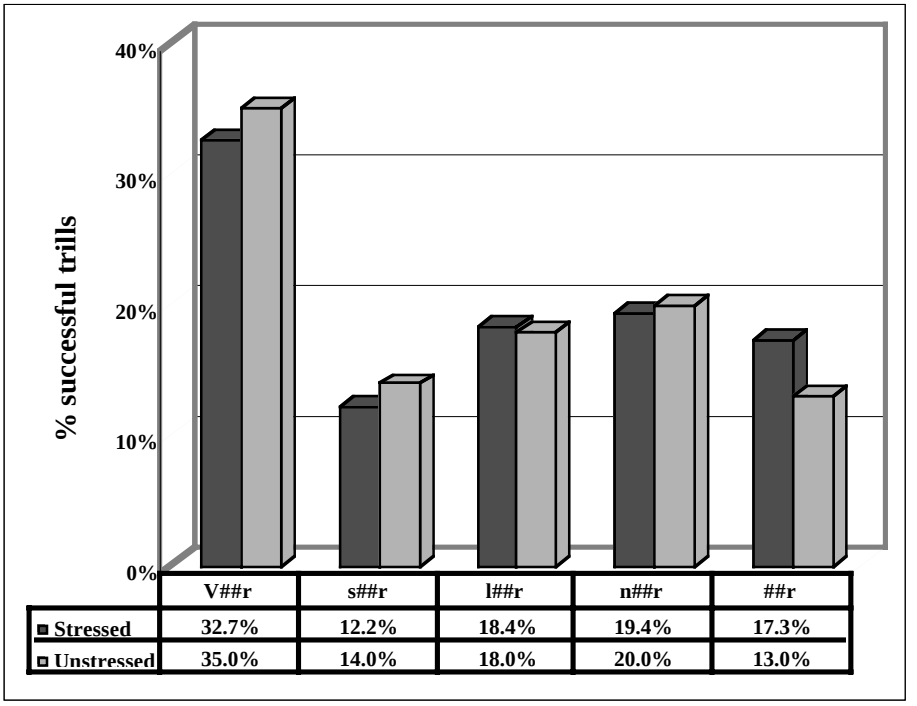


Figure 5. Percentage of successful trills as onsets to stressed versus unstressed syllables

As clearly seen in Figure 5, linguistic stress failed to play a significant role in predicting the likelihood of trilled allophones of /r/, with the exception of a slight preference for trilled productions in accented syllables in the absolute-initial context. However, attempts to correlate syllable type (accented or unaccented) with percentages of trilled allophones failed to reach statistical significance for any of the segmental contexts.

3.4 Duration of trills

The duration of voiced vs. voiceless trills is illustrated in Figure 6. Significantly longer values were obtained for voiceless trills in the two contexts that lack phonetic voicing, (s#__ and ##__).

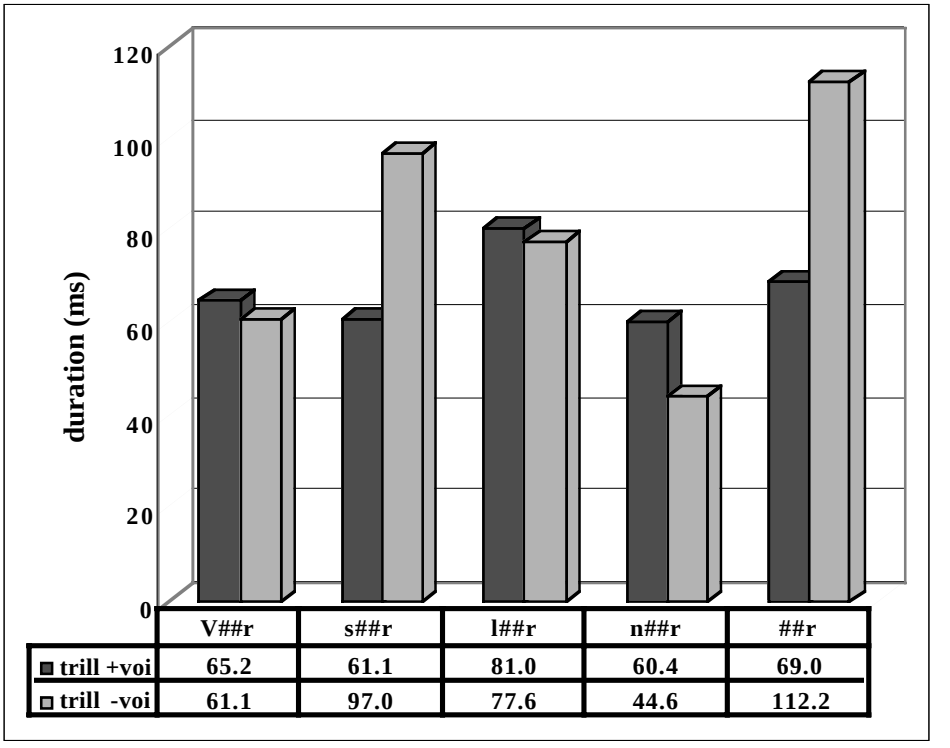


Figure 6. Mean duration of voiced and voiceless trills for each segmental context.

Longer duration values directly reflect speakers' ability to *sustain* a trill. In contrast to their voiced counterparts, voiceless trills benefit from the unimpeded flow of air through the glottis resulting in longer durations and a greater number of apico-alveolar contacts.

3.5 Relative intensity differences

Mean differences in relative intensity between the peak of the rhotic and the valley of the preceding segment proved to be the most reliable acoustic correlate for predicting successful versus unsuccessful trills, as illustrated in Figure 7.

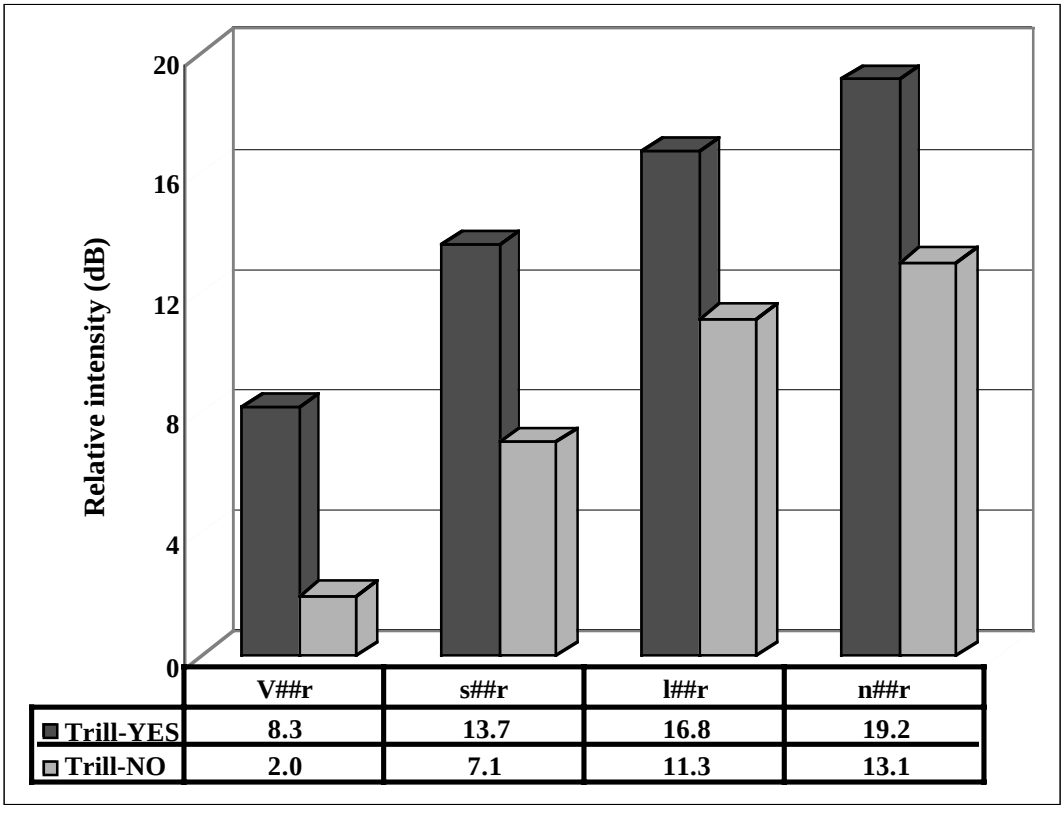


Figure 7. Mean differences in relative intensity (in dB) between rhotic and pre-rhotic segments.

Significant differences in relative intensity between rhotic and pre-rhotic segments were consistently associated with the successful production of trills. Acoustic wave forms with corresponding spectrograms are provided in Figures 8 and 9 below, exemplifying significant and insignificant differences in relative intensity respectively.

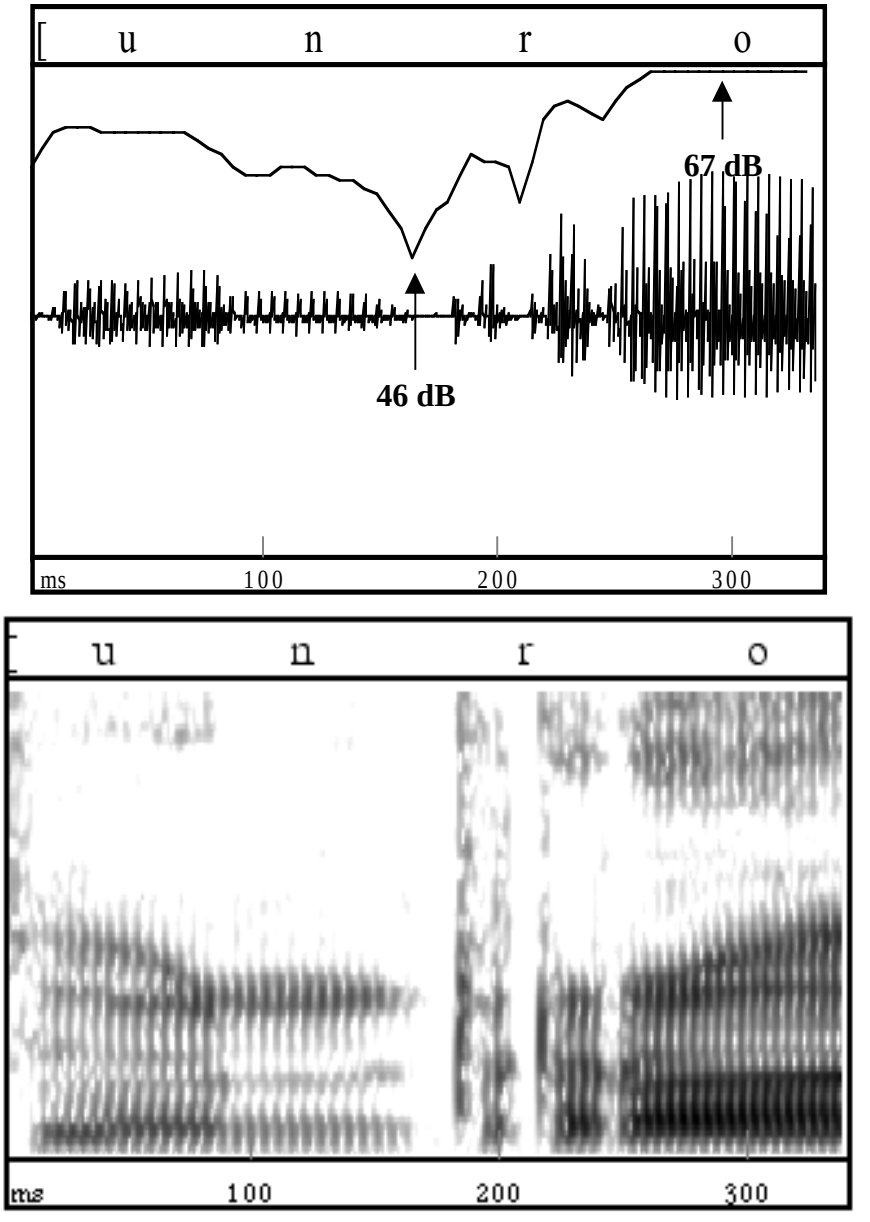


Figure 8. Wave form with intensity tracking and spectrogram of a [n##ɾ] sequence with an intensity difference of 21 dB between the pre-rhotic nasal and following voiced trill.

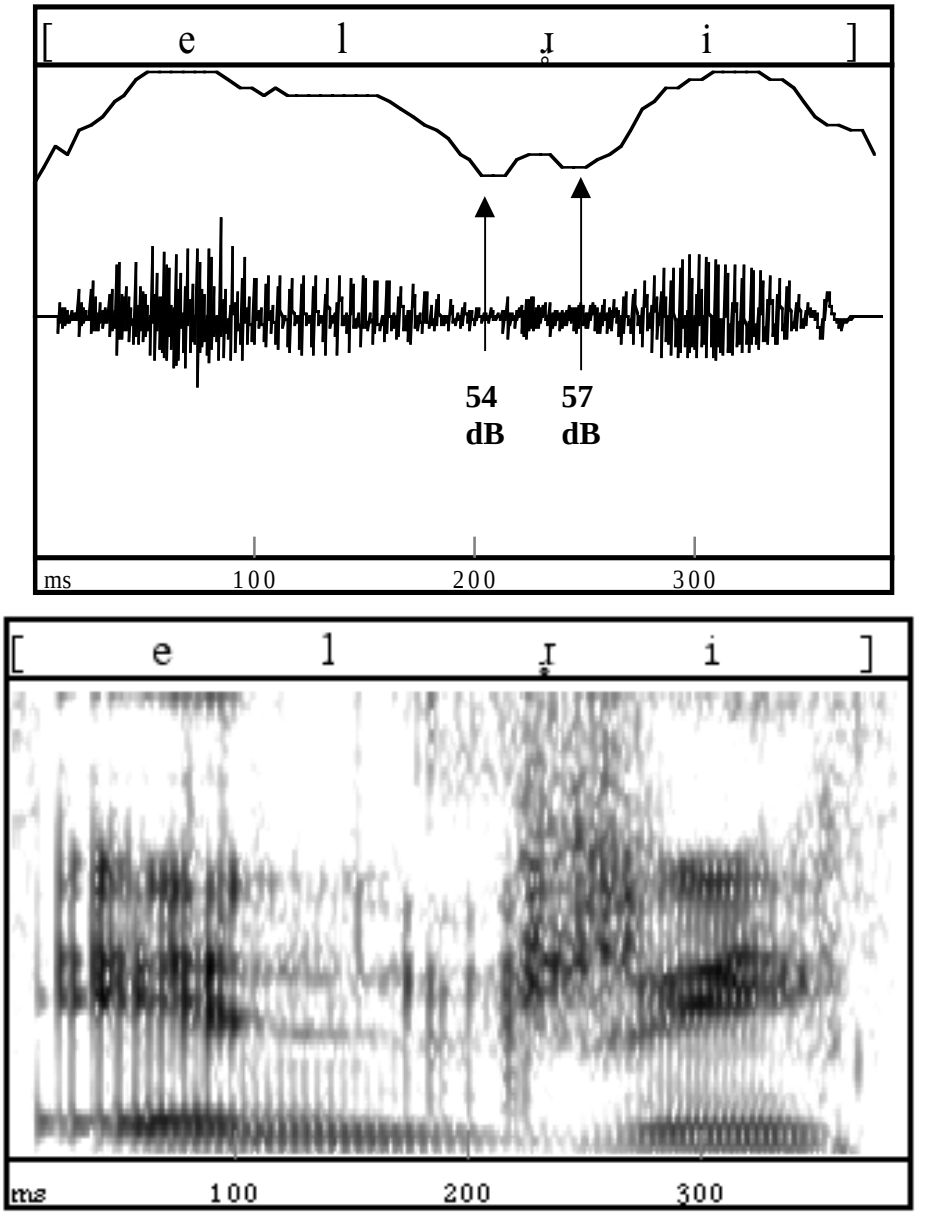
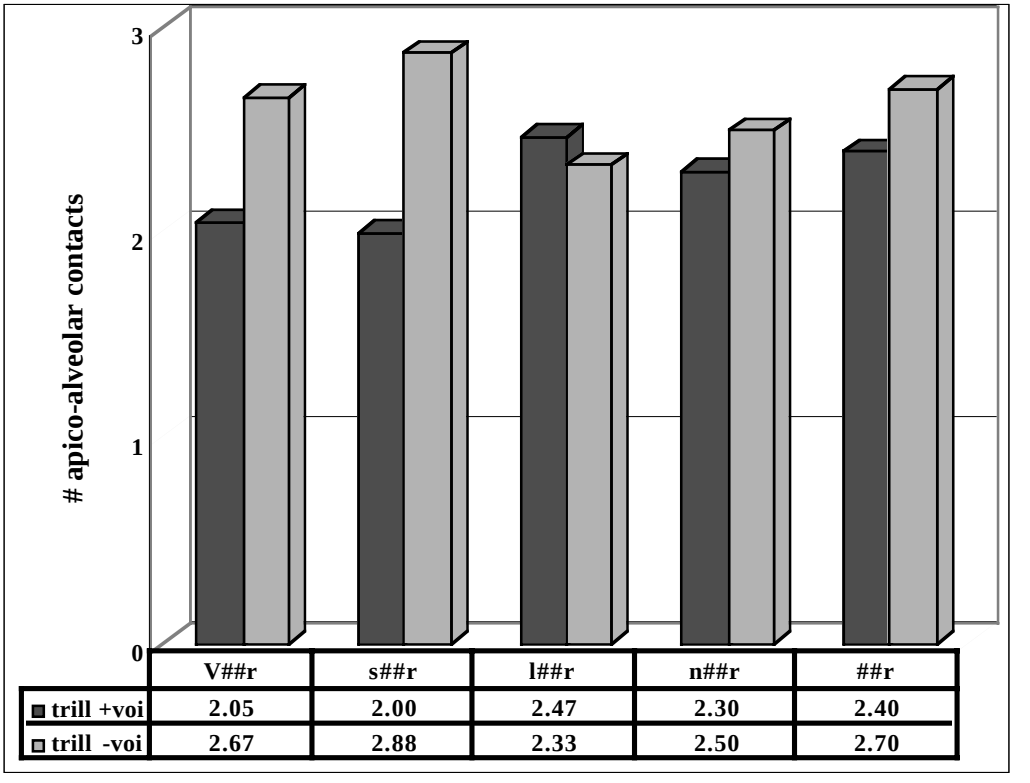


Figure 9. Wave form with intensity tracking and spectrogram of a [l##ɹ̥] sequence with an intensity difference of only 3 dB between the pre-rhotic lateral and following voiceless approximant.

A relatively large difference between the intensity values obtained for the pre-rhotic and rhotic segments (i.e., Figure 8) reflects an abrupt decline in acoustic energy immediately preceding the articulation of the rhotic. The rapid increase in the degree of articulatory stricture allows for the building of oropharyngeal pressure behind the place of articulation until the threshold is met for initiating the vibratory state of the tongue apex, resulting in a trilled phone.

3.6 Apico-alveolar contacts

The number of apico-alveolar contacts associated with the production of voiced and voiceless trills is illustrated in Figure 10.



	V##r	s##r	l##r	n##r	##r
trill +voi	2.05	2.00	2.47	2.30	2.40
trill -voi	2.67	2.88	2.33	2.50	2.70

Figure 10. Mean number of apico-alveolar contacts associated with the production of voiced and voiceless trills in distinct segmental contexts.

On the average, voiceless trills were characterized by a greater number of apico-alveolar contacts than were observed for their voiced counterparts. As proposed in Solé (2002), the smaller mean number of apico-alveolar contacts associated with the voiced trills is the direct result of the impedance to the airflow caused by phonation (i.e., phases of vocal fold vibration), resulting in a reduction in the residual flow upon reaching the site of the lingual stricture. Voiceless trills, on the other hand, were characterized by an overall greater mean number of apico-alveolar contacts than was noted for their voiced counterparts as a result of greater flow values at the site of the lingual stricture due to the lack of any form of impedance at the glottis when the vocal folds are abducted.

4. Conclusions

The present study has attempted to provide a physiological account for the wide range of allophonic variation associated with the implementation of Spanish /r/ in phonological contexts in which the Royal Academy proposes the occurrence of a single allophone, the voiced alveolar trill /r/. In accord with dialectal variation reported in Canfield (1981), Hammond (1999) and Lipski (1994), at least four allophones of /r/ were identified: voiced and voiceless trills and approximants. The voiced trill was the allophone that surfaced most frequently. A positive correlation was identified between an increase in the degree of stricture of the pre-rhotic consonants and the magnitude of the following /r/-allophone based on the acoustic correlates duration, relative intensity, and the number of apico-alveolar contacts. The acoustic correlate which most reliably predicted successful trills was the difference in relative intensity values between the rhotic and pre-rhotic segments. Relatively large

differences in intensity reflect an abrupt decline in acoustic energy resulting from a highly constricted articulatory gesture, which allows sufficient oropharyngeal pressure to build behind the point of stricture to initiate the vibratory state of the tongue apex resulting in a trilled phone.

A relatively large number of successful trills occurred post-vocalically as well as in absolute-initial position. Degree of stricture seemed to be less of a factor for trills occurring in post-vocalic and post-pausal position. In contrast to their post-consonantal counterparts, in neither context (V#__ or ##__) are demands placed on the position of the tongue prior to the articulation of the rhotic. In these two contexts it is assumed that speakers are better able control tongue position along with the aperture and size of the air channel, thus increasing the liklihood of producing a trilled phone.

The largest percentages of voiceless trills were observed in the two "post-voiceless contexts" (i.e., following [s], and in absolute-initial position, when the vocal folds are at rest) suggesting a strong tendency toward voicing agreement between the pre-rhotic segments and the corresponding /ɾ/-allophones.

While the voiced alveolar trill was clearly not a rare allophone in the environment prescribed by the Royal Academy to yield its uniform occurrence, the results of the present study indicate a much wider range of allophonic variation, and consideration of the stricture features associated with pre-rhotic segments has been shown to be a useful tool in predicting the likelihood of the /r/ allophone.

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