Aspects of consonant cluster mutations: the case of /sr/ sequences in Italian

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Abstract

Sequences of lingual fricatives + apical trills involve conflicting configurations of the tongue-tip/dorsum and create the conditions for assimilatory changes leading to the weakening or loss of the lingual fricative before the trill. In Italian, unlike other Romance languages, no assimilation of /s/ to /r/ has been reported. The aim of this paper is to explore the phonetic characteristics of /sr/ clusters in Italian and understand what prevents the assimilation of the lingual fricative to the apical trill. The hypothesis tested is that this may be due to the insertion of an epenthetic consonant or vowel at the release of the fricative impeding the gestural overlap between the fricative and the trill. To this purpose, the target sequences /Vs#rV, VzrV, Vz#rV/, and the control sequences /VrV, V#rV, VzdrV, VstrV/ were embedded in real words and read by several Northern and Southern Italian speakers. The acoustic characteristics of the segments in the sequences were measured. The data show that the fricative is maintained in Italian /sr/ sequences, and that an epenthetic vowel occurs after the obstruent in the test and control sequences. In addition, in the /sr/ sequences, the realization of the rhotic as a tap followed by a burst or period of frication may provide the cues for an epenthetic voiced stop at the transition between the /s/ and the /r/. The data also provide evidence for the presence of an actual stop occurring between /s/ and /r/, which parallels historical patterns from Latin into Romance.

1 Introduction

Many sound patterns in the world languages can be explained by reference to the phonetic requirements for speech sounds. For example, phonological patterns relating to trills, such as the preference for voiced over voiceless trills, the universal tendency for voiceless trills to disappear historically, and the alternation between trills and fricatives, have been explained on aerodynamic, articulatory, and acoustic-auditory grounds (Solé 2002b). The occurrence of similar sound changes in unrelated languages can also be explained by reference to universal factors governing the human speech production and perception mechanism (e.g, Cohn 1990; Goldstein ms; Ohala 1981, 1983, 1993; Ohala & Solé 2010; Recasens 2011a, 2011b; Solé 2002b).

In addition to universal, phonetically-driven factors, speakers' controlled, language-specific speech production and perception mechanisms also play a role in shaping language sound patterns. Specifically, language-specific coarticulatory structures may favor some coarticulatory patterns over others, and these may, in turn, condition listeners' expectations regarding the acoustic consequences of coarticulation, thus promoting language-specific patterns of perception of coarticulated speech (Beddor 2009).

Distinguishing between universal and language-specific sound properties in framing sound patterns is of central interest to phonological theory. However, it is not always easy to determine whether the variation found in the speech data is due to phonetic or phonological processes because, at any given time, a process may appear to have a variable status for some speakers, and be categorical for some other speakers. For example, investigating assimilatory patterns in Italian /nC/ clusters, Farnetani & Busà (1994) found that assimilation in Italian can be both a categorical and a continuous process, depending on speaker and cluster type. Similarly, while a process may be merely phonetic in one language, it may have been phonologized in another language (Solé 2007: 304).

To differentiate between universal and language-specific effects engendering sound change, it is important to compare data from different languages and to investigate how language-specific coarticulatory patterns may promote language-specific perception patterns. This may shed light on the interrelation of factors triggering the emergence of similar phonological processes in unrelated languages, and of different outcomes in related languages.

This paper investigates the phonetic characteristics of /sr/ clusters in Italian and compares the results with previous findings from different varieties of Spanish. The aim is to explore how Italian language-specific patterns of production of /sr/ sequences may cause the lingual fricative to be maintained before the apical trill, in spite of the articulatory and aerodynamic antagonism of the two segments that creates the conditions for the weakening or loss of /s/ before /r/ in Spanish. The paper also considers the effects of this process for sound change.

2 Phonetic requirements for /sr/ clusters

Sequences of lingual fricatives and apical trills involve antagonistic articulatory and aerodynamic requirements and create the conditions for assimilatory changes, leading to the weakening or loss of the fricative before the trill (Solé 2002a).

As for their articulation, lingual fricatives and apical trills are produced with conflicting configurations of the tongue tip/dorsum. That is, while alveolar fricatives require a raised and advanced tongue dorsum for their production, apical trills require a lowered predorsum and a retracted postdorsum (Recasens & Pallarès 1999). In addition, lingual fricatives and apical trills have opposite stiffness requirements: the former require a tense tongue tip-blade, the latter require a relaxed tongue in order for its vibration to occur (Recasens & Pallarès 1999). Because of their narrow postural requirements, both lingual fricatives and apical trills are highly constrained segments and exert a strong coarticulatory effect on the neighboring segments, while they are hardly affected by the neighboring segments involving the same articulator. [In fact, both lingual fricatives and apical trills would be considered ‘unyielding segments’ following the predictions of the Degree of Articulatory Constraint (DAC) model (Recasens & Pallarès 1999; Recasens *et al*. 1997)]. Thus, coarticulation between lingual fricatives and apical trills is not possible because it would impair the basic articulatory requirements for the production of the two segments (i.e., the tongue-tip tension for the fricative and tongue tip vibration for the trill) (Solé 2002a and literature reviewed therein). However, because of the tighter requirements necessary for the production of trills than of fricatives, trills dominate the assimilatory process, which accounts for many sequences of /sr/ becoming /r/ rather than viceversa.

Fricatives and trills also have strict aerodynamic requirements (Ohala 1983; Solé 1998). Both sounds require a build-up of oral pressure (P0) in the oral cavity, so that a pressure drop across the lingual constriction can take place, which is necessary to generate audible turbulence – in the case of fricatives –, and to set the tongue-tip into vibration – in the case of trills. However, as explained by Solé (2002a), in sequences of lingual fricatives and apical trills, any anticipation of the gesture for the trill during the fricative would bleed the aerodynamic requirements for the fricative. Thus, aerodynamic (as well as articulatory) constraints make coarticulation between the two sounds not possible, lest either frication or trilling get impaired.

Finally, trills are more complex sounds than fricatives, and require a fine neuromotoric control of articulatory movements and aerodynamic forces. Because of this, small variations in articulatory and aerodynamic conditions may result in an impairment of the vibrations necessary for their production. In fact, in the world languages, apical trills occur in alternation with non-trilled variants, i.e., taps, which are produced with a brief contact of the tongue-tip with the alveolar ridge. Other common alternative realizations of trills are approximants and fricatives, arising when the tongue-tip fails to vibrate, or when it approaches but does not make contact with the palate, generating a continuous flow of turbulent noise through the aperture (Solé 2002b). The articulatory and aerodynamic similarity of fricatives and trills explains why accommodations of the fine requirements for the trill may give rise to a fricative.

Though the severely constrained phonetic characteristics of lingual fricatives and apical trills make them incompatible sounds, it is still possible to produce /sr/ sequences. This happens when the articulators have enough time to satisfy the articulatory and aerodynamic requirements for their production. So, for example, in Catalan, /sr/ sequences can be produced when an intervening morpheme/syllable boundary gives the speaker enough time to reset the articulators for the production of the apical trill after the lingual fricative. In such cases, characterized by an intervening pause of at least 70 ms between the two sounds, the strong boundary prevents assimilation. Conversely, fast, colloquial speech, or weaker morphemic boundaries may give rise to more assimilated forms, characterized by the lack of co-occurrence of frication and trilling, with possible outcomes ranging from completely assimilated forms, i.e., /sr/ > [r, rː], to intermediate cases in which the trill is reduced to a fricative [ɹ̝] or a blend of a sibilant and a fricative [zɹ̝] (Solé 2002a: 360-361).

3 Phonetic outcomes of /sr/ clusters in Ibero-Romance and Italian

In her examination of the phonetic characteristics of lingual fricatives and apical trills, Solé (2002a) lists a number of cases where, in peninsular Ibero-Romance, the fricative is normally weakened or lost before trills in /sr/ sequences in colloquial speech. This process is reported to give rise to a single trill, a long trill, or a sequence of fricative rhotic plus trill in Iberian Spanish and Catalan; to a single trill in the varieties of Portuguese with an alveolar trill; or to a fricative assimilated to the trill in the varieties of Portuguese with a uvular trill [ʀ]. Examples of this process, taken from Solé (2002a: 353) and Bradley (2006: 1) are given in (a).

(a) Castilian Spanish:

/sr/	*Israel*	[ira'el]	‘Israel’
/s (#) r/	*las rojas*	[la 'roxas]	‘the red ones’

Catalan:

/s # r/	*has rebut*	[ə rə'βut̪]	‘you received’

Portuguese:

/ʃr/	*Israel*	[iʀɐ'ɛɫ]	‘Israel’
/ʃ # r/	*dos reis*	[du 'ʀɐjʃ]	‘of the kings’

In Italian, on the other hand, the lingual fricative in /sr/ sequences is always preserved, as shown in the examples in (b) below.

(b) Italian:
/sr/ *Israele* [izra'ɛle] 'Israel'
/s # r/ *autobus rosso* [autobus 'ros:o] 'red bus'

Solé hypothesizes that the maintenance of the fricative before the trill in Italian is due to the insertion of an epenthetic sound at the release of the fricative, which would prevent the gestural overlap between the fricative and the trill, yielding the following pronunciations:

(c) /sr/ *Israele* [iz^{d}ra'ɛle], [iz^{d}ɾa'ɛle] 'Israel'
/s # r/ *autobus rosso* [autobus^{ə} 'ros:o] 'red bus'

The tendency to insert an epenthetic [d] in cases like *Israele* > [iz^{d}ra'ɛle] might parallel historical outcomes from Latin into Italian. Older scholars of Italian etymology (e.g., Meyer-Lübke 1901: 97; Tekavčić 1972: 243) provided the reconstructions in (d). A similar epenthetic consonant may also explain the development of the French word *coudre* 'to sew' from Latin CONSÚERE (through CONSÚERE > CÓSERE > O. Fr. *cosdre* > *coudre)* (Tekavčić 1972: 243; Brachet 1878: 105).

(d)
*EX/DIS-ROTÈOLUS > It. *sdrucciolo*[1]
*EX/DIS-RESÚERE > It. *sdrucire*[2]

The presence of epenthetic sounds in Italian /sr/ sequences has not, to the author's knowledge, been investigated experimentally. However, that Italian speakers might insert an epenthetic sound between the two consonants in /sr/ sequences is not unlikely. Both consonant and vowel epenthesis occur in Italian, and particularly in the central-southern varieties (Romano 2008: 117). Consonant epenthesis occurs commonly as part of a process referred to as 'post-sonorant affrication'. Due to this process, /ns/, /ls/, /rs/ sequences are produced with an epenthetic alveodental stop, such that words like *penso* 'I think', *salsa* 'sauce', and *corso* 'course' are pronounced, respectively, as ['pɛntso], ['saltsa], and ['kortso]. The fact that this process applies regularly in Central-Southern Italian but not in Northern Italian may reflect differences in coarticulatory strategies in the production of clusters in different varieties of Italian (Busà 2007).

As for the epenthesis of a voiced stop in spoken /sr/ sequences, anecdotal evidence suggests that this could in fact be an active process in Italian: [izdra'ɛle] is a possible alternative pronunciation of the more common [izra'ɛle], and is found as a common spelling in the Internet. Also, 'Isdraele' was a common alternative spelling for 'Israele' in writings of previous centuries (e.g., in Ferdinando Zucconi's *Lezioni Sacre sopra la divina scrittura,* 1741). Finally, 'Isdraele' is found as a last name in Italian, and particularly in the central-southern regions.

Phenomena of anaptyxis (or vowel insertion) are also common in Italian and account for alternating pronunciations of words with and without a vowel in obstruent + sonorant clusters, for example in *comprare* ~ *comperare* 'to buy'. More generally, vowel epenthesis is used as a strategy to accommodate consonant clusters that violate the phonotactics of Italian, for

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1 The word was borrowed by Spanish and Portuguese, giving rise to the words *esdrújulo* and *esdrúxulo* respectively.

2 In fact, more recent etymologists provide a different interpretation for the development of these words. For example, Nocentini (p.c., and 2010) suggests that they are not the result of an epenthesis of /d/ in the cluster /sr/, but rather of the regressive assimilation of /t/ in the voiced context /strV/.

example in words like *psicologia* pronounced [pisikolo'ʤia], especially in central-southern Italian (Romano 2008: 116). In fact, vowel epenthesis in /Cr/ sequences is widely attested in the world languages (e.g., Fleischhacker 2002). Within Romance, evidence that an epenthetic vowel may be inserted in /Cr/ clusters has been provided for Catalan (Recasens & Espinosa 2007), Spanish and French (Colantoni & Steele 2005a: 8-9 and literature reviewed therein; Russell Webb & Bradley 2009). With particular reference to Spanish and French, it has been proposed that vowel epenthesis in obstruent + sonorant clusters correlates with the number of phonetic properties shared by the two consonants: the greater the similarity between the two segments, the greater the probability of dissimilation via epenthesis (Colantoni & Steele 2005a).

The interest in epenthesis goes back a long time, and has been the object of much investigation (reviewed in Fleischhacker 2002). The case of the production of /sr/ clusters raises the question of what combination of universal and linguo-specific patterns may favor the strategy of consonant vs. vowel epenthesis in the sequences. This is also addressed in the present paper.

4 Investigations of /sr/ clusters

The empirical investigations of /sr/ sequences carried out on a variety of Spanish dialects have shown that the outcomes of the process of fricative to trill assimilation vary greatly depending upon dialect, position in the word, and/or type of prosodic boundary, with realizations of the rhotic varying both in manner and place of articulation.

In Catalan, Solé (2002a, reviewed above) found evidence of a complete assimilatory process across minor word boundaries, characterized by realizations of the /sr/ cluster with a single trill and complete loss of /s/. In a study of Latin American Spanish, including data from Bolivia, Ecuador, Colombia, Guatemala, Honduras, and Mexico Spanish, Bradley (2006) found that assimilation at minor syllable boundaries is a non-categorical process. In these varieties, the most common realizations of the /sr/ cluster in word-boundary contexts include non-trilled, and often strident, rhotics with either loss or maintenance of the preceding sibilant. The pattern with the retained sibilant is particularly frequent across major prosodic boundaries with intervening pauses of about 120 ms. In Cochabambino Spanish, a variety of Highland Bolivian Spanish, Sessarego (2011) also found that the assimilation of lingual fricatives to rhotics is dependent upon phonological context: /sr/ sequences are produced most frequently as a single fricative rhotic, or, less often, as a lingual fricative followed by a fricative approximant; when the two sounds are separated by a pause, for example across major prosodic boundaries, the outcome of the sequence is a lingual fricative followed by a period of silence and a voiceless fricative rhotic.

For Italian, no experimental study has yet investigated the characteristics of /sr/ clusters, and provided data that is comparable to the Spanish data.

Like Spanish, Italian has an apical trill. When it occurs in intervocalic position, the trill can be realized as a singleton or a geminate consonant, like most Italian consonants, creating a singleton/geminate opposition (e.g., Canepari 1999: 97-98). An example of this opposition is in the words *caro* /'karo/ 'dear' vs. *carro* /'karro/ 'cart, wagon'. Single trills are produced with a maximum of two contacts, whereas geminate trills are produced with three to seven contacts (Ladefoged & Maddieson 1996: 221; Romano forthcoming: 45).

Like most languages having a trill in their linguistic inventory, including Spanish, Italian also has a tap.[3] The tap occurs in unstressed, non-emphatic syllables, or as a more casual

[3] For Spanish, a different phonological contrast is typically proposed, involving an alveolar flap and a trill, exemplified in the two words *pero* /ˈpero/ 'but' vs. *perro* /ˈpero/ 'dog'. Ladefoged & Maddieson (1996: 237) suggest that "In a number of languages in which,

pronunciation of single trills (Canepari 1999: 97-102). Italian taps are reported to have different variants in different Italian dialects (reviewed in Romano forthcoming: 47-72), spanning from fricatives to approximants, and involving more to less fronted articulations. However, with the exception of Romano's exploratory study, systematic studies on the production characteristics of Italian rhotics are lacking.

/sr/ clusters are not very common in Italian. If we exclude the word *Israele* and its derivatives (e.g., *Israeliano* 'Israeli'), the /sr/ cluster is not found morpheme-internally. However, there are quite a few words where the sequence can be found across two morphemes. This occurs when the *s-* prefix is added to a word beginning with /r/ to give it a reversative or privative meaning, that is, to create a meaning that reverses that expressed by the suffixed word. Some examples are the following: *rotolato* vs. *srotolato* 'rolled' vs. 'unrolled'; *radicato* vs. *sradicato* 'rooted' vs. 'uprooted'. The prefix *dis-* can also be used with the same function, but its use is more limited (Cerruti 2009: 55-57). The word *disrispetto* 'dis-respect', used in the corpus collected for the present study, is not common in Italian, and may present some pronunciation difficulties for the speakers. Across words, the sequence /s##r/, is not frequent, due to the fact that only a limited number of words in Italian end with /s/, *(auto)bus* being one of these. Whenever one of these words is followed by a word beginning with /r/, a sequence of lingual fricative + apical trill is created.

5 Experiment

The aim of the present work is to investigate the phonetic characteristics of /sr/ clusters in Italian and provide evidence showing that, unlike what happens in varieties of Ibero-Romance, in Italian the lingual fricative is maintained before the trill. This study also investigates processes of vowel and consonant epenthesis in Italian /sr/ sequences, and looks for acoustic cues that might trigger the perception of 'd' epenthesis in words like *Israele*, providing the conditions for a sound change.

The hypotheses tested in the present experiment are the following: (1) in Italian /sr/ sequences /s/ is maintained regardless of the type of prosodic boundary intervening between /s/ and /r/; this may be due to the insertion of epenthetic sounds (vowels or consonants) at the fricative-rhotic transition; (2) in the realization of /sr/ sequences, the trill may be detrilled into a tap; this may provide the cues for an epenthetic voiced stop at the transition between /s/ and /r/; (3) processes of epenthesis in /sr/ sequences are more frequent in the speech of Southern than of Northern Italian, as part of a more widespread tendency for epenthesis in the Southern than in the Northern varieties of Italian.

These hypotheses were tested using a corpus of 12 Italian phonological words containing:

(1) 3 target sequences: /VzrV/, /Vz(#)rV/, /Vs##rV/;
(2) 4 control sequences: /Vr:V/, /Vr##rV/, /V#zdrV/, /V#strV/.

The list of words recorded for the experiment is shown in Table 1.

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unlike Spanish, there is regularly a distinction between single and geminate consonants, the single and geminate rhotics differ in just the way that the Spanish segments do. Single rhotics are taps, and geminate are trills".

Context	Words	Meaning
/VzrV/	*Israele*	'Israel'
/Vz(#)rV/	*è sregolato* *è srotolato* *è sradicato* *disrispetto*	'is unruled' 'is unrolled' 'is uprooted' 'disrespect'
/Vs##rV/	*autobus rosso*	'red bus'
/Vr:V/	*terreno* *terrazza*	'terrain' 'terrace'
/Vr##rV/	*per Remo* *per razza*	'for Remo' 'by race'
/V#zdrV/	*la sdraio*	'(I) lay it down'
/V#strV/	*è strano* *la striscia*	'(it) is weird' 'the stripe'

Table 1. Words used in the experiment.

The words were presented as a list and were read 5 times in a row by each subject, with a short pause between each word. One speaker read the words 7 times. Other recordings of the words in sentences are not presented in this paper. The subjects were 4 Northern Italian (N.I.) speakers (from Veneto) and 4 Southern Italian (S.I.) speakers (from Apulia), of ages between 22 and 35. The total number of tokens collected in the corpus was: for N.I. 132 (target words) + 154 (controls); for S.I. 120 (target words) + 140 (controls).

The data were collected with a portable *Sony* DAT recorder and a *SHURE* SM58 microphone at the University of Padova. The signal was then digitized and transferred to a computer hard disk with the software *Goldwave* v.5.58, at a 44100 Hz sampling rate and a 16 bit resolution. These data were analyzed acoustically with *Praat*.

6 Analysis

The rhotic was produced with a number of phonetic variants. This was expected, based on previous studies of the phonetic realization of rhotics (e.g., Bradley & Willis 2012; Ladefoged & Maddieson 1996; Recasens & Espinosa 2007; Solé 2002b). Thus, a first necessary step in the analysis was the acoustic and auditory inspection of the data to define criteria for categorizing the observed variability of the rhotics. This preliminary analysis yielded the following categorization:

(a) Trills. These were defined as two- to five-contact rhotics, with or without a period of aperiodic noise at the release of the final contact, or an r-colored approximant before the following vowel, characterized by continuous formant movements into the vowel. This rhotic had an average duration of 90-150 ms, depending on the context, and was found mainly in the /Vr:V/, /Vr##rV/ control sequences. This kind of rhotic is described in detail in Ladefoged & Maddieson (1996: 219-221).

(b) Voiced and voiceless fricated rhotics. These were characterized by the presence of aperiodic noise concentrated around 3000 Hz, sometimes preceded by a short, few ms closure. They had variable durations, ranging around 35-50 ms. Voiced fricated approximants were also included in this category. This category of rhotics was found relatively infrequently in the data. An example is shown in Figure 1.

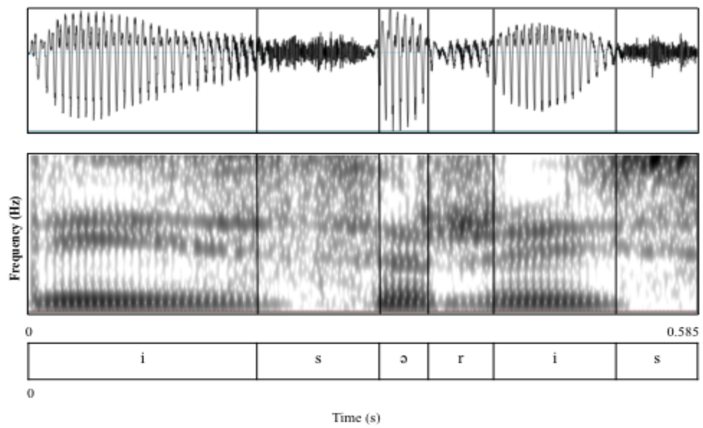

Figure 1. An example of a voiced fricated rhotic, as produced in the word *disrispetto*. An epenthetic vowel, indicated with [ə], is noticeable between /s/ and /r/.

(c) Taps. These were characterized by a short 15-25 ms closure, typically voiced. In this category were included both fricated taps and approximant taps. An example of a voiced fricated tap is provided in Figure 2.

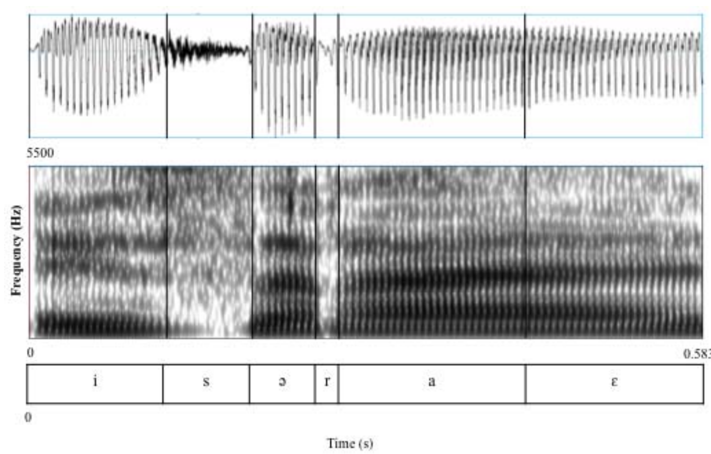

Figure 2. An example of a tap, as produced in the word *Israele*. An epenthetic vowel, indicated with [ə], is noticeable between /s/ and /r/.

(d) Taps with a burst or fricated release. These were characterized by a short 20 ms closure followed by a long fricated burst, a 20-30 ms period of aperiodic noise, or a short approximant with continuous formant movements into the vowel. This kind of rhotic, also reported by Bradley & Willis (2012), was found most frequently in the test /VzrV/, /Vz(#)rV/, /Vs##rV/ sequences, though, here too, other variants were also possible. This rhotic is exemplified in Figure 3.

(e) Extremely reduced rhotics or 'perceptual taps' (Willis & Bradley 2008: 93). These were produced like approximants, with considerable reduction in the waveform and an uninterrupted formant structure of the surrounding vowels. However, unlike the short approximant taps in the previous category, the acoustic landmarks delimiting the rhotic were hardly identifiable. In a few cases, the rhotic was so reduced that it was completely indistinguishable from the flanking vowel. An example of a perceptual tap is shown in Figure 4.

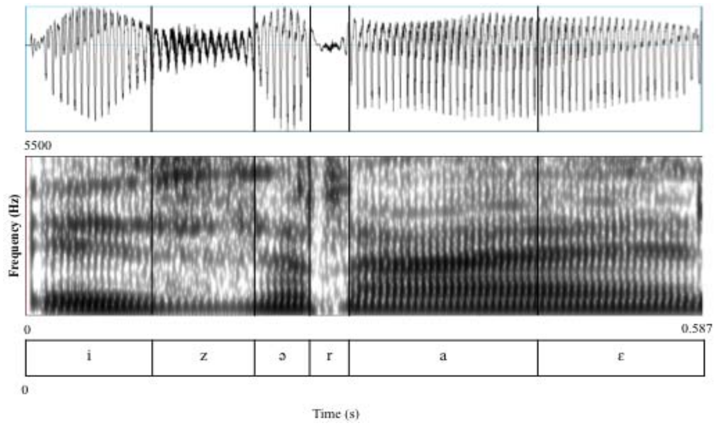

Figure 3. An example of a tap with a long fricated release, as produced in the word *Israele*. An epenthetic vowel, indicated with [ə], is noticeable between /s/ and /r/.

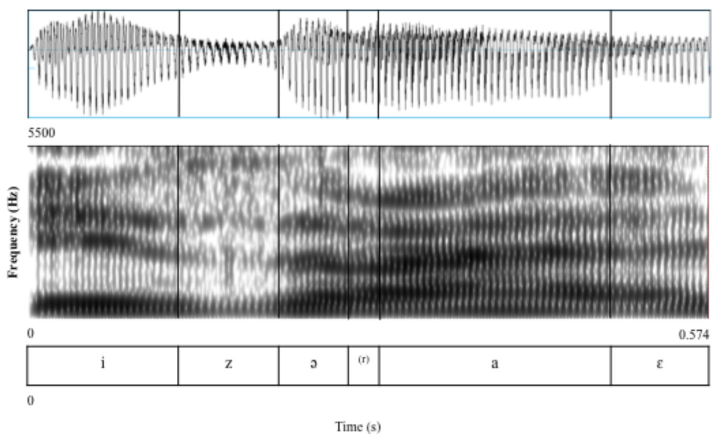

Figure 4. An example of a perceptual tap, as produced in the word *Israele*. An epenthetic vowel, indicated with [ə], is noticeable between /z/ and /r/.

The following acoustic measures were taken:

- duration of the rhotics;
- duration of the lingual fricative in the /VzrV/, /Vz(#)rV/, /Vs##rV/, and /V#zdrV/, /V#strV/ sequences;
- duration and formant frequencies of any epenthetic vowels in the /VzrV/, /Vz(#)rV/, /Vs##rV/, and /V#zdrV/, /V#strV/ sequences;
- duration of the stop in the /V#zdrV/ and /V#strV/ control sequences, and of any epenthetic stop found in the data;
- formant frequencies of V2, i.e., the vowel following the rhotic, in the clusters.

7 Results

7.1 Rhotics in intervocalic position

Table 2 shows the frequency of occurrence, with mean and standard deviations, of the rhotics in the /Vr:V/ and /Vr##rV/ sequences, divided by category. There was no significant effect of the across-word boundary condition on the type or duration of the rhotic. In both /Vr:V/ and /Vr##rV/ sequences, the rhotic was realized as a trill in nearly all occurrences (96%), confirming previous finding (Ladefoged & Maddieson 1996) and phonological descriptions of Italian (e.g., Canepari 1999) that long or geminate rhotics in intervocalic position are realized as trills. The trill was realized mainly as a 3-contact trill, but realizations as 2- or 4-contact trills were also frequent. More rarely, the rhotic in this context was realized as a one-contact trill with a long fricated release, or a fricated rhotic. As the table shows, long intervocalic trills have a duration spanning from 77 ms to 152 ms. The between-group differences in the rhotic duration were not significant.

	Category of Rhotic		N.	Mean Duration (ms)	St. Dev. (across subjects)
N.I.	1-contact rhotics		6	**58**	*13*
	multi-contact trills	2-contact	17	**87**	*25*
		3-contact	34	**99**	*21*
		4-contact	26	**129**	*9*
		5-contact	1	**149**	
	fricated rhotic				
	Total		84	**104**	*28*
S.I.	1-contact rhotics		7	**93**	*21*
	multi-contact trills	2-contact	21	**77**	*20*
		3-contact	42	**105**	*11*
		4-contact	2	**152**	*10*
		5-contact			
	fricated rhotic		7	**100**	*24*
	Total		79	**97**	*22*

Table 2. Variation in the realization of phonological trills, by category, in the /Vr:V/ and /Vr##rV/ control sequences for the Northern Italian (N.I.) and Southern Italian (S.I.) speakers.

7.2 Rhotics in /V#zdr/ and /V#str/ clusters

The rhotics in the /V#zdrV/ and /V#strV/ control sequences were invariably realized with a short epenthetic vowel, occurring after the burst of the preceding stop and before the rhotic. An example of this pattern is shown in Figure 5. The rhotic was mainly produced as a tap (70% in N.I.; 58% in S.I.). Other rhotics were: a tap with a burst release (15% in N.I.; 22% in S.I.); a perceptual tap (5% in N.I.; 13% in S.I.); a two-contact trill (6% in N.I.; 5% in S.I.); and a fricated rhotic (4% in N.I.; 2% in S.I.). The epenthetic vowel was found in all the tokens produced by two groups of speakers. Evidence for the presence of a vocalic element between a stop and the subsequent rhotic is not new, as it was found in studies of /Cr/ sequences in Catalan (Recasens & Espinosa 2007; Russel Webb & Bradley 2009), Greek (Baltazani 2009) and French and Spanish (Colantoni & Steele 2005b) among others. These studies describe this type of epenthetic vowel as having a formant structure that is influenced by the formants of the following vowel, and a duration that is longer than that of the following tap.

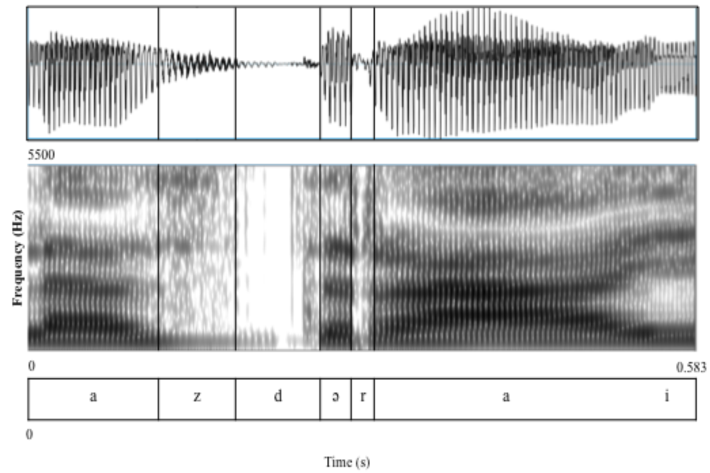

Figure 5. An example of the epenthetic vowel [ə] produced after the stop burst and before the rhotic in /V#zdrV/ and /V#strV/ sequences. Here the word is *la sdraio*.

The data in Table 3 show some of the production details of the /V#zdrV/ and /V#strV/ sequences for the two groups of speakers. The two groups have similar durations of the fricative and the stop consonants (the differences between groups are non significant). Both groups show about 20 ms longer fricatives in the voiceless than in the voiced context [for N.I., $F(1, 65) = 10.77$, $p = 0.002$; for S.I., $F(1, 58) = 10.96$, $p = 0.002$]. For both groups, the voiceless stop is about 10 ms longer than the voiced stop, but the difference is significant only for N.I. [$F(1, 65) = 15.07$, $p = 0.000$].

As for the epenthetic vowel (*v*) occurring after the burst of the preceding stop and before the rhotic, its duration ranges around 27-39 ms (in agreement with what reported for Catalan in Recasens & Espinosa 2007: 5), with non-significant differences across groups. *v* is significantly longer after the cluster with the voiced than the voiceless stop (also in agreement with Recasens & Espinosa's data) [for N.I., $F(1, 42) = 16.8$, $p = 0.000$; for S.I., $F(1, 38) = 12.14$, $p = 0.001$]. For both groups and in all contexts, the duration of *v* is longer than that of the following rhotic, also as reported in the literature (for N.I., the mean value of *v* is 34 ms, for N= 66, St.dev. = 7.5, while the rhotic /r/ is 19.61 ms, for N=67, St.dev. = 9.97; for S.I., the mean value of *v* is 30.71 ms, for N = 56, St.dev. 9.15, while /r/ is 18.53, for N = 50, st.dev. 4.69). The quality of *v* is influenced both by the flanking vowel and the consonantal context. In fact, for both groups, *v* in the /V#stri/ sequence is higher and more fronted than *v* in the /V#stra/ and /V#zdra/, as shown by lower F1 and higher F2 values, indicating an effect of V2 on the quality of the epenthetic vowel. However, *v* in the /V#stra/ and /V#zdra/ sequences is higher and more fronted than V2 (as is shown by the lower F1 values and higher F2 and F3), indicating a possible effect of the flanking apical consonants, particularly in the speech of N.I. This calls for a closer investigation of the production characteristics of the consonants in the cluster.

The effect of the word context is significant for both *v* and V2 [for N.I.'s *v*, F1: $F(2, 63) = 29.93$, $p = 0.000$; F2: $F(2, 63) = 37.31$, $p = 0.000$; F3: $F(2, 63) = 5.5$, $p < 0.006$; for S.I.'s *v*, F1: $F(2, 57) = 8.69$, $p = 0.001$; F2: $F(2, 57) = 15.75$, $p = 0.001$; F3: non significant]; [for N.I.'s V2, F1: $F(2, 64) = 306.5$, $p = 0.000$; F2: $F(2, 63) = 149.25$, $p = 0.000$; F3: $F(2, 64) = 34.57$, $p = 0.000$; for S.I.'s V2, F1: $F(2, 57) = 166.78$, $p = 0.000$; F2: $F(2, 57) = 661.12$, $p = 0.000$; F3: $F(2, 57) = 166.78$, $p = 0.000$].

Finally, the data show that the groups differ in their realizations of V2 quality, with S.I. vowels being more back than N.I. vowels. This is expected, based on previous studies showing that vowel quality varies in the dialects of Italian and reflects in the way in which Italian is spoken regionally (Ferrero *et al*. 1996; Grimaldi 2003). The across-group differences are significant for F2 and F3 of both /a/ [for F2: F(1, 82) = 31.36, p =0.000; for F3: F(1, 82) = 5.19, p < 0.02] and /i/ [for F2: F(1, 41) = 8.18, p < 0.00; for F3: F(1, 41) = 31.54 p = 0.000]. The values of F2 and F3 of *v* are also different across groups [for *v* in the context of /a/, F2: F(1, 82) = 50.34, p = 0.000; F3: F(1, 82) = 4.11 p < 0.04]; [for *v* in the context of /i/, F2: F(1, 40) = 53.89, p = 0.000; F3: F(1, 40) = 5.24 p < 0.02].

N.I.		/s, z/	/d, t/	*v* (= epenthetic vowel)				/r/	V2		
context		Dur.	Dur.	Dur.	F1	F2	F3	Dur.	F1	F2	F3
V#zdra	Mean	**67**	**74**	**39**	**539**	**1751**	**2805**	**18**	**856**	**1504**	**2557**
	N	22	22	22	22	22	22	22	22	22	22
	Std. Dev.	*20*	*13*	*6*	*46*	*135*	*197*	*9*	*77*	*147*	*138*
V#stra	Mean	**83**	**87**	**31**	**558**	**1652**	**2724**	**16**	**831**	**1569**	**2781**
	N	22	22	22	22	22	22	22	22	22	22
	Std. Dev.	*27*	*10*	*6*	*62*	*146*	*179*	*8*	*102*	*122*	*348*
V#stri	Mean	**92**	**88**	**31**	**425**	**2028**	**2921**	**25**	**335**	**2562**	**3181**
	N	23	23	22	22	22	22	23	23	23	23
	Std. Dev.	*23*	*16*	*7*	*73*	*165*	*214*	*11*	*54*	*347*	*243*

S.I.		/s, z/	/d, t/	*v* (= epenthetic vowel)				/r/	V2		
context		Dur.	Dur.	Dur.	F1	F2	F3	Dur.	F1	F2	F3
V#zdra	Mean	**65**	**74**	**37**	**545**	**1503**	**2717**	**17**	**802**	**1388**	**2509**
	N	20	20	20	20	20	20	19	20	20	20
	Std. Dev.	*15*	*29*	*10*	*82*	*93*	*208*	*4*	*111*	*89*	*168*
V#stra	Mean	**87**	**86**	**28**	**564**	**1456**	**2642**	**19**	**826**	**1403**	**2597**
	N	20	20	20	20	20	20	19	20	20	20
	Std. Dev.	*34*	*30*	*6*	*75*	*171*	*176*	*4*	*106*	*80*	*136*
V#stri	Mean	**88**	**75**	**27**	**460**	**1685**	**2777**	**19**	**352**	**2330**	**2830**
	N	20	20	16	20	20	20	13	20	20	20
	Std. Dev.	*21*	*18*	*7*	*95*	*137*	*189*	*13*	*45*	*110*	*158*

Table 3. Acoustic measures of the segments in the /V#zdr/ and /V#str/ control sequences. N.I. speaker group (upper panel) and S.I. speaker group (lower panel).

7.2.1 Phonetic patterns in /VzrV/, /Vz(#)rV/ and /Vs##rV/ clusters

The most interesting pattern of the production of the /VzrV/, /Vz(#)rV/, and /Vs##rV/ sequences was the presence of an epenthetic vowel at the release of the fricative and before the rhotic. This short epenthetic vowel, averaging 30-50 ms duration, was found in all but 4 of the tokens (98%), regardless of whether there was a word or morpheme boundary or not. This vowel, clearly visible in Figures 1-4, appears to have slightly longer duration than the one found in the /V#zdrV/ and /V#strV/ control sequences. Its average, across contexts, is 49 ms (vs 34 ms in the /V#zdrV/ and /V#strV/ sequences) for N.I., and 39 ms (vs. 31 ms in the /V#zdrV/ and /V#strV/ sequences) for S.I. These differences are significant [for N.I., F(1, 186) = 59.67, p = 0.000; for S.I., F(1, 173) = 21.50, p = 0.000]. As for its formant structure, F1, F2 and F3 appear to vary quite considerably in the different contexts. These differences were significant for both N.I. [F1: F(3, 124) = 9.88, p = 0.000; F2: F(3, 124) = 22.05, p = 0.000; F3: F(3, 124) = 2.93, p <0.03], and S.I. [F1: F(3, 112) = 5.41, p = 0.002; F2: F(3, 112) = 216.29, p = 0.000; F3 non significant]. As was the case for the epenthetic vowel in the control /V#zdrV/ and /V#strV/ sequences, the quality of this epenthetic vowel is affected by the quality of the following vowel: for both groups, the epenthetic vowel in the word *disrispetto* is the most fronted (i.e., has the highest F2 values) because it is followed by the vowel /i/. The epenthetic N.I. vowels in the words *israele*, *sradicato* and *sregolato* appear much more fronted than the S.I. vowels, which might be explained on the ground of differences in the point of articulation of the rhotic by the two speaker groups (see § 4). The variations in the epenthetic vowel formant frequency values in relation to context require further investigation.

The data relating to the acoustic measures of the /VzrV/, /Vz(#)rV/, and /Vs##rV/ sequences are shown in Tables 4 and 5.

N.I.		/s, z/	/d, t/	*v* (= epenthetic vowel)				/r/
Context		Dur.	Dur.	Dur.	F1	F2	F3	Dur.
autobus rosso	Mean	**139**		**36**	**413**	**1477**	**2663**	**24**
	N	22		22	22	22	22	22
	Std. Dev.	*15*		*15*	*85*	*155*	*321*	*9*
disrispetto	Mean	**84**		**52**	**439**	**1909**	**2831**	**35**
	N	21		20	20	20	20	20
	Std. Dev.	*25*		*11*	*63*	*191*	*228*	*11*
israele	Mean	**74**		**50**	**494**	**1801**	**2815**	**26**
	N	22		22	22	22	22	20
	Std. Dev.	*15*		*12*	*57*	*156*	*205*	*9*
sradicato	Mean	**84**	**36**	**47**	**526**	**1691**	**2760**	**25**
	N	22	1	22	22	22	22	22
	Std. Dev.	*19*		*10*	*39*	*190*	*214*	*10*
sregolato	Mean	**89**		**54**	**502**	**1722**	**2731**	**30**
	N	21		21	21	21	21	21
	Std. Dev.	*14*		*10*	*52*	*235*	*197*	*13*
srotolato	Mean	**79**		**53**	**483**	**1551**	**2675**	**23**
	N	21		21	21	21	21	21
	Std. Dev.	*11*		*13*	*69*	*206*	*220*	*7*

Table 4. Acoustic measures of the segments in the /VzrV/, /Vz(#)rV/ and /Vs##rV/ sequences.
N.I. speaker group.

S.I.		/s, z/	/d, t/	*v* (= epenthetic vowel)				/r/
context		Dur.	Dur.	Dur.	F1	F2	F3	Dur.
autobus rosso	Mean	**123**		**38**	**466**	**1392**	**2752**	**23**
	N	20		20	19	19	19	18
	Std. Dev.	*14*		*10*	*177*	*266*	*304*	*7*
disrispetto	Mean	**77**		**42**	**352**	**1748**	**2725**	**23**
	N	20		20	20	20	20	17
	Std. Dev.	*14*		*12*	*41*	*196*	*204*	*8*
israele	Mean	**72**	**68**	**41**	**458**	**1583**	**2708**	**17**
	N	20	5	20	19	19	19	17
	Std. Dev.	*20*	*16*	*17*	*96*	*121*	*177*	*7*
sradicato	Mean	**76**	**49**	**40**	**464**	**1542**	**2644**	**21**
	N	20	9	20	20	20	20	15
	Std. Dev.	*24*	*35*	*12*	*82*	*98*	*231*	*9*
sregolato	Mean	**74**	**34**	**42**	**422**	**1556**	**2709**	**25**
	N	20	5	20	19	19	19	19
	Std. Dev.	*22*	*25*	*12*	*57*	*189*	*244*	*12*
srotolato	Mean	**61**	**61**	**33**	**379**	**1432**	**2652**	**19**
	N	20	6	19	19	19	19	19
	Std. Dev.	*23*	*13*	*8*	*60*	*132*	*213*	*7*

Table 5. Acoustic measure of the segments in the /VzrV/, /Vz(#)rV/ and /Vs##rV/ sequences. S.I. speaker group.

The sibilant consonant was present in nearly all tokens (98%). In the N.I. data, it is realized mostly as a voiced fricative (77%), less often as a voiceless fricative (21%), and a voiced approximant (2%). Its duration spans from 74 ms in the /VzrV/ and /Vz(#)rV/, sequences, to 139 ms in the /Vs##rV/ sequence. The effect of the morpheme boundary on /s/ duration is significant [$F(2, 126) = 100.82$, $p = 0.000$]. The epenthetic vowel following the fricative has a duration of about 50 ms in the /VzrV/ and /Vz(#)rV/, sequences, and is shorter in the /Vs##rV/ context. The effect of the context on the epenthetic vowel duration is significant [$F(2, 125) = 15.66$, $p = 0.000$]. The rhotic has a duration ranging around 23-35 ms, with non-significant differences across the different contexts. In the S.I. data, the sibilant is realized mostly as a voiced fricative (81%), less often as a voiceless fricative (19%). Its duration spans from 60-77 ms in the /VzrV/ and /Vz(#)rV/, sequences, to 123 ms in the /Vs##rV/ sequence. The duration of /s/ is significantly affected by the across word boundary [$F(1, 118) = 106.37$, $p = 0.000$]. The epenthetic vowel has a duration ranging around 30-40 ms, with non-significant differences across contexts. The rhotic duration ranges around 17-23 ms, with non-significant differences across the different contexts.

The comparison of the data of the two groups shows that S.I. has overall shorter /s/, shorter epenthetic vowels and shorter /r/ than N.I. The mean duration values, averaged across all contexts, show that: /s/ is 80 ms (N. 120, st.dev. 27.7) for S.I., and 92 ms for N.I. (N. 129, st.dev. 28.03); the epenthetic vowel is 39 ms (N. 119, st.dev. 12.51) for S.I., and 49 ms (N. 128, st.dev. 13.2) for N.I.; /r/ is 21 ms (N. 105, st.dev. 8.81) for S.I., and 27 ms (N. 126, st. dev. 10.65) for N.I. Thus, it appears that S.I. speakers have an overall faster articulation rate than N.I. speakers. This may have an influence on the production of the cluster and result in a greater tendency, discussed below, to produce an epenthetic stop in the /sr/ cluster as compared to N.I.

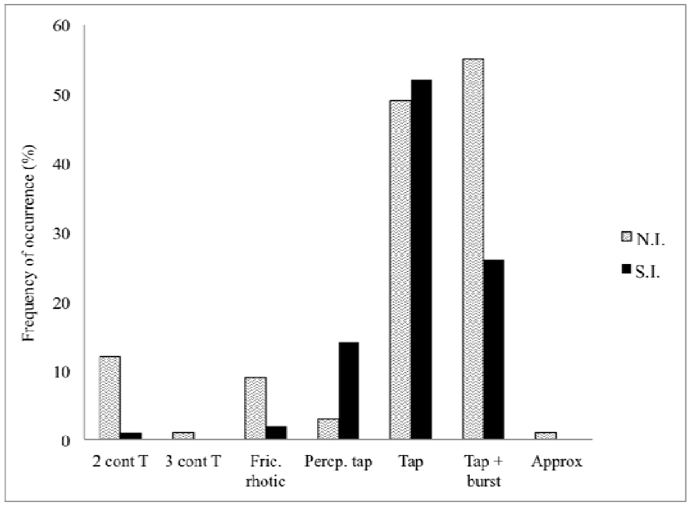

Figure 6. Frequency of occurrence of rhotics, by category, in the /VzrV/, /Vz(#)rV/ and /Vs##rV/ sequences.

In the /sr/ cluster, as in the control sequences, the rhotic was produced with a number of phonetic variants. The category subdivision of the rhotics produced by the two speaker groups is shown in Figure 6. As the Figure shows, the two most frequently occurring rhotics were taps and taps + burst (and/or fricated release). In the N.I. data, taps occurred in 38% of the total tokens and taps + burst (and/or fricated release) in 42%. In the S.I. data, taps occurred in 57% of the total occurrences and taps + burst (and/or fricated release) in 27%.

Evidence of an epenthetic /d/ between the /s/ and the /r/ segments in the clusters was present in 1 token in the N.I. data, and in 24 tokens in the S.I. data (20%). The epenthetic /d/ was found in the words *sradicato* (37%), *israele* (21%) *sregolato* (21%) *srotolato* (20%). No evidence of consonant epenthesis was found in *autobus rosso* or *disrispetto*. An example of the epenthetic /d/ in the sequence /Vz(#)rV/ is shown in Fig. 7. This sequence looks very similar to the control /V#zdrV/ sequence shown in Fig. 5. Both sequences are also characterized by the presence of an epenthetic vowel after the stop release; however, in the example in Fig. 7, /s/ and /d/ are partially voiceless and /r/ is a long fricated rhotic rather than a tap (compare Fig. 5).

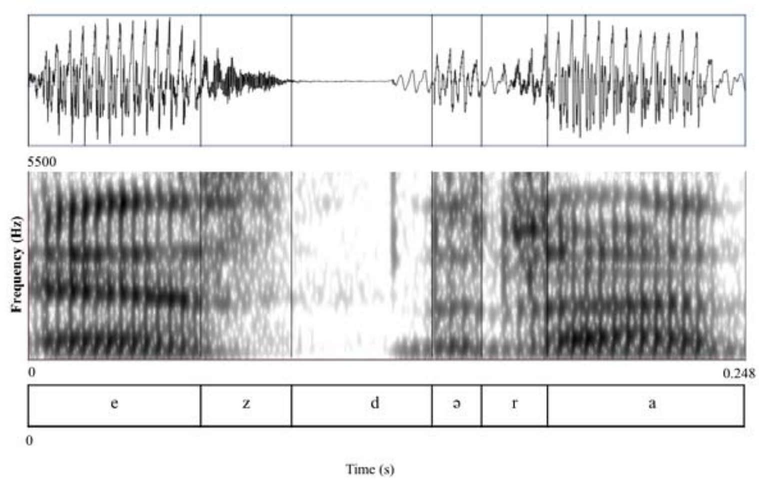

Figure 7. Evidence of consonant epenthesis in the word *sradicato*. An epenthetic vowel [ə] is noticeable between /d/ and /r/.

8 Discussion and conclusion

This study was aimed to investigate the acoustic characteristics of sequences of lingual fricatives and apical trills in Italian, and to understand why these sequences have different outcomes in Italian than in Spanish. In Spanish, studies have provided evidence of an assimilatory process occurring to different degrees and in different contexts in various dialects. In Italian, the results of this investigation show no evidence of an assimilatory process leading to the deletion of the fricative before the rhotic. Rather, the fricative is always maintained, both across and within word boundaries. In addition, an epenthetic vowel occurs, consistently, at the release of the fricative and before the rhotic, again, both across and within word boundaries. This epenthetic vowel is about 30-50 ms long and has a formant structure that is affected by the quality of the following vowel, though some effect of the flanking consonants cannot be excluded and requires further investigation. A 30-40 ms epenthetic vowel also occurs at the release of the stop and before the rhotic in the control /V#zdr/ and /V#str/ sequences. An epenthetic /d/, occurring between the fricative and the rhotic in /sr/ clusters, was also found in 20% of the total test tokens. When this epenthetic /d/ is present, the /sr/ sequence looks like the control /V#zdr/ sequence, that is, there is an epenthetic vowel after the burst of the stop and before the rhotic. The epenthetic /d/ was found almost only (99%) in the data from the Southern Italian speakers, who also showed overall shorter segments than the Northern speakers. Thus, the observed /d/ epenthesis process may be related to other processes of consonant epenthesis, frequently occurring in the Central-Southern varieties of Italian more than in the North, and/or may be due to the faster speaking rate of the Southern than the Northern Italian speakers. This calls for further investigation. In general, the emergence of epenthesis in /sr/ sequences in Italian may be part of a widely attested Italian strategy for cluster simplification via epenthesis that is realized in different forms and to a different extent depending upon the geographical area and dialectal influence under consideration (Canepari 1979: 221; Romito 2010; Sobrero 1974: 61, 1988: 734).

This study partially confirms the initial hypothesis that in Italian /sr/ sequences the lingual fricative is maintained due to the insertion of epenthetic sounds (vowels or consonants) at the fricative-rhotic transition that prevent the coproduction of the two segments in a sequence. In fact, however, the present data show that in Italian /sr/ sequences, trills do not occur very frequently. Rather, the most common rhotics occurring in Italian /sr/ sequences are taps, as well as taps released with a burst and/or a long fricated noise. In all cases, the rhotic in the sequence is preceded by an epenthetic vowel, of which the speakers seem to have no awareness. The presence of this vowel can be explained as a short transition that is created when the articulators move from being tense for the production of the fricative to being relaxed for the production of the rhotic, requiring the tongue to touch rapidly the alveolar region. In this sense, it would appear to be a phonetic mechanism. It, could, however, be favored by a tendency of the Italian language towards the minimal overlap of fricatives+rhotics in a sequence. Spanish, on the other hand, would appear to favor a greater overlap of these segments and thus show more assimilatory patterns. In other words, the different outcomes in Italian and Spanish could be explained as due to the differences in coarticulatory timing in the two languages, which would, on the one hand, favor assimilatory processes in Spanish through a tendency towards greater gestural overlap, and, on the other, favor epenthesis in Italian due to a tendency towards less overlap (see Bradley 2006: 11, for a similar interpretation). Note, though, that while the present study has investigated Italian words produced in a list (i.e., rather careful speech), the investigations of assimilatory processes in /sr/ sequences in Spanish (reviewed above) have examined casual speech. A better measure of the differences in articulatory timing between Italian and Spanish, as well as differences in assimilatory processes, would come from comparing similar styles of speech.

The presence of an epenthetic vowel in /sr/ clusters may be part of a wider phenomenon involving /Cr/ clusters. Epenthetic vowels have been attested for many /Cr/ clusters in a variety of languages, including Spanish and Catalan (reviewed in Colantoni & Steele 2005b; Russel Webb & Bradley 2009), and have been characterized as a short vowel transition having a formant structure that is dependent on that of the following vowel, and having longer duration than that of the following rhotic (Recasens & Espinosa 2007: 5). The present data show that the epenthetic vowel in /sr/ clusters has the same characteristics, as far as vowel quality and duration are concerned, as epenthetic vowels in /Cr/ clusters. The data also indicate that there is a direct relation between the duration of the epenthetic vowels and the duration of the preceding and following segments in the cluster, with longer flanking segments giving rise to longer epenthetic vowels in Northern Italian than in Southern Italian.

Epenthetic vowels involving rhotics are expected to occur more frequently in heterorganic than in homorganic clusters. This is because epenthesis may be caused by the gestural adjustments necessary for the production of the segments in clusters involving a tongue displacement, like clusters of apicals + labials or dorsals. Such adjustments are not necessary in homorganic clusters where the two consonants share the place of articulation (Colantoni & Steele 2005b). The outcomes of the articulatory processes leading to epenthesis may be related to the number and type of acoustic and auditory cues retrievable in the context. Studies suggest that epenthesis is favored when it increases the perceptual salience of the segments involved. In this sense, it has been considered a type of dissimilation (Ohala 1992). Ramírez (2006) found that, in clusters of dental stops + alveolar rhotics, native speakers of Spanish perceive the presence of the epenthetic vowel even when it is very reduced in duration (i.e., 13.5 ms), and that the epenthetic element ensures the distinguishability of the two consonants in the cluster. Thus, with reference to the present data, the short vocalic element found at the /sr/ transition prevents the coarticulation between the segments, and at the same time enhances their perceptual distinctiveness.

The presence of the epenthetic vowel in sequences of a fricative followed by an apical rhotic can be related to the emergence of sound changes involving /sr/ sequences in various languages of the world (see examples in Fleischhacker 2002). One of these is Sanskrit *Sri* 'Mr.' (a polite form of address) > Malay *Seri*, Thai *Siri*. In these cases, a sound change occurred when the listeners took the epenthetic vowel at its face value, and re-produced it in their speech (Ohala 1981).

As for the epenthesis of the stop consonant in the /sr/ sequences, an explanation for its emergence needs to be sought in the articulatory-acoustic domain. Because in this context the rhotic is frequently realized as a short tap followed by a burst and/or frication noise, listeners may come to associate the closure phase of the tap and the following burst with a voiced stop, and interpret the following frication noise as a rhotic, as learners know that a rhotic can often be realized as a short fricative. Because the lingual fricative preceding the rhotic and the rhotic itself are voiced, the stop is perceived as voiced too. A support to this proposal comes from Ladefoged & Maddieson (1996: 245), who explain the acoustic similarity of rhotics and stops based on the fact that both classes of sounds involve closures; this similarity also explains why rhotics and stops alternate both synchronically and diachronically. In our case, the observed pattern of /d/ epenthesis provides an explanation of what may trigger the perception of /d/ in the word *Israele*, and explain the mini sound-change which is attested in written records of the word *Isdraele* and possibly in historical changes from Latin (see § 3 above).

What remains to be explained is why, out of the two possible outcomes of /sr/ sequences, i.e., /sr/ > /sVr/ and /sr/ > /sdr/, one outcome might be favored over the other. There is some evidence (for example, attested in casual texts found on the Internet) that Italians perceive, at least some of the times, the epenthetic /d/ in words like *Israele*. On the contrary, they report being unaware of the epenthetic vowel when questioned about it. This does not necessarily mean that the epenthetic vowel may not be perceived at some pre-lexical level. Exploring the extent to which vowel and/or consonant epenthesis is perceived requires a more accurate study of the production characteristics of the segments in the cluster as well as their perception. This will be the object of future work.

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