# Chapter 5

# Articulatory Modeling of Spanish Liquids

In this chapter, phonological representations of the Spanish liquids will be outlined, and a gestural account of the major phonological properties of the class will be proposed.

Experimental evidence presented in Chapter 4 indicates that the Spanish liquid consonants share the phonetic characterization that they are all produced with both coronal and dorsal gestures. In Chapter 3 it was shown that the Spanish liquids are phonologically characterized by their common distribution within the syllable and their interchangeability within the class. I propose that these essential phonetic and phonological properties are best reconciled under a gestural model in which a coronal liquid segment corresponds to a stable, coordinated pattern of tongue tip and tongue body gestures.

The structure of this chapter is as follows. Representations of Spanish coronal consonants under an articulatory phonology framework (Browman & Goldstein 1985a, 1992) will first be proposed. The gestural organization of Spanish coronal consonants within the syllable will be discussed. Data from TADA simulations demonstrating the validity of the gestural model of liquid articulation will be presented, and the limitations of the model will be addressed. Finally, articulatory analyses of some phonological phenomena involving liquids in Spanish will be proposed.

## 5.1 Gestural Characterization of Spanish Coronal Consonants

The conclusion drawn from the experiments in Chapter 4 is that the liquid consonants are characterized by the presence of a dorsal articulatory component, unlike coronal stops, which are produced with a tongue-tip gesture alone. This contrast can be represented at the planning level by the presence or absence of a tongue body gesture coupled to the tongue-tip gesture (Figure 5.1).

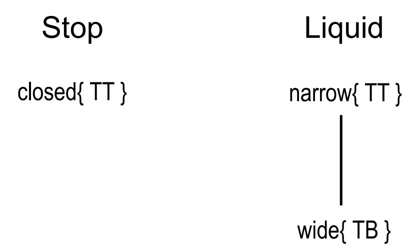



FIGURE 5.1: Contrasting coupling graphs: **Spanish coronal stops and liquids**.

Consonants do not occur in isolation, but are intrinsically bound to a companion vowel in a syllabic unit (Liberman et al. 1967). In syllable onsets, this relationship can be modeled as the synchronous coupling of a coronal gesture with the vocalic gesture of the syllabic nucleus. In a liquid onset, there are three gestures which need to be coordinated: the liquid tongue tip gesture, the liquid tongue body gesture, and the vocalic tongue body gesture. If Spanish onset liquids are organized in the same manner as multi-gestural segments in English (Krakow 1999, Goldstein et al. 2006), we can propose a three-way coupling relationship between each of these gestures, consistent with the hypothesis that all gestures in the onset are coupled in-phase with the nucleus (Browman & Goldstein 1985a, 1992; Gafos 2002).[1] The two onset structures are contrasted in the phonological representations of the Spanish words *da* 'he gives' and *la* 'her' (Fig. 5.2).

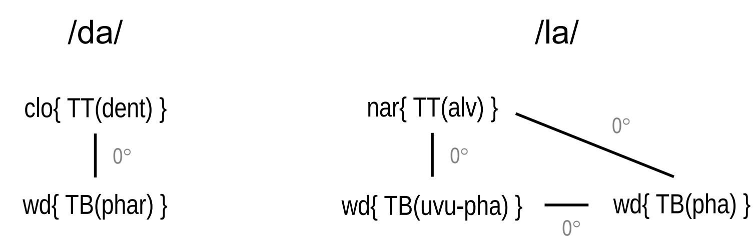



FIGURE 5.2: **Gestural organization in Spanish stop and liquid onsets**.

[1] It remains to be seen whether segment-internal gestures in Spanish onsets are best modeled in a synchronous coupling relationship – like English initial laterals (Browman & Goldstein 1995) – or an asynchronous relationship, as has been proposed for complex onsets in languages which display a 'C-Center' effect (Browman & Goldstein 2000).

The articulation of the gestural constellation /da/ is straightforward: both tongue-tip and tongue-body tract variables have single goals, and the articulators which are recruited to achieve these goals commence their activity at the same time because the gestures are coupled synchronously (Fig. 5.3 left).

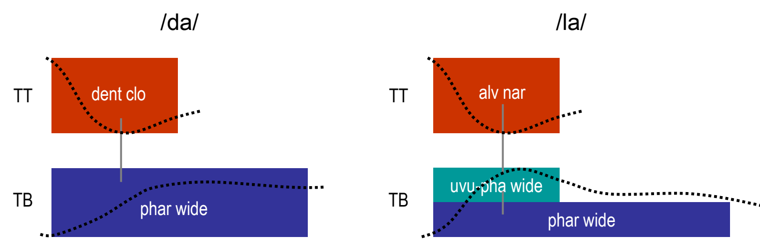



FIGURE 5.3: **Gestural timing and lingual trajectories in Spanish stop and liquid onsets**.

The liquid onset differs from the stop in that the tongue body is recruited for both consonantal and vocalic gestures. Because both consonantal and vocalic dorsal gestures begin at the same time, the trajectory which the dorsum will follow will be the result of 'blending' between the two gestures. If the consonantal gesture dominates, and is shorter in duration than the vocalic gesture, the result of this interaction will be that the dorsum will follow a trajectory which best satisfies first the tongue body target of the liquid (in that vocalic context – the result of the gestural blending), followed by the vocalic target. In the case of a clear lateral onset to a low back vowel, for example, this means that the dorsum will first raise and advance before returning to the pharyngeal target of the nucleus (Fig. 5.3 right) – a pattern of dorsal movement observed in the ultrasound data presented in Section 4.3.5.

### 5.1.1 Gestural Characterization of Spanish Liquids

The difference in gestural constituency contrasted in Figure 5.1 captures the essential difference between the classes of coronal stops and liquids; individual liquid consonants will differ in their specifications for location and degree of constriction of both tongue tip and tongue body gestures. The location of the tongue body gesture in the trills produced by the Spanish speakers in this study, for example, is typically forward of the mid-back vowel /o/, which can be described as a wide uvular-pharyngeal tongue body target. A preliminary set of gestural specifications for the Spanish coronal consonants, based on the results of the articulatory study, are proposed in Table 5.1.

Two additional aspects of liquid articulation which will need to be addressed as the model is refined are labial articulation, and the representation of lateralization.

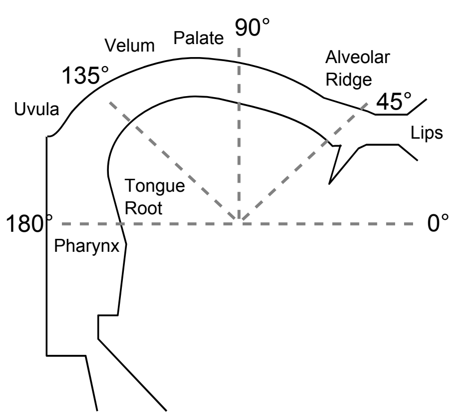
| TV | /d/ | /l/ | /r/ | /r/ |
|---|---|---|---|---|
| **TTCL** | dental | dental | alveolar | alveolar |
| **TTCD** | closed | narrow | narrow | narrow |
| **TBCL** | – | palatal | uvular | uvular-pharyngeal |
| **TBCD** | – | wide | wide | wide |

TABLE 5.1: **Tract variable specifications for Spanish voiced coronal consonants**.

Ladefoged & Maddieson (1996) observe that the side channels in an English lateral are formed largely as a result of the elongation of the tongue, and Browman and Goldstein (1995) demonstrate that a purely midsagittal specification for synchronized coronal and dorsal gestures is capable of adequately modeling the articulatory and acoustic properties of English /l/. It remains to be seen whether lateralization can be modeled in the same way in a clear lateral, where the relative proximity of the dorsal and tongue tip gestures mean that the tongue is less elongated than in a dark lateral, which uses a more retracted tongue body gesture.

### 5.1.2 Articulatory Modeling of Spanish Liquids

In order to test the representations of Spanish coronal consonants proposed in Table 5.1, articulatory simulations were conducted using TADA. The gestural parameters used to model the three liquids are shown in Figure 5.4.




| ARPA | Organ | Osc | TV | Constr | Target | Stiff | Dmp | Alph |
|---|---|---|---|---|---|---|---|---|
| L | TT | nar | TTCL | DENTALV | 45 | . | . | . |
| | TT | nar | TTCD | NAR | 2 | . | . | . |
| | TT | rel | TTCL | REL | 24 | 8 | 1.0 | . |
| | TT | rel | TTCD | REL | 11 | . | . | . |
| | TB | voc | TBCL | VEL | 100 | . | . | . |
| | TB | voc | TBCD | V | 11 | . | . | . |
| R | TT | nar | TTCL | ALVPAL | 60 | . | . | . |
| | TT | nar | TTCD | NAR | 2 | 10 | 0.3 | . |
| | TT | rel | TTCD | REL | 24 | . | . | . |
| | TT | rel | TTCL | REL | 11 | . | . | . |
| | TB | voc | TBCL | UVU | 125 | . | . | . |
| | TB | voc | TBCD | V | 10 | . | . | . |
| | Lips | voc | LA | NAR | 2 | . | . | . |
| RR | TT | nar | TTCL | ALVPAL | 60 | . | . | . |
| | TT | nar | TTCD | NAR | 2 | 20 | 0.2 | . |
| | TT | rel | TTCL | REL | 24 | . | . | . |
| | TT | rel | TTCD | REL | 11 | . | . | . |
| | TB | voc | TBCL | UVUPHAR | 150 | . | . | . |
| | TB | voc | TBCD | V | 6 | . | . | . |
| | Lips | voc | LA | NAR | 2 | . | . | . |

FIGURE 5.4: Left: **Semi-polar coordinate system** used to specify constriction location in TADA; Right: **Gestural parameters used in TADA simulations of Spanish Liquids**.

The Spanish lateral, for example, is modeled using six tract variable specifications corresponding to two gestures: a tongue tip approximation (and release), and a tongue body constriction. The gestural target for the tongue tip is a narrow constriction (TTCD = 2 mm) in the alveolar region (TTCL = 45°). The tongue body target is specified as a vowel-like constriction (TBCD = 11 mm) in the velar region (TBCL = 100°). Two additional sets of parameters (TTCL REL = 11°; TTCD REL = 24 mm) specify a tongue tip release target.[2] Parameters not explicitly specified in Figure 5.4 were modeled using default values for consonants.[3]

### Modeling Spanish Laterals

Data from a simulation of Spanish lateral articulation are shown in Figure 5.5. The acoustic waveform and time course of the tongue tip (TTCD) and tongue body constriction degree (TBCD) tract variables generated in a simulation of the word /pala/ *'spade'*, using the gestural specifications in Figure 5.4, are shown on the right. Midsagittal articulation during the pre-consonantal vowel and the point of closest coronal approximation of the lateral are shown on the left.

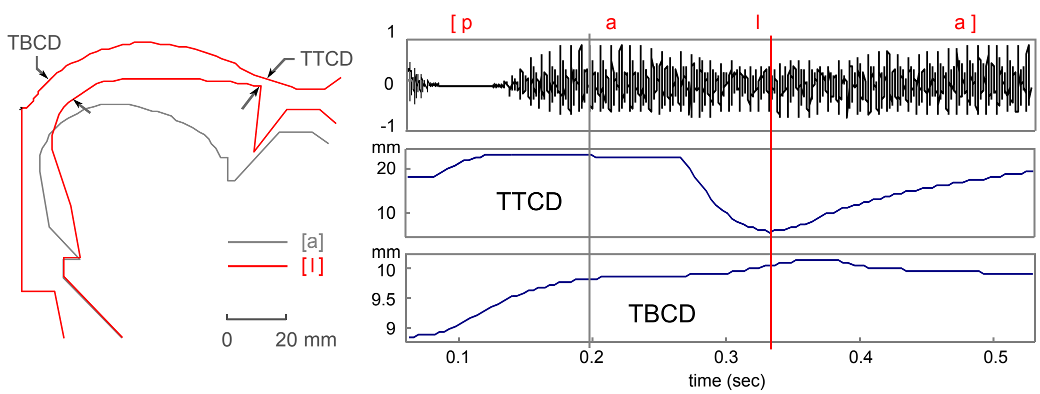



FIGURE 5.5: **TADA simulation of Spanish intervocalic lateral articulation: [pala] *'spade'*.** Left: midsagittal articulation during pre-consonantal vowel and mid-consonant; Right: acoustic waveform and time course of tongue tip and tongue body constriction degree tract variables.

TADA simulations of laterals produced in different vowel contexts exhibit the same changes in dorsal articulation which were observed in the ultrasound study. Data from three simulations of Spanish intervocalic laterals have been shown in Figure 5.6 (left). Midsagittal lingual profiles captured at the point of closest coronal approximation in [ele], [pala] and [pulula] simulations have been superimposed. Comparing the laterals with stops produced in the same contexts (Fig. 5.6,

2 For discussion of the need to specify separate release gestures see Browman (1994) and Nam (2007).

3 For explanations of differences between vocalic and consonantal stiffness, damping and blending parameters, see Nam et al. (2004). For details of implementation and default values used in TADA, see Goldstein et al. (2008).

right), the same resistance to vocalic coarticulation can be observed in the simulated liquids as was shown to characterize the laterals produced by Spanish speakers (4.3.6).

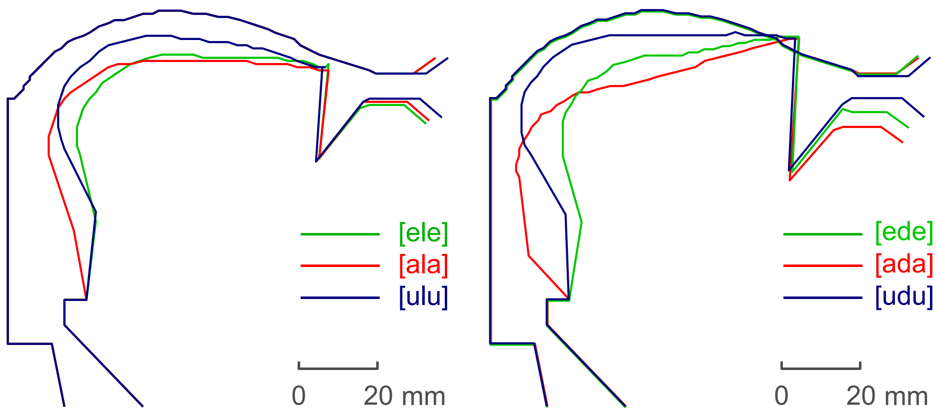



FIGURE 5.6: **Simulated vocalic coarticulation in Spanish intervocalic stops and laterals**. Left: comparison of midsagittal articulation in laterals produced in three different vowel contexts in /ele/, /ala/ and /ulu/ simulations; Right: midsagittal articulation in simulated coronal stops: /ede/, /ada/ and /ulu/.

The results of these simulations demonstrate that the model of gestural organization proposed for onset liquid consonants – in which liquid dorsal gestures blend with, and dominate, the synchronous but longer vocalic gestures – is capable of modeling a critical property of Spanish liquids: their resistance to vocalic coarticulation.

The spectrogram of an intervocalic lateral synthesized from the articulatory simulation is shown in Figure 5.7, where it is compared to spectra of intervocalic laterals produced by male and female Spanish speakers. The primary way that the synthesized lateral differs from the Spanish laterals is in the higher formants – in particular F4, which is not high enough in the context vowel and does not lower into the lateral.[4] As a result, the synthesized lateral, although sounding clearer than a dark [ɫ] , has an excessively 'palatal' quality.

Nevertheless, the important characteristic of the synthesized spectrum is that the lower two formants follow the same trajectories as in the real speech – a lowering of F1 and a raising of F2 in the transition into the lateral from the pharyngeal context vowel, consistent with a tongue body constriction target anterior to and above that of the pharyngeal vowel. The acoustic and articulatory output of the TADA simulation suggests that the gestural specification of a dorsal target resembling that of /e/ is an appropriate model for the clear lateral of Spanish.

4 Discrepancies in the higher formant trajectories of the synthesized spectra appear to be due to the absence of side channels in the midsagittal model, which have the effect of introducing a spectral zero around 2 kHz, lowering both F3 and F4 (Fant 1960).

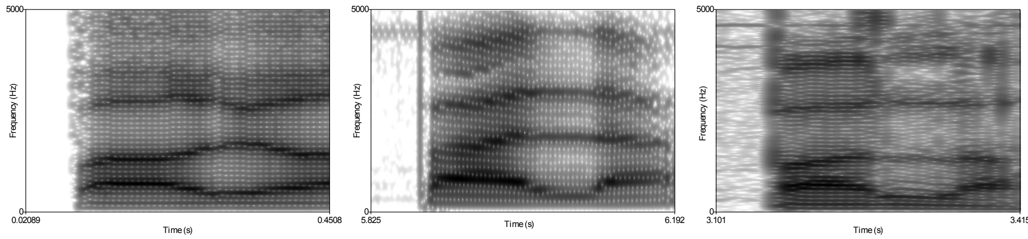



FIGURE 5.7: **Spectra of simulated and spoken Spanish intervocalic laterals**. Left: Speech synthesized from articulatory sequence [pala] simulated in TADA; Center: [pala] spoken by female subject W1; Right: [pala] spoken by male subject M1;

### Modeling Spanish Rhotics

Articulatory trajectories and synthesized waveforms from TADA simulations of the two Spanish rhotics are shown in Figures 5.8 and 5.9. The data show that the trill has been successfully modeled as a multi-contact coronal consonant, and the tap as single-contact. Spectra compared in Figure 5.10 show the simulated rhotic to be characterized by the same stability of formants in the back vowel context as observed in the spoken trills.

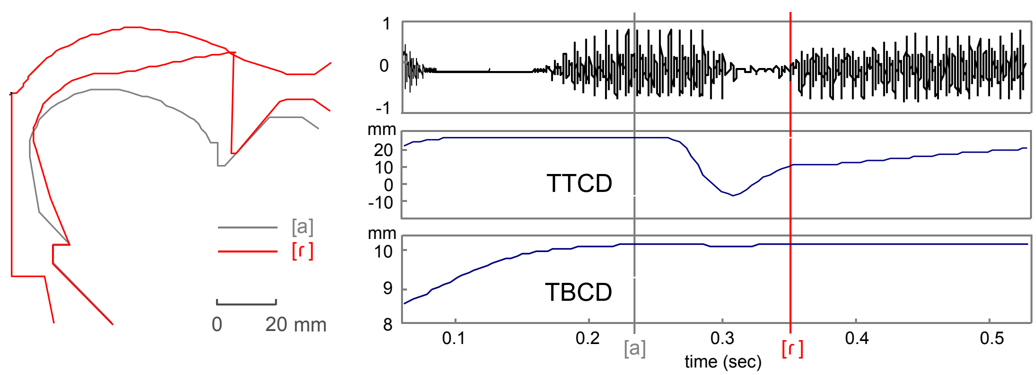



FIGURE 5.8: **TADA simulation of Spanish intervocalic tap articulation: [paɾa] *'for'***. Left: mid-sagittal articulation of pre-consonantal vowel, and during consonantal closure; Right: acoustic waveform and time course of tongue tip and tongue body constriction degree tract variables.

Although different tongue body constriction locations were specified for the trill and the tap – reflecting the difference in mean dorsal location observed in ultrasound study (Fig. 4.33) – the essential difference between the two rhotics in these TADA simulations is in the stiffness and damping of the tract variable associated with the tongue tip.

In the model of inter-articulator coordination implemented in TADA, the default TV frequency (stiffness) assigned to consonantal gestures is 8 Hz – twice that of gestures associated with a vowel oscillator (4 Hz). This 2-to-1 V:C frequency ratio is

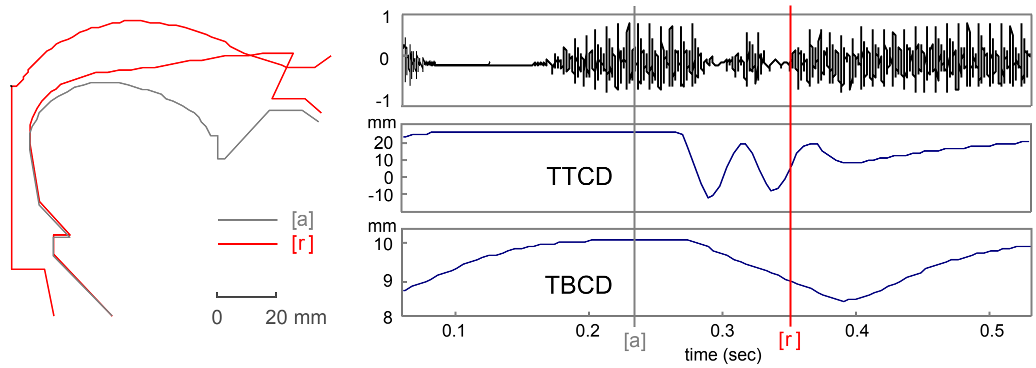



FIGURE 5.9: **TADA simulation of Spanish intervocalic trill articulation: [parra]** ***'vine'***. Left: mid-sagittal articulation of pre-consonantal vowel, and during consonantal closure; Right: acoustic waveform and time course of tongue tip and tongue body constriction degree tract variables.

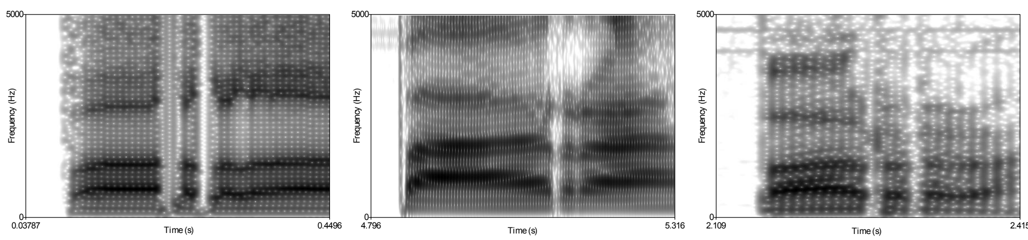



FIGURE 5.10: **Spectra of simulated and spoken Spanish intervocalic trills**. Left: HL-Syn synthesized speech of sequence [para] simulated in TADA; Center: [para] spoken by female subject W2; Right: [para] spoken by male subject M1;

used to model a syllable structure in which all onset gestures begin synchronously with the vowel, but are only activated for half of the duration of the vocalic gesture. In the rhotic simulations illustrated in Figures 5.8 and 5.9, TTCD stiffness was specified to be much shorter (10 and 20 Hz) than the consonantal default, and the tongue tip damping ratio was reduced from the default value of 1. Standard consonantal parameters were used for the tongue body tract variable gesture of the rhotics.

The articulatory configuration being modeled with this set of specifications is one in which a stable tongue body gesture is coordinated with a less rigidly controlled coronal gesture – a lingual configuration which has been shown to be conducive to the onset of trilling (McGowan 1992, Solé 2002). Because it is not possible to specify aerodynamic parameters in TADA, trill initiation is emulated as a brief coronal approximation of a weakly damped tongue tip.

While acknowledging the artificiality and limitations of this type of simulation, the importance of this experiment is to demonstrate that a computational articulatory model is able to capture the essential difference between the rhotics and the coronal obstruents: oscillatory coronal articulation can result from the coordination of a weakly damped tongue-tip approximation with a stable tongue body gesture (rather than the active closure gesture used to simulate coronal stops).

Another important point to be made about the simulations compared in Figures 5.8 and 5.9 is that the same fundamental model has been for both the trill and the tap. This demonstrates that both types of rhotics can be produced using the same articulatory configuration – a configuration in which the number of coronal contacts depends, in part, on the degree of tongue-tip damping. The variability in the frequency of oscillation of the tongue tip observed in different simulations run using this model is consistent with the variability in the number of coronal contacts observed amongst both rhotics produced by the Spanish speakers in this study (Figure 4.35).

Considerable variability was also observed in the degree (and duration) of tongue tip closure produced at different stages in different rhotic simulations. As observed in Section 4.4.2, spirantized rhotics sometimes result from the same basic articulatory configuration used in trill production. In these cases, it seems likely that the different rhotic allophones are the result of small differences in aerodynamics, tongue-tip stiffness, or coronal aperture; if so, the variability in tongue tip articulation produced by the TADA rhotic simulation is consistent with the variability in the degree of spiratization observed amongst the rhotics elicited in the ultrasound study (Section 4.3.2).

## 5.2 Gestural Organization in Spanish Codas

It was demonstrated in Section 3.2 that Spanish has a strong preference for open syllables (Table 3.3), and that codas overwhelmingly consist of one of the consonants {/n/,/r/,/l/,/s/} (Table 3.5). Each of the consonants in this set is a complex segment, consisting of a tongue-tip gesture coordinated with a velic or tongue body gesture (assuming that sibilant production involves dorsal articulation to condition the airstream into the coronal constriction). This suggests that Spanish has a preference for coda structures in which the tongue body gesture of the nucleus can be coupled to the non-coronal gesture of the coda consonant (Fig. 5.11).

Under this model, dorsal or velic coda gestures would always be contiguous with the nucleus; the timing of other coda gestures would depend on their phasing with the dorsal (or velic) gesture. This model of Spanish coda structure is consistent with accounts of syllable-final timing differences in English and other languages. Observing the lag in tongue tip gestures of nasals and laterals, relative to their corresponding velic and dorsal gestures in English, Browman & Goldstein (1995a) pro-

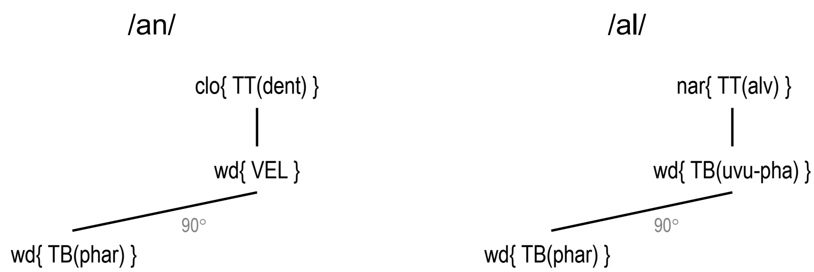



FIGURE 5.11: **Gestural organization in Spanish nasal and liquid codas**.

posed that coda organization in English is governed by the principle that "gestures involving wider constrictions precede those with narrower constrictions". Similar effects have been observed in laterals in Squamish Salish, and the rhotic liquid of Mandarin Chinese (Gick et al. 2006). These timing differences would result from an anti-phase coupling between tongue-body and tongue-tip gestures in the model in Figure 5.11).

Although it is beyond the scope of this dissertation to provide a thorough analysis of intergestural timing in Spanish coda consonants,[5] the articulatory evidence suggests that, as in other languages, tongue body gestures precede coronal activity in coda liquids. Dorsal movement (fronting and raising) toward the target constriction in Figs. 4.37 and 4.38, for example, commences up to 150 msec before the tongue blade is approximated toward the alveolar ridge, and is largely completed before the tongue tip achieves first closure. Articulation of another coda rhotic by the same speaker is shown in greater temporal resolution in Figure 5.12: dorsal advancement commences some -74 msec before any independent movement of the tongue blade can be observed.

It remains to be seen what intergestural timing relationships exist in Spanish coda consonants, and how they are best modeled. Preliminary evidence from the ultrasound data indicates that coronal gestures lag tongue body gestures, which would be consistent with the model of coda structure in which tongue-tip gestures are coupled anti-phase to the tongue-body gestures, which in turn are coupled anti-phase to the nucleus (Fig, 5.11). Such a configuration is broadly consistent with coordination relations which have been proposed for codas in English (Browman & Goldstein 2000) and Morrocan Arabic (Gafos 2002).

[5] Because of the difficulty of reliably tracking tongue tip activity and quantifying gestural timing in ultrasound data, such a study would require the use of an alternative imaging modality such as EMMA.

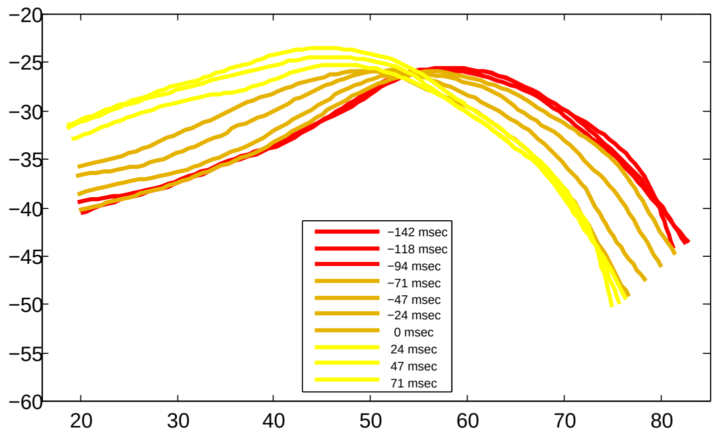



FIGURE 5.12: **Coronal lag in Spanish coda rhotic articulation** – Subject W3, [ar]. Red frames: tongue static in vocalic gesture; Tan frames: tongue fronting as a single unit; Yellow frames: dorsal fronting complete, tongue blade raising independently.

## 5.3 Gestural Organization in Spanish Complex Onsets

The same principle which has been proposed to account for Spanish coda structure – that the most open tongue body gesture is always coupled more closely to the nucleus – will also account for the phonotactics of Spanish onset clusters. As discussed in Section 3.2.1, Spanish uses a limited set of complex onsets in which the segment appearing between the obstruent and the nucleus is always a liquid.

In onset clusters, and onset consonants consisting of multiple components, all gestures are modeled as existing in an in-phase relationship with the vocalic gesture of the nucleus. If these gestures are associated with different articulators, this means that they will all commence synchronously with the nuclear vowel. If multiple gestures are associated with the same articulator, then in order to ensure perceptual recoverability (Chitoran et al. 2002), the competition for control of the single tract variable must be resolved through temporal reordering, to prevent the parallel execution of homorganic gestures. We can model this using an asynchronous coupling relationship between the competing tongue body gestures in the onset (Figure 5.13).

In both rhotic- (/krema/) and lateral-internal clusters (/klima/) in Spanish, for example, each of the tongue body gestures in the onset (dorsal stop and liquid) will be coupled in-phase to the pharyngeal vowel. If the tongue-body gesture of the liquid has a greater affinity for the nucleus, then it will always appear closer to the vowel than the dorsal obstruent, which involves the less inherently sonorant tongue body closure constriction.

If it is the case that there is a universal preference for coupling gestures of greater

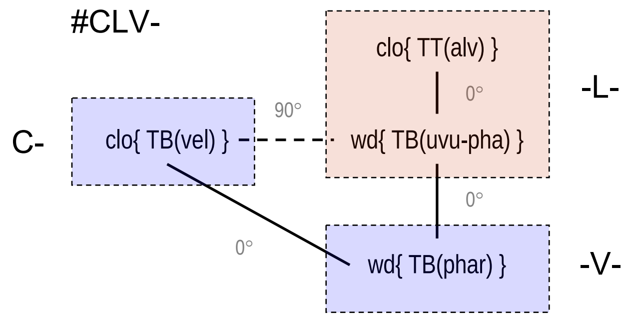



FIGURE 5.13: **Organization of complex Spanish onsets** – /kla-/.

tongue body or velic aperture more 'tightly' to the nucleus in both onsets and codas, this would prove to be an important principle of organization which could account for the sonority-sequencing phenomena observed in many languages, consistent with the principles of organization which have been hypothesized in articulatory theories of syllabic organization.

Principles of gestural organization in complex onsets and codas are discussed in more detail in Chapter 9, where it is proposed that the cluster phonotactics observed in Spanish, as in all languages, result from the interaction of universal and language-specific constraints on gestural coordination and recoverability. According to this view of the syllable, it is because of their intrinsic gestural complexity that liquid consonants play a special role in the structure of clusters.

## 5.4 Articulatory Analysis of Phonological Processes Involving Spanish Liquids

A number of phonological processes involving liquids in Spanish can be explained in terms of changes in the type, timing, and organization of their constituent gestures.

### 5.4.1 Rhotacism, Lambdacism, and Liquid Neutralization

Under the gestural model proposed here, all three Spanish liquid consonants are characterized as having the same fundamental phonological representation – individual consonants being differentiated by their individual specifications for those gestures. Because of this underlying unity in gestural constituency, phonological phenomena such as neutralization and allophonic variation within the class may be considered to be the result of changes in the articulatory parameters of liquid consonants.

Changes in the target location and degree of constriction for tongue body and tongue tip gestures, as well as the stiffness, degree of damping, and blending parameters associated with each of the gestures which constitute a liquid, will all result in changes in the realization of the consonant.

Rhoticization of final laterals in Havana Spanish, for example, could result from a reduction in the degree of damping of the tongue tip gesture, while stiffening of the tongue blade would be a contributing factor in the reverse process of lateralization. The intermediate liquid allophones attested in Puerto Rican Spanish codas – *puerta* [ˈpueʳl.ta] 'door'; *por favor* [poʳl.fa.ˈβol] 'please' (Hualde 2005) – would appear to be realizations in which the coronal gesture is adopting an articulation configuration intermediate to that prototypically associated with the lateral and the tap.

### 5.4.2 Liquid Vocalization

Another phonological process involving Spanish liquids which bears reconsideration under a gestural framework is vocalization. As discussed in Section 3.2.2, in many Spanish varieties, liquids in coda positions are prone to realization as glides or central vowels, e.g. *algo* [ˈai̯.ɣo] 'something', *mujer* [mu.ˈhei̯] 'woman'.

Accounting for liquid vocalization is problematic under feature-based phonologies. In the feature-geometric representations proposed by Walsh Dickey (1997), for example, rhotics and laterals have an inherently different structure – only laterals having a dual place node (Fig. 5.14 left). Furthermore, in the feature geometry of McCarthy (1988), upon which Walsh Dickey bases her hypothesized structures for liquids, both types of consonant have an inherently different structure to vowels (Fig. 5.14 right).

Although lateral vocalization might be explained in part as the result of the delinking of the laminal place node, there is no straightforward account of rhotic vocalization using the feature geometry of Figure 5.14 (center). Furthermore, it is not obvious how to account for the differences in the major class features between vocalized and non-vocalized liquids under this framework, since the structure of the root node differs between laterals and rhotics (±cont), and between the liquids and vowels (±liquid).

Accounting for liquid vocalization is straightforward under the articulatory model being proposed here: it would result from lenition, deletion or masking of the tongue tip gesture of the liquid. The organization of gestures in the word /algo/

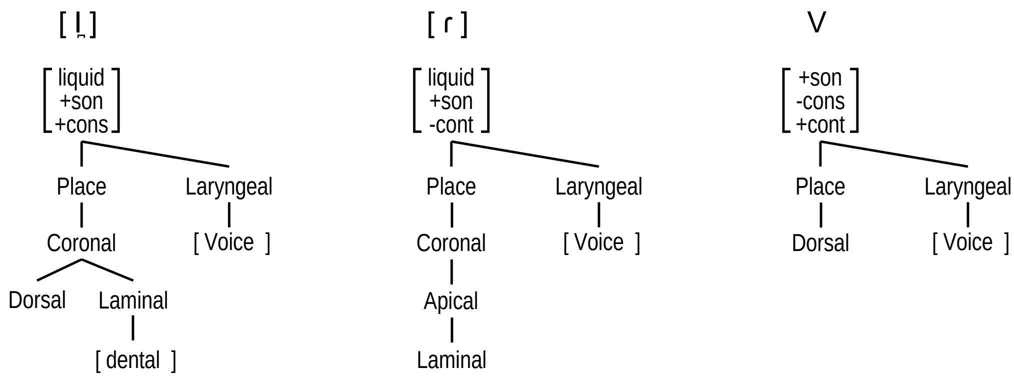



FIGURE 5.14: **Feature Geometries of liquids and vowels** (Walsh Dickey 1997).

*'something'*, for example, is illustrated in the score in Figure 5.15.[6] Prototypically, the coda lateral is articulated with a partial coronal closure, coordinated with a dorsal constriction in the palatal region. If the tongue tip gesture is deleted or undershot, the wide tongue body constriction which will remain is identical to that which defines palatal vowel /algo/ → [ˈai̯.ɣo].

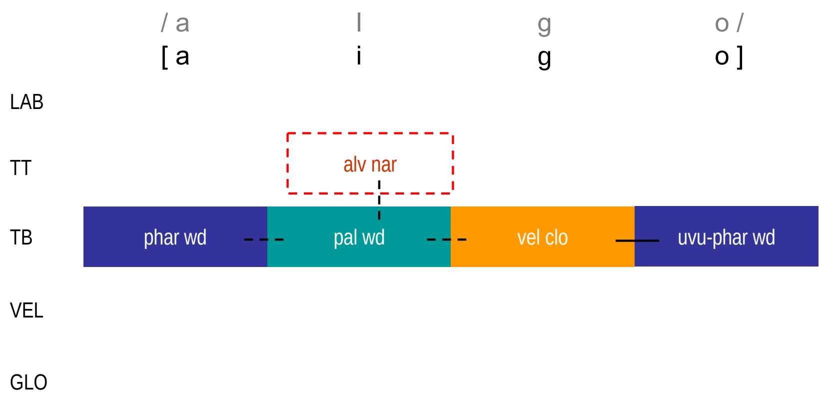



FIGURE 5.15: **A gestural account of liquid vocalization in Spanish codas**: deletion of tongue tip gesture, leaving only vocalic tongue body gesture.

Similar accounts of vocalization have been proposed for dark laterals in Brazilian Portuguese (/l/ → [u], Leidner 1976), British English (/l/ → [ɤ], Hardcastle& Barry 1989) and child Dutch (/l/ → [w], Browman & Goldstein 1995). The fact that coda vocalization affects both laterals and rhotics in Spanish is consistent with the hypothesis that there is a gestural basis to the class of liquids, and constitutes another important piece of evidence that clear laterals, like velarized laterals, are produced

6 The spirantized velar fricative [ɣ] which typically appears in place of the intervocalic stop [g] could result from undershoot of the tongue body clo closure gesture (Parrell p.c.); alternatively, this gesture may be specified as crit in Spanish varieties in which intervocalic stop spirantization is lexicalized.

with a vowel-like dorsal gesture. The fact that the outcome of lateral vocalization in Spanish is typically a high front vowel or a palatal glide is consistent with the hypothesis that the dorsal target of the clear lateral resembles that of a front vowel.

Under a gestural phonology, we are able explain liquid vocalization without having to account for differences in major class features, as there is no inherent difference between the phonological primitives of consonants and vowels. All types of oral sonorants are produced with a wide lingual constriction gesture – the same gesture will correspond to a vowel, glide or liquid, depending on the coordination of this gesture with others in the organization of the syllable.

### 5.4.3 Metathesis

Another phonological process in which Spanish liquids pattern together – for which there is no straightforward explanation under feature-based phonological theory – is metathesis. As observed in Section 3.2.2, the most commonly attested type of metathesis in Spanish involves the interchange of liquids with adjacent vowels: *porfiar* → [pɾofiaɾ] 'to insist', *clueca* → [kuleka] 'broody'. While such phenomena could conceivably be explained in terms of feature spreading and delinking in an autosegmental framework, the asymmetrical structure of the feature hierarchies proposed for laterals and rhotics make a unified account of metathesis problematic – it is unclear which nodes should be spread and how major class features should be handled.

Blevins & Garrett (1998) have argued that rhotic metathesis in Romance results from the spreading of 'long phonetic cues' (specifically, a lowered third formant) into rhotic-adjacent vowels; however, we have seen that there is no such invariant acoustic property which unifies Spanish rhotics, even amongst the five participants in this study. Furthermore, this explanation cannot account for lateral-vowel sequences, which metathesize in the same environments as rhotics in Spanish, as in many other languages (Hume 2004).

Russell Webb & Bradley (200x), following Hall (2003, 2004), propose an optimality theoretic account of diachronic metathesis in which "gestural alignment constraints favor complete overlap of adjacent rhotic and vowel gestures". All of these accounts assume a stage in the historical development of these changes in which obstruent-rhotic clusters are broken through vowel epenthesis (or as a result of underlying vocalic gestures becoming more prominent, cf. Steriade 1990), after which a realignment of gestures results in the metathesized forms.

I propose that the articulatory model of Spanish liquids being developed here suggests a simpler, more unified account of liquid-vowel metathesis. In the organization of a syllable, the fundamental difference between onset and coda consonants is their phasing with respect to the nucleus (Nam & Saltzman 2003). Comparing the gestural constituency of the first syllable of the word *porfiar* 'to insist' with that which would result in the metathesized version [pɾo] (Fig. 5.16 left), we can see that the relocation of the rhotic is the result of the shift of its tongue tip and tongue body gestures so that they are timed with respect to the beginning, rather than the end of the vowel.

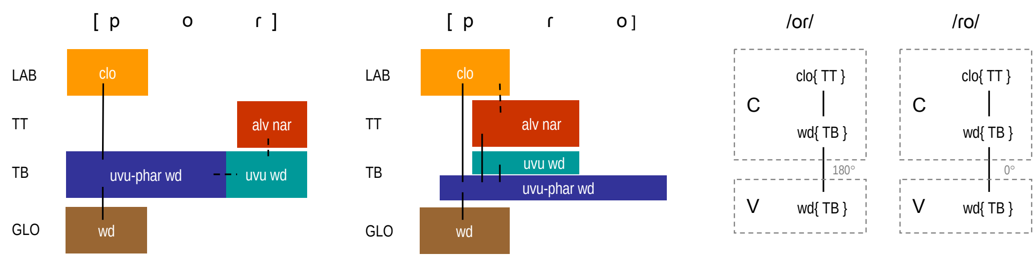



FIGURE 5.16: **Metathesis of Spanish coda liquids**: change in phasing of liquid and nucleus tongue body gestures.

VL metathesis may therefore be modeled as a phase change in the coupling relationships between the gestures corresponding to the liquid and the nucleus (Fig. 5.16 right). While both in-phase (onset) and anti-phase (coda) couplings correspond to stable states of inter-gestural organization in the syllable, the in-phase relationship appears to be more stable than the anti-phase (Nam & Salzman 2003). Evidence from speech error experiments suggests that changes in gestural phasing can occur spontaneously between syllables (Pouplier 2005), and experiments into gestural organization amongst populations of interactive agents indicate that in-phase structures tend to emerge as the preferred coupling relationship over time (Browman & Goldstein 2000). These results are consistent with the Spanish preference for open syllables, as well as the tendency for metathesis to move rhotics out of coda positions into onsets, even when the change results in a complex onset.

### 5.4.4 Rhotic Svarabhakti

The phonetic analysis of the svarabhakti phenomena presented in Section 4.4.3 suggests an alternative account to that proposed by Bradley (2004). The resonant fragments which have been interpreted as intrusive or underlying context vowels are instead argued to result from the same dorsal gestures, intrinsic to the rhotic, which were observed in intervocalic environments. In medial coda position, these fragments are more salient because they are immediately followed by a heterosyllabic consonant. In certain realizations, if the coronal component of the rhotic does not mask the dorsal component (as it invariably does in coda laterals because the coronal gesture is sustained), the coda rhotic will be perceived as a CV sequence. The timing relationships which could result in the appearance of svarabhakti are illustrated in the gestural score in Figure 5.17.

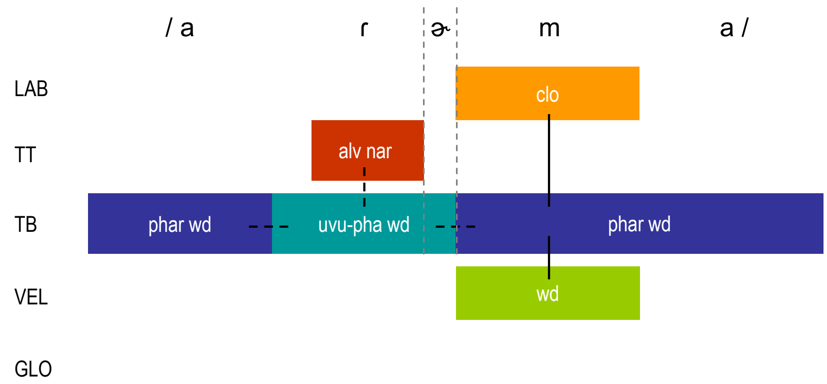



FIGURE 5.17: **A gestural account of svarabhakti** in Spanish medial rhotic-final clusters: resonant fragments inherent to rhotic.

Although the activation interval for the TTCD tract variable indicates that the coronal gesture of the rhotic ends earlier than the associated tongue body gesture, svarabhakti could also result if the tongue tip gesture persisted into the interval of activation of the following labial. Because Spanish rhotics are articulated with sporadic coronal contact, there will be intervals of time during which the dorsum adopts a vowel-like posture while there is no coronal closure – an articulatory configuration which may be perceived as short intrusive vowel.

## 5.5 Conclusions

In this chapter, the class of Spanish liquids has been characterized as consisting of a subset of recurrent phonological structures in which a tongue-tip gesture is coordinated with a vowel-like tongue body constriction. The three liquids are argued to be differentiated by their target tongue body constriction locations, and the stiffness and damping of their tongue tip gestures. Allophonic variation and neutralization of liquids is argued to result from changes in these gestural parameters.

Articulatory simulations have demonstrated that gestural models specified for these characteristics are capable of capturing some of the essential phonetic behaviors of liquids. Trajectories of the lower two formants in modeled intervocalic liquids are consistent with those observed in spoken Spanish. Variation in coronal articulation was successfully simulated by manipulating the degree of tongue tip damping, consistent with the hypothesis that trills and taps are characterized by the same underlying articulatory configuration.

The phonotactic properties of Spanish liquids – uniquely appearing as nucleus-adjacent segments in onset clusters; preferentially appearing in codas – are argued to result from a preference in Spanish syllabic organization for coupling relationships between the nucleus and adjacent tongue-body gestures. Under this model, liquid-vowel metathesis might arise from changes in the phasing of these gestures.

The picture which emerges from the analysis of laterals and rhotics in Spanish is that the production of coronal liquids prototypically involves the coordination of a vowel-like dorsal gesture with a tongue tip approximation – a representation which is also broadly consistent with phonetic descriptions of trills in Catalan (Recasens ref) and Serbo-Croatian (Gick et al. 2006), and approximant liquids in English (Delattre & Freeman 1968; Giles & Moll 1975) and Mandarin (Gick et al. 2006). It remains to be seen whether this characterization holds true in languages which use secondary articulation to contrast pairs of consonants. To examine this question, we next consider the phonological behavior and phonetic properties of liquids in Russian.