

On the Phonetic Reality of Spanish /r/ in Complex Onsets

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1. Introduction

Rhotics are known for the considerable phonetic variety they exhibit across languages, dialects, and speech styles. Although the same is true among Spanish varieties, a common trend among contemporary generative studies of Spanish rhotics is that of glossing over what are deemed to be irrelevant, low-level details of phonetic implementation. Consequently, much of the variation underlying the phonetic reality of these segments is ignored. Such a move is taken, for instance, by Harris (1983:62), who reduces the "astonishing variety of *r*-quality phones ... to just two ... which will be understood to jointly exhaust the rich phonetic variety [...] I will say little more about phonetic detail..." However, by not investigating rhotic variation, we might fail to recognize other systematic aspects in the cross-linguistic patterning of rhotics, which ultimately deserve some explanation. Recent investigations have begun to redress the lack of attention given to phonetic detail (e.g., Bradley 1999, to appear, Colantoni 2001, Hammond 1999, 2000, to appear-a,b, and Willis and Pedrosa 1998). The present work contributes to this line of research by investigating the role of gestural timing in Spanish complex onsets of the form /Cr/.

This paper is organized as follows. In Section 2, we identify some prosodic, segmental, and stylistic influences on the realization of /Cr/ clusters. In Section 3, we develop a model of gestural timing for these clusters, couched within a phonetically-based version of Optimality Theory (OT; Prince and Smolensky 1993, McCarthy and Prince 1995), in which the articulatory drive to coarticulate adjacent consonantal gestures in the output conflicts with the perceptual requirement that input clusters be recoverable. Section 4 shows how the analysis captures the attested influences on /Cr/ realization. In Section 5, we discuss the role of phonetic detail in phonological analysis and suggest some areas for further empirical investigation. Section 6 concludes.

2. Phonetic realizations of Spanish /r/ in complex onsets

In Spanish, two-segment onsets consist of a single obstruent (with some exceptions) followed by one of the liquids /l/ or /r/ (Harris 1983:13-4). It has long been noted that /Cr/ onsets may exhibit an intervening SVARABHAKTI vowel fragment, as shown in (1) (Gili Gaya 1921, Lenz 1892, Navarro Tomás 1918).¹ Although represented here in narrow phonetic transcription simply as [ʔ], this fragment typically has formant structure similar to that of the nuclear vowel appearing on the opposite side of the tap constriction (Quilis 1993:337-42).

- (1)
- | | | |
|---------------|--------------------|---------------|
| <i>pronto</i> | [p ^ə r] | 'soon' |
| <i>fresco</i> | [f ^ə r] | 'cool, fresh' |
| <i>otro</i> | [t ^ə r] | 'other' |
| <i>negro</i> | [ɲ ^ə r] | 'black' |

In an early phonetic study on Peninsular Spanish, Gili Gaya (1921) performed duration measurements on a corpus containing 73 /Cr/ tokens that were systematically varied with respect to prosodic position within the word and segmental makeup of the cluster. Overall results indicate the following:

"The duration of the intervening vocalic element is highly variable even in the same word repeated several times by the same individual. This variability probably stems from rate of speech and from the fact that speakers are unaware of the existence of this vowel fragment, even though in most cases it attains a duration greater than that of the *r*" (pp. 278-9).

When Gili Gaya's measurements for /Cr/ clusters are grouped according to the prosodic and segmental variables shown in Table 1, a trend emerges whereby longer svarabhakti is favored in certain clusters.

Table 1: Prosodic and segmental influences on the duration of svarabhakti in /Cr/ clusters (based on measurements from Gili Gaya 1921:277-8)

Variable	Mean duration of svarabhakti (cs) by cluster type		
Position within the word	Word-initial	5.3	Word-internal 3.7
Stress	Stressed syllable	6.5	Unstressed syllable 5.2
Order of constriction location	Back-to-front	6.3	Front-to-back 5.5

Although not significant, the differences between the means in Table 1 show that vowel fragments tend to be longer in word-initial and stressed /CrV/ demisyllables than in non-initial or unstressed ones, respectively. Longer svarabhakti is also favored in clusters that exhibit a back-to-front order of constriction location (i.e., dorsal+/r/) than in clusters with the opposite order (i.e., labial+/r/). These results are summarized in (2), where [v] and [ə] denote relatively longer and shorter vowel fragments, respectively, while still allowing for durational variability within each category.

- (2)
- | | | | |
|---------------------------------|------------------------|---|-----------------------|
| Position within the word: | #Cv ^v rV | > | C ^ə rV |
| Stress: | Cv ^v rV | > | C ^ə rV |
| Order of constriction location: | { kv ^v rV } | > | { p ^ə rV } |
| | { gv ^v rV } | | { b ^ə rV } |
| | | | { f ^ə rV } |

In a later study of Spanish /r/, Malmberg (1965:10, 35) observed that the duration of svarabhakti often approximates that of an unstressed vowel. In fact, svarabhakti has occasionally given rise to a lexicalized copy vowel whose quality matches that of the underlying nucleus tautosyllabic with the complex onset, as shown by the diachronic examples in (3) (Gili Gaya 1921:280, Quilis 1988:300).² These forms suggest that in theory, any /CrV/ demisyllable may be reanalyzed over time as /CVrV/, not just those demisyllables that favor longer svarabhakti fragments as shown in (2) above. That is, lexicalized copy vowels may emerge non-initially (3d,f), in unstressed syllables (3b,d), and in clusters with a front-to-back order of constriction location (3a).

- | | | | |
|--------|------------------|-------------------|----------------|
| (3) a. | <i>peréces</i> | < <i>préces</i> | 'prayers' |
| b. | <i>tarabilla</i> | < <i>trabilla</i> | 'stirrup' |
| c. | <i>corónica</i> | < <i>crónica</i> | 'chronicle' |
| d. | <i>chácara</i> | < <i>chácra</i> | 'farm' |
| e. | <i>gurúpa</i> | < <i>grúpa</i> | 'hindquarters' |
| f. | <i>tiguere</i> | < <i>tigre</i> | 'tiger' |

The data presented thus far suggest that /Cr/ clusters are realized along an intersegmental duration continuum as a function of the relative phonetic separation between the consonants of the cluster. At the other end of this continuum are cases of coarticulation, exemplified in (4), as documented extensively by Alonso (1925) for Peninsular varieties.

- | | | | |
|-----|-----------------|------|------------------|
| (4) | <i>apretar</i> | [p̠] | 'to squeeze' |
| | <i>hombre</i> | [bɾ] | 'man' |
| | <i>otro</i> | [t̠] | 'other' |
| | <i>vendrá</i> | [dɾ] | 's/he will come' |
| | <i>padre</i> | [ðɾ] | 'father' |
| | <i>escribir</i> | [k̠] | 'to write' |
| | <i>magras</i> | [ɣɾ] | 'lean (FEM PL)' |

Coarticulation entails some frication of the rhotic and the loss of both the intervening svarabhakti fragment and the extra-short constriction period of apicoalveolar [r]. As shown in (4), rhotics are progressively devoiced when coarticulated with a preceding voiceless consonant (e.g., [p̠] versus [p^ər]), and dental /t̠/ and /d̠/ assimilate regressively to the rhotic, yielding an alveolar quasi-affricate realization (e.g., [t̠] versus [t̠^ər]). The articulatory descriptions provided by Alonso (1925) and Malmberg (1965) are particularly revealing on all of these points:

"The *r* combines with the consonants with which it groups, without any epenthetic vocalic element" (Alonso 1925:185).

"The *r* tends to be formed during the articulation of the preceding voiceless stop, invading its release, letting itself in turn be invaded by the voicelessness of the release ... I have heard in speakers from diverse regions of the

Peninsula the same fusion in moments of physical fatigue, when speaking casually or in a low voice" (Alonso 1925:186,189).

"This tendency of the consonant *r* to combine with a dental to form a new consonant, which is generally a compromise between the two, is not unknown in other languages" (Malmberg 1965:39).

"Careful speech allows the identity of the sounds to be recovered ... Careful speech is sufficient to ensure greater intelligibility by isolating the elements of the consonant group" (Alonso 1925:186-7).

Furthermore, realizations of /Cr/ clusters are dependent upon speech style, as per Alonso's observations that casual speech favors coarticulation while careful speech enhances recoverability.

Lipski (1994) points out that in Highland Peru, "pronunciation of the groups /tr/, /pr/, /kr/ is partly determined by ethnolinguistic background. Among bilingual speakers, the /r/ in these combinations is a fricative or retroflex approximant, and in the case of /tr/ may fuse with the preceding consonant to produce a quasi-affricate" (p. 320). Lipski's description of the Peruvian pattern mirrors that of Alonso (1925) for Peninsular Spanish in that coarticulation may affect /Cr/ clusters regardless of the place specification of C₁. However, other Latin American varieties appear to limit coarticulation specifically to homorganic clusters in which C₁ is a coronal stop. Representative data in (5) are from Argüello's (1978) study of Highland Ecuadorian Spanish.³

(5) a.	<i>tres</i>	[t̪r̪]	'three'
	<i>cuatro</i>	[t̪r̪]	'four'
b.	<i>vendrá</i>	[n ^d r̪]	's/he will come'
	<i>saldrá</i>	[l ^d r̪]	's/he will leave'
c.	<i>padre</i>	[að ^ɔ r̪]	'father'
d.	<i>premio</i>	[p ^ɔ r̪]	'prize'
	<i>cruz</i>	[k ^ɔ r̪]	'cross'

In casual speech, coarticulation affects clusters such as those in (5a,b), where the preceding coronal is realized as non-continuant. In (5c), however, the voiced coronal surfaces as a continuant after a preceding vowel, and the underlying cluster surfaces intact. Coarticulation also fails to affect heterorganic clusters, as in (5d). Furthermore, Lipski (1994) documents a similar pattern for other geographic zones, namely Northern interior Argentina (p. 172), Highland Bolivia (p. 189), Chile (p. 200), Colombia (pp. 209-10), Central Costa Rica (p. 222), Guatemala (p. 265), Honduras (p. 272), Mexico (p. 279), and Paraguay (p. 308). Available phonetic descriptions suggest that coarticulation between /r/ and a preceding homorganic stop is widespread across these varieties, but similar behavior involving heterorganic C₁ is presumably unattested.

The empirical generalization emerging here suggests an implicational relationship between two types of /Cr/ coarticulation in casual speech across Spanish dialects. In Peninsular and Peruvian varieties, coarticulation affects poten-

tially any /Cr/ cluster in casual speech, while in other Latin American varieties, it is restricted to clusters in which C_1 is a coronal non-continuant. For a given dialect, coarticulation of heterorganic clusters entails coarticulation of homorganic ones (with non-continuant C_1), but the opposite does not hold, as evidenced in by the data (5).

3. Gestural timing in phonetically-based Optimality Theory

In this section, we explore the role of gestural timing in /Cr/ clusters and propose a constraint-based analysis of the realizations documented in Section 2. In Browman and Goldstein's (1989, 1990, 1991, 1992) *Articulatory Phonology*, gestures are dynamically defined articulatory movements that produce a constriction in the vocal tract. Three aspects of the gestural model are relevant for an analysis of Spanish /Cr/ realizations. First, articulatory gestures have internal duration, a property represented abstractly in terms of a 360° cycle. Phonetic timing is thus intrinsic to the phonological representation, and gestures are phonological primitives as well as units of articulation. This property sets *Articulatory Phonology* apart from most theories of phonology which relegate phonetic timing to an implementation component derivationally ordered after the phonology proper. Second, adjacent gestures are temporally coordinated with respect to each other and may exhibit varying degrees of overlap. Finally, within a syllable, consonantal articulations are superimposed on the vowel gesture (see Gafos 1999).

Following Cho (1998b:35), we assume that throughout the course of first language acquisition, learners construct a permissible range of overlap between adjacent gestures and that this range is encoded in lexical entries in terms of a Phase Window (Byrd 1994, 1996). Figure 1 illustrates three hypothesized patterns of gestural overlap between adjacent /C/ and /r/, where the dotted lines delineate the lexically specified Phase Window.

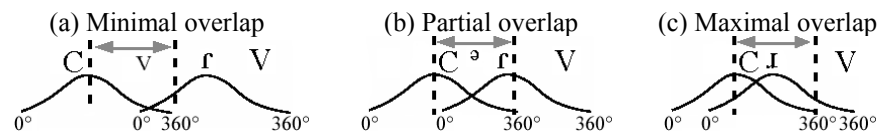


Figure 1: Three patterns of gestural overlap for /Cr/ clusters

While minimal overlap in (a) permits a greater recovery of the overlapping vowel gesture (not shown in the diagrams), partial overlap in (b) yields a shorter vowel fragment. On the other hand, maximal overlap in (c) shifts the 0° onset of the /r/-gesture outside the Phase Window, which precludes the svarabhakti fragment and results in coarticulation of the /Cr/ sequence.

The timing-based account in Figure 1 provides a phonetic explanation for both the existence of svarabhakti vowels and the nature of coarticulation in casual speech. The fact that consonantal gestures are superimposed on the vowel gesture within the syllable explains why svarabhakti is always a continuation of the formant structure present on the opposite side of the tap constriction. Both the nuclear vowel and the svarabhakti fragment stem from the same vocalic ges-

ture, and the superimposed tapping gesture produces a brief interruption separating the two.⁴ As two anonymous reviewers point out, a question arises as to why a vowel preceding the /Cr/ cluster has no effect on the acoustic quality of svarabhakti. An explanation for this stems from the fact that the consonantal gestures comprising the complex onset are coordinated relative to the nuclear vowel of the syllable with which the gestures are associated. Given a word such as *tigre* [t̥i.ɣ̥re] 'tiger', it follows that the svarabhakti fragment will be colored by the following tautosyllabic vowel [e], since the surrounding consonantal gestures are superimposed on the gesture for this vowel. Further evidence for such coloring is found in the diachronic example *tiguere* [t̥i.ɣ̥e.re] in (3f), in which the svarabhakti fragment has been reanalyzed as a full vowel whose quality matches that of the following [e]. We return to this issue in the discussion surrounding Figure 5 below.

The assimilatory behavior observed in coarticulated clusters receives a straightforward explanation as the effects of gestural overlap. According to Browman and Goldstein (1990:360), gestures in casual speech are expected "to show decreased magnitudes (in both space and time) and to show increasing temporal overlap." Many types of casual speech alternations, such as deletions, assimilations, and weakenings, can be seen as the consequences of gestural reduction and overlap. On this view, the assimilations observed under coarticulation plausibly result from maximal overlap, as illustrated in Figure 2.⁵

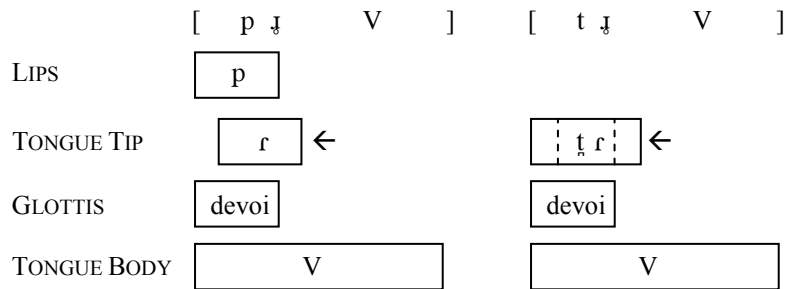


Figure 2: Maximal overlap in [p̥] and [t̥] clusters

Consider first the progressive devoicing of the rhotic. Coordination of the glottal devoicing gesture with the bilabial and dental closure gestures is responsible for the voicelessness of [p̥] and [t̥], respectively. Rhotic devoicing stems from greater overlap between the tongue tip gesture for /r/ and the glottal devoicing gesture of the preceding consonant. The fact that overlap-induced devoicing is limited to casual speech lends support to the gestural explanation, given that casual speech is characterized by greater overlap. With respect to clusters in which the initial consonant is an underlying dental stop, coarticulation with the following rhotic results in an alveolar quasi-affricate [t̥r̥]. In the gestural model, overlap between adjacent gestures engaging the same articulator will produce BLENDING of the characteristics of the two gestures, which "shows itself in spatial changes in one or both of the overlapping gestures" (Browman and Goldstein 1990:362). The retraction of dental stops when overlapped with a follow-

ing apicoalveolar /r/ plausibly reflects a compromise between the lexically specified constriction locations of the adjacent tongue tip gestures.

We propose to capture the patterns of /Cr/ realization discussed in Section 2 in terms of interacting constraints on gestural timing. Cho's (1998a,b) constraint-based analysis of Korean palatalization offers a means of evaluating gestural overlap in the Correspondence-theoretic version of OT (McCarthy and Prince 1995). In the present account, we assume that intergestural timing relevant to /Cr/ clusters is governed by the constraints in (6):⁶

- (6) a. IDENT(timing)
The relative timing of gestures in the output must fall within the lexically specified Phase Window, which determines a permissible range of gestural overlap.
- b. OVERLAP
Adjacent consonantal gestures must be maximally overlapped.

As shown in Tableau 1 below, the faithfulness constraint IDENT(timing) in (6a) bans any output timing relationship in which the 0° onset of the /r/-gesture falls outside the lexically specified Phase Window. Given that phonetic timing is a continuous dimension, the optimal candidates in Tableau 1 should be interpreted as abstractions denoting a range of intermediate degrees of gestural overlap. Therefore, IDENT(timing) will permit a certain amount of variability as long as the timing relation falls within the lexically specified Phase Window. (On the influence of prosodic and segmental context, see Section 4 below.)

Tableau 1: Faithfulness to Phase Window ensures perceptual recoverability

	IDENT(timing)
<p>Minimal overlap</p>	
<p>Partial overlap</p>	
<p>Maximal overlap</p>	*!

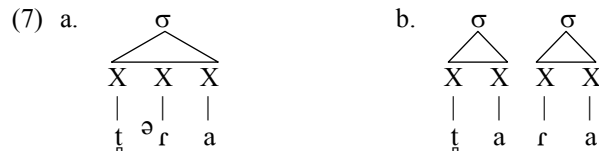
In conflict with faithfulness is OVERLAP in (6b), an articulatory markedness constraint that prefers maximal coarticulation between adjacent consonantal gestures. In the case of /Cr/ clusters, OVERLAP is responsible for the assimilatory effects associated with maximal overlap, as shown in Tableau 2. While IDENT(timing) ensures perceptual recoverability, OVERLAP yields an articulatory

advantage in terms of PARALLEL TRANSMISSION, which allows information about several linguistic units to be transmitted simultaneously (Lieberman et al. 1967).⁷

Tableau 2: Coarticulation favors parallel transmission

	OVERLAP
<p>Minimal overlap</p>	*!
<p>Partial overlap</p>	*!
<p>Maximal overlap</p>	

It is important to define the notion of adjacency implied by the markedness constraint OVERLAP in (6b). Consider the syllabic representations of the hypothetical sequences shown in (7).



In (7a), the consonants comprising the tautosyllabic $[t^ə r]$ cluster are adjacent on the timing tier, whereas $[t]$ and $[r]$ are non-adjacent in (7b) due to the presence of an intervening, lexically sponsored vowel. OVERLAP, therefore, can target structures such as (7a) but not (7b). The syllabic status of svarabhakti differs from that of a full vowel in that the former does not function as a syllable nucleus but is merely the acoustic result of minimal or partial gestural overlap between the adjacent C_1 and $/r/$. We further motivate the non-syllabic status of svarabhakti in the discussion surrounding (10) in Section 4.

In sum, the constraints proposed above give formal expression to two competing influences on intergestural timing, which Chitoran et al. (2002) characterize as a need (1) to ensure recoverability of linguistic units from the signal and (2) to encode and transmit information at a high rate. Because OT is built upon the notion of competition and conflict resolution, it is an appropriate framework for analyzing the intergestural timing patterns of Spanish $/Cr/$ clusters, to which we now turn.

4. Analysis of Spanish /Cr/ realizations

In the Phase Window model, minimal and partial overlap scenarios actually comprise a continuous range of intermediate degrees at which the gestures for /C/ and /r/ may be timed with respect to one another. Variability in the duration of svarabhakti, as observed by Gili Gaya (1921) and Malmberg (1965), stems from the variable timing of gestures during speech production. Recall from Section 2, however, that the duration of svarabhakti is influenced by the cluster's prosodic position (word-initial vs. word-internal, stressed vs. unstressed syllable) and segmental composition (back-to-front vs. front-to-back order).

These observations are corroborated by an independent study of gestural timing in Georgian stop-stop sequences. Chitoran et al. (2002) show that perceptual recoverability conditions place limits on the degree of gestural overlap between adjacent stops in clusters that appear word-initially (vs. word-internally) and that exhibit a back-to-front (vs. front-to-back) order of constriction location. Their explanation for these patterns is as follows. First, word onsets are potential utterance onsets, in which case no preceding vowel is available to provide formant transitions into the first consonant (see Redford and Diehl 1999). Furthermore, word onsets have been shown to be important for lexical access (Marslen-Wilson 1987). Therefore, it is plausible that minimal overlap is favored word-initially so as to preserve more acoustic information about each consonant of the cluster. Second, gestural overlap in clusters exhibiting a back-to-front order entails that the acoustic release of the first consonant will be perceptually obscured because the second constriction lies ahead of the first constriction in the vocal tract. In contrast, overlap in clusters with a front-to-back order does not obscure the acoustic release of the first consonant because the second constriction lies behind the first. We assume that this difference is also relevant with respect to /Cr/ clusters:

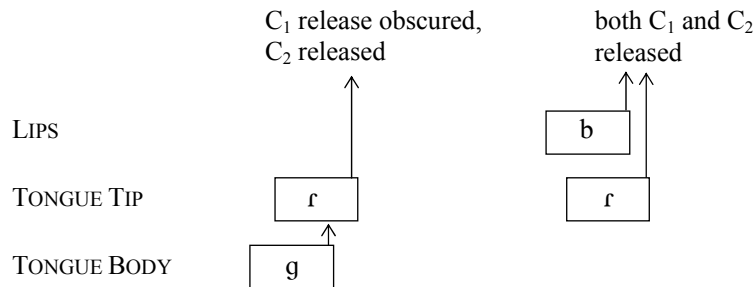


Figure 3: Gestural overlap obscures the acoustic release of C₁ in the back-to-front cluster /gr/ but not in the front-to-back cluster /br/

Figure 3 illustrates the hypothesis that overlap is more likely to perceptually compromise the acoustic release of the initial consonant in dorsal+/r/ sequences than in labial+/r/. Since the constriction of /g/ lies behind that of /r/ in the vocal tract, the overlapped release of /g/ is more vulnerable than that of /b/, whose

constriction lies ahead of /r/. Minimal overlap is plausibly favored more so in dorsal+/r/ sequences in order to ensure recoverability of the underlying cluster.

Although Chitoran et al. (2002) do not examine the possible effects of stress, it seems plausible to expect less overlap in clusters belonging to stressed syllables, again for perceptual reasons. With respect to overlap in /Cr/ clusters, we hypothesize that the prominence of stressed syllables favors the preservation of acoustic information about each consonant and that minimal overlap is the type of gestural coordination that achieves this.⁸ We propose to integrate the role of perceptual recoverability into the Phase Window model of intergestural timing presented in Section 3. Recall that the very function of Phase Windows is to define a permissible range of overlap for adjacent gestures. Since what counts as a permissible range is constrained by the requirements of perceptual recoverability, it is plausible that Phase Windows are constructed for individual /Cr/ clusters according to the degree of perceptibility of the phonetic contexts in which they appear. Specifically, those clusters appearing word-initially or in stressed syllables, as well as those with a back-to-front order of constriction location, have a delayed Phase Window, whereas like clusters in other contexts have an earlier Phase Window:

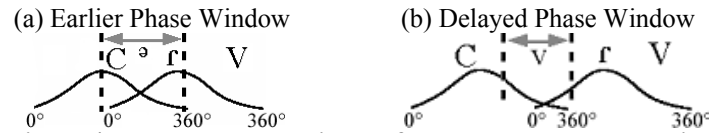


Figure 4: Delayed Phase Window favors longer svarabhakti

In Tableau 3, the ranking IDENT(timing) » OVERLAP permits a range of gestural overlap in accordance with the lexically specified Phase Window for the /Cr/ cluster in question. Since partial overlap is disfavored by the delayed Phase Windows of clusters appearing word-initially or in stressed syllables, high-ranking IDENT(timing) rules out candidates (e) and (k), respectively. The coarticulated candidates (c), (f), (i), and (l) are also ruled out by faithfulness because maximal overlap places the /r/-gesture outside any Phase Window, whether early and delayed. As a result, variability between shorter and longer svarabhakti is optimal in non-initial position (a,b) and in unstressed syllables (g,h), while longer ones are favored word-initially (d) and under stress (j). For reasons of space, we omit clusters differing in the order of constriction location since their evaluation is identical to those shown in Tableau 3.

Tableau 3: Longer svarabhakti in word-initial and stressed /CrV/ demisyllables than in word-internal and unstressed ones

		IDENT(timing)	OVERLAP
☞	a. /CrV/ → Cv _r V		*
☞	b. C ^ə _r V		*
	c. C _r V	*!	
☞	d. /#CrV/ → #Cv _r V		*
	e. #C ^ə _r V	*!	*
	f. #C _r V	*!	
☞	g. /Cr [̃] V/ → Cv _r [̃] V		*
☞	h. C ^ə _r [̃] V		*
	i. C _r [̃] V	*!	
☞	j. /Cr [̂] V/ → Cv _r [̂] V		*
	k. C ^ə _r [̂] V	*!	*
	l. C _r [̂] V	*!	

Recall Alonso's (1925:186-9) observation, discussed in Section 2, that coarticulation of Spanish /Cr/ is characteristic of casual speech, while in careful speech the perceptual integrity of the cluster is preserved. Furthermore, two major patterns of coarticulation were identified among varieties of Spanish: coarticulation of any /Cr/ cluster versus coarticulation of /r/ with only a preceding homorganic stop. We propose to capture this segmental effect in terms of an additional articulatory markedness constraint targeting the latter type of cluster:

- (8) *FAST/SAME (adapted from Bradley 2001; cf. also Steriade 1995)
 Avoid faster-than-usual transitions between adjacent periods of greater stricture involving the same articulator.

The claim that articulatory transitions are more marked between homorganic consonants than heterorganic ones is supported by consonantal transition phenomena in Sierra Popoluca, a Zoquean language spoken in Mexico (Elson 1947, 1956; Foster and Foster 1948). Consonant clusters in this language are realized with an intervening open transition if the consonants are heterorganic, while homorganic clusters lack such a transition, as shown in (9).

- (9) a. kek^h.paʔ 'it flies'
 mij^ə.paʔ 'he comes'
 b. kek.gak^h.paʔ 'it flies again'
 ʔaŋ.kiʔ 'yard'

In (9a), the open transition is realized as aspiration after the voiceless velar stop and as a short schwa-like vowel after the palatal nasal. The homorganic stop

sequences [k.g] and [ŋ.k] in (9b) lack an open transition. While OVERLAP is a general constraint favoring maximal overlap of adjacent consonantal gestures, *FAST/SAME is more specific, targeting only those homorganic clusters in which an open transition intervenes between two periods of maximal oral constriction. The additional articulatory markedness of the latter type of cluster is responsible, we claim, for both the absence of open transitions in Sierra Popoluca, seen in (9b), and the coarticulation of homorganic /Cr/ in Highland Ecuadorian Spanish and other Latin American varieties, as in (5a,b).

The stylistic variation effects on coarticulation follow straightforwardly in the constraint-based account proposed here. As seen previously in Tableau 3, when faithfulness to input Phase Windows is highly ranked in careful speech, perceptually optimal timing is enforced. In casual speech, however, IDENT(timing) is subordinate to articulatory markedness. As shown in Tableau 4 below, high-ranking OVERLAP yields coarticulation of any /Cr/ cluster. Maximal overlap of /r/ is optimal after heterorganic consonants in (c) and homorganic continuants in (f), as well as homorganic stops in (i,l).⁹

Tableau 4: Coarticulation of /r/ with any consonant

	OVERLAP	IDENT(timing)	*FAST/SAME
a. /prV/ → pvrV	*!		
b. p ^ə rV	*!		
☞ c. p ₁ V		*	
d. /Vd _r V/ → Vd _v rV	*!		
e. Vd ^ə rV	*!		
☞ f. Vd _r V		*	
g. /t _r V/ → t _v rV	*!		*
h. t ^ə rV	*!		*
☞ i. t ₁ V		*	
j. /nd _r V/ → nd _v rV	*!		*
k. nd ^ə rV	*!		*
☞ l. nd ₁ V		*	

When only *FAST/SAME dominates IDENT(timing), on the other hand, coarticulation is restricted to only those clusters in which C₁ is a homorganic stop. As shown in Tableau 5, candidates (i,l) exhibit coarticulation, while variable svarabhakti obtains after heterorganic C₁ in (a,b) and homorganic non-continuant in (d,e).

Tableau 5: Coarticulation of /r/ with only homorganic stops

		*FAST/SAME	IDENT(timing)	OVERLAP
☞ a.	/prV/ → pvrV			*
☞ b.	p ^ə rV			*
c.	p _ɹ V		*!	
☞ d.	/VdrV/ → VðvrV			*
☞ e.	Vð ^ə rV			*
f.	Vð _ɹ V		*!	
g.	/trV/ → tvrV	*!		*
h.	t ^ə rV	*!		*
☞ i.	t _ɹ V		*	
j.	/ndrV/ → n _ɹ dvrV	*!		*
k.	n _ɹ d ^ə rV	*!		*
☞ l.	n ^d _ɹ V		*	

The constraint-based account effectively captures the implicational relationship observed in the coarticulation of different types of /Cr/ clusters. Candidates incurring a violation of *FAST/SAME are always a subset of the candidates violating the more general OVERLAP constraint. Given this subset relation, no ranking of the constraints can produce coarticulation of heterorganic /Cr/ without also producing coarticulation of /r/ with homorganic stops. In an earlier, non-constraint-based analysis of Highland Ecuadorian Spanish, Bradley (1999) argues that /r/ is overlapped by adjacent consonantal gestures, with overlap resulting in gestural blending next to coronals. Such a general statement of gestural overlap turns out to be descriptively inadequate, since it also predicts coarticulation of /r/ after both homorganic continuants and heterorganic consonants—contrary to the facts in (5c) and (5d), respectively. The analysis developed here is superior, however, because gestural overlap is governed by specific articulatory markedness constraints that are subject to ranking permutation. *FAST/SAME targets [t_ɹ] and [n^d_ɹ] sequences independently of other types of cluster, while OVERLAP affects all /Cr/ clusters equally. As a result, the interleaving of IDENT(timing) between *FAST/SAME and OVERLAP in Tableau 5 successfully predicts coarticulation of the former type of cluster versus svarabhakti elsewhere.

Although minimal overlap between the adjacent gestures of a /Cr/ cluster creates the appearance of two vowels, there is evidence to suggest that the longer vowel fragment does not create a new syllable. In an extensive cross-linguistic survey of svarabhakti phenomena, N. Hall (in progress) observes that svarabhakti vowels are METRICALLY COHESIVE with the adjacent full vowel whose quality they copy. That is, languages tend to count svarabhakti and the original vowel as one for stress purposes. An example from Spanish suffices to illustrate this point:

- (10) *hidrómetro* [i.ðró.me.ɾo] *[i.ðró.me.ɾo.ro] 'hydrometer'

In Spanish, main stress is confined without exception to a three-syllable window at the right edge of the morphological word (Harris 1995:869). If the svarabhakti fragment surfacing in the final /t̪r/ cluster in (10) were to create a new syllable, then stress would fall outside the three-syllable window yielding ungrammatical results. This evidence suggests that svarabhakti is not the result of a synchronic process of vowel epenthesis inducing a reorganization of the timing tier. On this view, the copy vowels in (3) are more appropriately analyzed as occasional historical developments whereby longer svarabhakti fragments are phonologically reinterpreted over time as full lexical vowels, as illustrated in Figure 5.

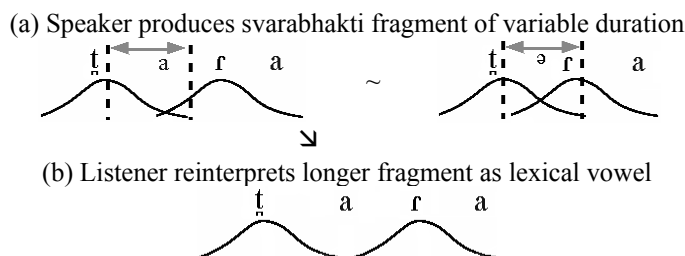


Figure 5: Lexical copy vowels as phonologized svarabhakti

Once phonological restructuring has taken place as in stage (b), the Phase Window of permissible gestural overlap for /t̪/ and /r/ is dissolved because the epenthetic vowel has broken up the onset cluster and the associated consonantal gestures are no longer adjacent.¹⁰

Crucial to the above explanation is the notion of *GESTURAL MISPARSING*, whereby language learners erroneously interpret certain aspects of the acoustic signal to be the result of intentional articulatory gestures on the part of the speaker. Browman and Goldstein (1991:331-3) observe that changes which arise from misparsing "do not involve adding articulations that were not there to begin with; rather they involve changes in the parameters of gestures that are already present." In Figure 5, the svarabhakti fragments in (a) and the lexicalized copy vowel in (b) all stem from the same overlapping vowel gesture, and the misparsing that occurs in (b) involves a change in the relative timing of adjacent consonantal gestures.

5. The role of phonetic detail

In the analysis developed here, input morphemes already have their gestural timing relations fully and reliably specified in terms of Phase Windows so that faithfulness can depend on them. This assumption is consistent with Browman and Goldstein's model of Articulatory Phonology, in which gestures are both units of articulation and primitives of phonological organization, and timing relationships are specified directly in the gestural score. On this view, a predictable non-contrastive property of phonetic detail—intergestural timing—is incorporated directly into the phonological representation. As John McCarthy (personal communication) points out, however, assuming fully-specified inputs runs

counter to the Richness of The Base hypothesis of OT which forbids placing restrictions directly on input representations (Prince and Smolensky 1993). Moreover, the direct appeal to phonetic detail goes against conventional models of phonology in which underlying representation is assumed to be devoid of non-contrastive properties.

In a possible alternative to the account developed here, faithfulness to Phase Windows in the input might be supplanted by phonetic constraints that determine gestural timing relations directly in the output. For example, the alignment constraints of Zsiga (2000) specify gestural coordination in a separate phonetic implementation component, derivationally ordered after the phonology proper. On this view, phonological representations remain abstract, categorical, and timeless, while implementation constraints supply quantitative, non-contrastive temporal specifications to yield a fully-specified phonetic representation. In order to decide between the two competing approaches, future investigation must ultimately evaluate both on the basis of a wider range of empirical test cases. Preliminary evidence supporting the existence of Phase Windows is found in recent analyses of derived environment effects in Korean palatalization (Cho 1998a,b) and in the Norwegian "retroflex rule" (Bradley 2002). Both of these accounts show that faithfulness to the timing specifications of underived input morphemes explains why overlap-induced morphophonological alternations systematically appear only in derived (heteromorphemic) environments: Phase Windows are specified for gestures within a single morpheme but not across two separate ones. IDENT(timing) is active in the former case, while OVERLAP is free to induce the relevant alternation in the latter.¹¹

Finally, Jill Beckman (personal communication) suggests a potential problem of the Phase Window approach with respect to cases of stress shift. In Section 4, stressed /CrV/ demisyllables were claimed to have a delayed Phase Window, as shown in Figure 4b, which accounts for the greater duration of svarabhakti under stress. Now, consider the alternation between *ómicron* and its plural *omicrónes*, where the demisyllable /kro/ is stressed only in the latter form. If learners construct the Phase Window for /kr/ on the basis of the singular, then IDENT(timing) would fail to account for the durational effects of stress on svarabhakti in the plural. However, there are only six stress-shifting plural forms in Spanish, all of which involve erudite words. We follow Harris (1983) in assuming that "speakers probably memorize these forms in isolation from the generalizations internalized on the basis of the rest of the language" (p. 132). Lexical storage of plural *omicrónes* as a separate form entails that a delayed Phase Window will be associated with stressed /kro/, and the problem of IDENT(timing) with respect to stress shift disappears.

The analysis presented in Section 4 captures the influences on /Cr/ realization observed by Gili Gaya (1921) in terms of different Phase Window specifications according to the prosodic position and segmental make-up of the cluster. However, Gili Gaya's early study needs to be replicated on an expanded set of empirical data with appropriate statistical procedures in order to determine the exact nature of the purported prosodic and segmental effects across dialects. Given the extreme variability of the duration of svarabhakti vowel fragments, a much larger corpus of /Cr/ tokens is likely to be necessary for any statistically

significant effects to emerge. In addition, further research is required to verify the patterns of /Cr/ coarticulation across different Spanish varieties, as discussed in Section 2. An empirical study of these issues is now being carried out by the present authors.

6. Conclusion

In this paper, we have explored the phonetic reality of Spanish /Cr/ by incorporating phonetically detailed information such as intergestural timing into a formal, constraint-based analysis. The main advantage of such a direct approach is that it exposes the phonetic motivation underlying the possible realizations of such clusters. Furthermore, the proposed account captures the effects of prosodic and segmental context in terms of perceptual recoverability requirements and explains stylistic and dialectal variation through the re-ranking of a small set of universal and violable constraints. Finally, we have also shown that svarabhakti vowels are invisible to prosodic and metrical structure in the synchronic grammar, although they may be phonologically reanalyzed as full vowels over time.

Notes

* For helpful comments and feedback, we wish to thank the members of the audience of the Sixth Hispanic Linguistics Symposium held at the University of Iowa, October 18-20, 2002, in particular Jill Beckman, Joan Mascaró, and Carlos Eduardo Piñeros. Also, thanks to Adamantios Gafos and John McCarthy for discussion of relevant issues over e-mail and to two anonymous reviewers for their suggestions. We assume responsibility for any shortcomings that remain.

1. Our primary focus on the behavior of rhotics precludes an exhaustive investigation of /Cl/ clusters in this paper. It should be noted that in the studies we cite that deal with Spanish, svarabhakti in onset clusters is only ever discussed with respect to /r/, which justifies the restriction here. This is not to say, however, that svarabhakti vowel fragments cannot occur with sonorants other than /r/ in other languages. See N. Hall (in progress) for an extensive cross-linguistic survey.

2. For expository convenience, we indicate stressed syllables with a written accent, even where Spanish orthographic conventions do not require it.

3. In accordance with the convention of Hispanic linguistics, Argüello employs [r̄] and [r̥̄] to represent voiced and voiceless variants, respectively, of the *r asibilada* (assibilated/fricative *r*). For consistency, we continue to use Alonso's transcription of the coarticulated rhotic as [ɾ] and [ɾ̥] in (5a,b), and we also indicate the lack of coarticulation by transcribing the svarabhakti fragment [ə] in (5c,d).

4. A similar gestural explanation is proposed by Steriade (1990) and more recently Bradley (1999, 2001, 2002, to appear) and N. Hall (in progress). Such an account concurs with the definition of Spanish /r/ proposed by Gili Gaya (1921:279): "[E]s un sonido vocálico interrumpido por una oclusión alveolar, sonora, más or menos intensa [It is a vocalic sound interrupted by an alveolar contact that is voiced and more or less tense]."

5. In the gestural representation, the activity of each relevant articulator is depicted on a separate tier, whose labels appear on the left. Boxes represent gestures, and the length

of a box denotes the period of time during which the articulator is under active control. The arrow indicates that the tongue tip gesture for /r/ has shifted leftward such that it coincides temporally with preceding gestures. Dotted lines denote same-tier overlap.

6. Adamantios Gafos (personal communication) suggests that the "timing" predicate in (6a) and the notion of overlap in (6b) should be formally related in terms of representational primitives (cf. the gestural coordination constraints of Gafos 2002, which refer to specific temporal landmarks within gestures such as ONSET, TARGET, C-CENTER, etc.). In contrast, the constraints in (6) assume a lexically-specified Phase Window in the sense of Byrd (1994, 1996), which defines a permissible, gradient target range within which the relative timing of adjacent gestures must fall (see the discussion surrounding Figure 1).

7. As an anonymous reviewer points out, OVERLAP may also be motivated in terms of articulatory effort reduction, similar to Kirchner's (1998 et seq.) LAZY constraint. Similarly, the same motivation holds with respect to the constraint *FAST/SAME, which is discussed later in Section 4.

8. The claim that stressed syllables are perceptually prominent positions vis-à-vis unstressed ones finds support, for example, in American English tapping: intervocalic /t/ and /d/ undergo temporal reduction to [ɾ] only when in onset position of unstressed syllables, whereas the process fails to affect stressed syllables (see Inouye 1995). An anonymous reviewer also highlights the importance of stressed syllables for lexical access. Finally, see the OT work of Beckman (1998), who proposes that Correspondence-theoretic faithfulness constraints may be relativized to prominent positions, including stressed syllables.

9. We assume that the continuancy alternation between [ð] in candidates (d-f) and [d] in (j-l) of Tableaux 4 and 5 is due to other constraints not shown here.

10. This account predicts that diachronic reanalysis of svarabhakti cannot yield forms such as the ungrammatical one in (10), which, to the best of our knowledge, is correct.

11. However, neither of these studies provides an explicit comparison with the alternative approach in which gestural coordination constraints supplant IDENT(timing).

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