On the Current State of Vowel Intrusion Analysis in Spanish within Optimality Theory

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1. Introduction[1]

One particular area of Spanish linguistics[2] that has garnered much attention in recent years is that of vowel intrusion (Bradley, 2004, 2005, 2006a; Bradley & Schmeiser, 2003; Colantoni & Steele, 2005, 2007; Kilpatrick, Kirby & McGee, 2006; Ramírez, 2002, 2006; Schmeiser, 2006, 2007, 2009). Vowel intrusion in Spanish occurs between the tap and its adjacent obstruent (Lenz, 1892; Araujo, 1894; Josselyn, 1907; Colton, 1909), as in:

(1)	**Tautosyllabic /Cɾ/ clusters**:	**Heterosyllabic /ɾC/ clusters**:
	a. *pronto* [p^{ə}ɾ] 'soon'	e. *enorme* [ɾ^{ə}m] 'enormous'
	b. *otro* [t^{ə}ɾ] 'other'	f. *parte* [ɾ^{ə}t] 'part'
	c. *fresco* [f^{ə}ɾ] 'cool, fresh'	g. *porque* [ɾ^{ə}k] 'because'
	d. *negro* [ɣ^{ə}ɾ] 'black'	h. *cerdos* [ɾ^{ə}d] 'pigs'

In Spanish, /Cɾ/ clusters are tautosyllabic and /ɾC/ clusters are heterosyllabic. The current study limits itself to the tautosyllabic environment, which exhibits a shorter intrusive vowel[3] mean duration than its heterosyllabic counterpart (Schmeiser, 2006). Throughout the paper, I follow previous phonetic representation of the intrusive vowel (henceforth, IV) in Spanish (Lenz, 1892; Malmberg, 1965; Bradley, 2004, 2005, 2006a,b; Bradley & Schmeiser, 2003; Kilpatrick, Kirby, & McGee, 2006; Schmeiser, 2006, 2007) by denoting the IV as the superscripted schwa, [^{ə}].

Based on previous work from Bradley and Schmeiser (2003) on Spanish /Cɾ/ clstuers, Schmeiser (2007) analyzes the effects of segmental and prosodic factors on IV duration and finds two prosodic factors, namely order of constriction location and obstruent voicing, evidence significant results; longer IV duration is found in a back-to-front order of constriction (27.77 ms) as compared to a front-to-back order (20.76 ms) and longer IV duration is found after a voiced obstruent (27.33 ms) as compared to its voiceless counterpart (20.07 ms). Colantoni and Steele's work (2005) on Argentine Spanish evidences longer IV duration after a voiced obstruent, though they also find two prosodic factors to significantly affect IV duration, namely word position and prosodic stress. Their study (2007) on Argentine and Chilean Spanish corroborates previous findings of longer IV duration after a voiced obstruent.

Ramírez's (2002, 2006) work corroborates the notion of significantly longer mean IV duration after a voiced obstruent. His study (2006) also reveals that place of articulation might play a role in IV duration, though the data are not significant. In their study of IVs in the Spanish of Santa Cruz, Bolivia, Kilpatrick, Kirby, and McGee (2006) find only one variable to evidence significant results in the majority of their subjects, namely longer IV after a voiced obstruent; significant findings are not found for prosodic stress, word position, place of articulation, or tongue height of the nucleic vowel.

[1] I wish to thank the audience members of HLS 2007 for their feedback and express my gratitude to Rocío Morales Schmeiser, Rajiv Rao, and Angelo J. Rodríguez for their support.
[2] For studies outside of Spanish, see Davidson (2003) and Hall (2003).
[3] I utilize the term 'intrusive vowel' in the current study. Observe that it is also referred to in the literature as 'the epenthetic', 'epenthetic vowel', 'excrescent vowel', 'schwa insertion', 'excrescent schwa' or 'svarabhakti vowel'.

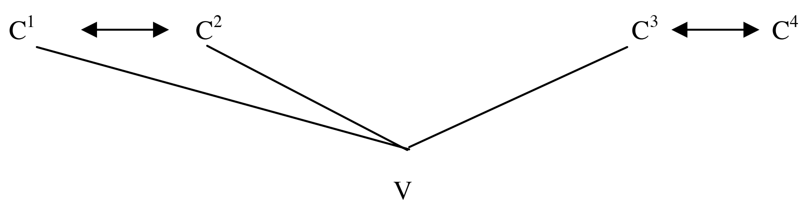
Finally, Schmeiser's work (2006, 2009) evidences longer IV duration after a voiced obstruent, however it also offers significant results for hypotheses that test three categories; that is, manner of articulation (fricatives, stops, and approximants) and place of articulation (labials, coronals, and dorsals) exhibit a continuum from shorter IV duration to longer, as listed in parentheses.

In short, these studies have furthered our knowledge with regard to the factors that affect IV duration. That withstanding, as Hayes (1996) correctly points out, "the phonetic research that explains the phonological has been done very well and is quite convincing; it is only the question of how to incorporate it into formal phonology that is difficult" (p. 5). In light of Spanish vowel intrusion, OT constraints exist to illustrate IV *presence* (about 65% of all /Cɾ/ clusters exhibit an IV; Schmeiser, 2006, p. 50). However, I note that we currently have no (known) OT constraints that distinguish longer IV duration from shorter, which is especially surprising given that certain prosodic and segmental factors (e.g. obstruent voicing) significantly affect IV duration. This study offers a review of previous attempts in gesture-based OT to incorporate fine-grained, phonetic detail (i.e. vowel intrusion, in the current study) into formal phonology and seeks to add to the previous work by addressing this shortcoming that currently exists in the analysis. The rest of the paper is organized as follows: §2 discusses how vowel intrusion is currently viewed in a gesture-based OT approach outside of Spanish, §3 treats studies within Spanish, §4 offers the current analysis, and §5 concludes.

2. Vowel intrusion in gesture-based Optimality Theory (OT)

Gafos's (2002) influential work on Moroccan Colloquial Arabic offers a rigorous analysis in which constraints are proposed based on gestural timing. Gafos (2002) uses Articulatory Phonology (AP) (Browman & Goldstein, 1989, et seq.) as its framework. The framework uses the 'gesture', which are physical articulations that express spatio-temporal articulatory functions. These gestures combine to form a syllable, as illustrated in the following figure:

Figure 1 Gestural phasing relationships within a syllable (adapted from Gafos, 2002, p. 316)



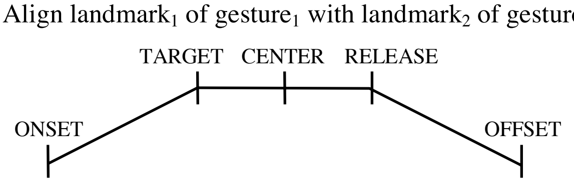
In the above figure, we see that both the first consonant, C^1, and the second, C^2, have a timing relationship with the underlying vowel; both consonants also have a timing relationship with each other. This tautosyllabic cluster evidences tighter gestural constriction (Byrd, 1996) than the heterosyllabic cluster in which the second consonant, C^4, does not have a timing relationship with nucleic vowel in Figure 1, but rather maintains a timing relationship with the nucleic vowel in its own syllable.

Gafos (2002) proposes alignment constraints in OT for which intergestural timing is punctate (Saltzman & Byrd, 2000, p. 503). Punctate refers to invariant point-to-point phasing, which is represented by Gafos in the form of 'landmarks', as illustrated in Figure 2:

Figure 2 Gafos's (2002) proposed landmarks of a gesture

a. ALIGN(G_1, LANDMARK$_1$, G_2, LANDMARK$_2$)
Align landmark$_1$ of gesture$_1$ with landmark$_2$ of gesture$_2$.

b.



Gafos (2002) puts forth a series of constraints based on the above landmarks[4] that is comprised of ALIGN(MENT) constraints based on faithfulness to the input, as illustrated in (2). Gafos (2002) offers a gesture-based OT account of vowel insertion in terms of the aforementioned gestural landmarks. In his account, faithfulness alignment constraints are employed to express intergestural phasing, of which there are three: C-V, V-C and C-C:

(2)
a. CV-COORD -- requires that the c-center of the C gesture be synchronous with the onset of the V gesture: ALIGN (C, C-CENTER, V, ONSET)
b. VC-COORD -- requires that the target of the C gesture is synchronized with the release of the V gesture, ALIGN (V, RELEASE, C, TARGET)
c. CC-COORD -- the release of the first gesture is synchronous with the target of the second gesture, ALIGN (C^1, RELEASE, C^2, TARGET)
d. RECOV -- requires that in a CC complete overlap between the two consonants is prohibited

Note in (2) that Gafos also adds a constraint that ensures recoverability (i.e. prohibits complete overlap) of each consonant (2d). For his study on Moroccan Colloquial Arabic (MCA), Gafos utilizes three of these four constraints in the adjectival diminutive [CCiCᵊC], with a template of /CCiCC/; for example, in the word /smin/ 'fat', the derived form is [smimᵊn]. In terms of OT constraint ranking, RECOV must outrank CV-COORD to ensure vowel (fragment) insertion, as in the following tableau:

Tableau 1[5] Tableau for the diminutive of /smin/ 'fat': [smimᵊn] (adapted from Gafos, 2002, p. 319)

Base: /smin/ 'fat'	RECOV	CV-COORD	CC-COORD
a. /s⊗m i mon/ [m] [mᵊn]	*!		*(sm)
☞ b. /s•m i mon/ [sm] [mᵊn]		**	*(sm)
c. /som i mon/ [sᵊm i mᵊn]		***!	

In the tableau, candidate a. fatally violates RECOV because there is complete overlap (marked with a '⊗') and therefore only /m/ is perceptible. Candidates b. and c. both violate CV-COORD because this constraint states that the optimal C-V requires complete overlap of the two consonants. Candidate b. incurs two violations of CV-COORD in that the alignment with the vowel ('•' signifies a close transition; that is, both consonants are perceptible, but with no intervening vowel fragment) requires movement from the c-center of both /s/ and /m/ to move one landmark along the gestural plateau (i.e. either the target or release). Candidate c. evidences a longer duration of the vowel fragment between /s/ and /m/ and therefore, the temporal distance away from the c-center is longer, which entails more violations. Candidate b. has fewer violations of CV-COORD and is the optimal candidate in that CV-COORD is a fatal violation for candidate c., which has a vowel fragment.

[4] Notice in Figure 2b. that the onset of a gesture refers to the time in which the articulator moves toward the specific target, the gestural plateau (from target to release) refers to the acheivement of target; the release refers to the point in which the articulator begins to move away from the target, and finally the offset, refers to the point when active control of movement away from the target stops (Gafos, 2002, pp. 276-292).

[5] To read an OT tableau, one observes that the input is located at the top of the first column and the list of outputs is generated underneath it. Constraints appear at the top of the remaining columns, in order of their relative position within the constraint hierarchy, which is language specific. EVAL(uation) runs left to right, beginning with Constraint 1, which is the highest ranking constraint. The objective of OT is to find the optimal output candidate by generating (GEN) a list of potential outputs. Then, given a particular ranking of the constraints, EVAL(uation) will find the winning candidate from the list of outputs on the left side of the tableau by showing which candidate fares best against the constraints provided.

In his analysis, Gafos measures gradient change in terms of the distance from the c-center to either the target or release. This distance, 'τ', is defined as the 'minimal unit of temporal distance employed in gradient evaluation of coordination constraints' (p. 279). This is a pertinent consideration for IV analysis, which requires an analysis that considers gradient temporal distance. Though Gafos employs 'τ' as the minimal distance measured, the current analysis does not require movement from one landmark to another, but rather perceptible differences in IV duration may transpire *along* the gesture, and not simply measuring phasing from one landmark to another. For example, we observe in the above tableau that the three outputs only treat complete overlap, two perceptible consonants with no vowel fragment (i.e. close transition) and finally, an output with the vowel fragment. That is to say, outputs that differ solely in terms of the duration of the vowel fragment are not considered (See §4 for more elaboration).

In making reference to Gafos's gestural representation of a syllable (see Figure 1), Davidson (2003) puts forth a series of ASSOC(IATION) constraints, illustrated in (3), which consists of inputs without association lines and explains different output realizations in terms of association lines. In Davidson's (2003) account of IV insertion in non-native realizations of consonant clusters in Polish, she uses Gafos's alignment constraints, however she also proposes the use of association constraints. Crucially, associations are defined as the 'gestural correlates of syllable structure' (p. 104).

(3)
a. ASSOC(IATE)-CV: A consonant gesture must have a coordination relationship with the nearest following vowel gesture.
b. ASSOC(IATE)-CC: A consonant gesture must have a coordination relationship with adjacent consonant gestures.
c. ASSOC(IATE)-C: A (non-nuclear) consonant gesture must not be unassociated.
d. *MULT(IPLE)ASSOC(IATION): A consonantal gesture must not be associated with multiple vowels or with consonants that are associated with a vowel other than the one that consonantal gesture is associated with.

Making reference to Gafos's (2002) notion of gestural representation in a syllable, Davidson (2003) envisions inputs without association lines and explains different output realizations in terms of association lines, as exemplified in the following tableau:

Tableau 2 Example of association lines for IVs in C-C clusters (adapted[6] from Davidson, 2003, p.114)

f p a	ASSOC-C	CC-COORD	ASSOC-CV
☞ a. f ----- p (f and p both associated with a, dashed lines) a [f^{ə}p^{h}a]		*	
b. f ----- p (p associated with a) a [f^{ə}p^{h}a]		*	*!
c. f p (p associated with a) a [f^ə.p^{h}a]	*!		

[6] Some outputs and constraints were removed in both Tableau 2 and Tableau 3 due to space limitations.

As illustrated in the tableau, the output candidates contain certain (or no) associations with the nuclear vowel. Candidate c. contains a non-nuclear consonant that is unassociated, which incurs a fatal violation of ASSOC-C. Candidates a. and b. each incur a violation of CC-COORD in that there is a perceptible vowel fragment in the tautosyllabic cluster; I note in passing that, for Gafos, CC-COORD is 'tailored to different languages' (p. 284). Candidate b. suffers a fatal violation in ASSOC-CV in that /f/ does not have an association line to the nuclear vowel. Finally, observe that, as in Gafos's (2002) constraints, her association constraints do not consider minute (i.e. fine-grained) variation in gestural timing.

Hall (2003) also uses Gafos (2002) as her base, but does not deem necessary multiple constraints for a CC cluster. Her proposal is to view alignment constraints in terms of the *nucleic vowel* and its duration across a syllable:

(4) a. ALIGN (V, OFFSET, SYLL, OFFSET): The offset of every vowel is aligned with the offset of the rightmost segment that belongs to the same syllable as that vowel.
b. ALIGN (V, ONSET, SYLL, ONSET): The onset of every vowel is aligned with the onset of the rightmost segment that belongs to the same syllable of that vowel.

She follows Gafos's gestural timing in that the onset of C_2 aligned with the c-center of C_1 will produce an intervening vowel. The constraints in (4) conserve the intervening vowel. However, she proposes a constraint that would prohibit the intervening vowel:

(5) $*\text{Gesture}_x$ in Gesture_y: A gesture of type x does not fully surround a gesture of type y (extending on both sides of it).

In her analysis of Hua vowel intrusion, she uses these constraints to illustrate when an IV is realized, as in candidade b. below, or a copy vowel, as in candidate a., which duplicates the nucleic vowel:

Tableau 3 Hua vowel intrusion (adapted from Hall, 2003, p. 24)

/kra/	*OBSTRUENT IN V	ALIGN (V, ONSET, SYLL, ONSET)	*C IN V
☞ a.  k r a [k^{a}ra]			*
b.  k r a [k^{ə}ra]		*!	

In this particular tableau, *OBSTRUENT IN V restricts completely surrounding the gesture of an obstruent consonant. Given that for both outputs, the obstruent is partially surrounded, no violation is incurred. The ALIGN constraint fatally violates candidate b. because the vowel onset is not aligned with the syllable onset, but rather with the onset of the C_2. The constraint, *C IN V, stipulates that a vowel articulation does not fully surround a consonant articulation, hence the violation in candidate a. due to the fully surrounding vowel gesture. *C IN V is, though, crucially lower ranked and thus candidate a. is deemed optimal. In sum, this section has discussed novel work in gesture-based OT. The following section considers how a gesture-based OT account has been utilized specifically for Spanish.

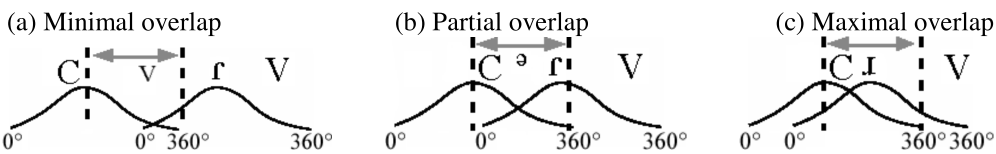
3. Gesture-based OT accounts of Spanish /Cɾ/ clusters[7]

Bradley and Schmeiser (2003) use two faithfulness constraints (Cho, 1998a,b) with the Phase Window (Byrd, 1996) as their point of reference in terms of temporal distance (i.e. intergestural phasing):

(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.

In their account, they use a Phase Window and, like Gafos (2002), use OT constraints to compare coarticulation, as in (c) in Figure 3, to IV insertion, as in (a) and (b) in the same figure. The constraint in 6a requires that the onset of the tap gesture must begin in the phase window for an IV to be perceptible. Take note that in the following figure, (c) incurs a violation of IDENT (TIMING) because the onset for the tap gesture begins *before* the phase window, whereas in (a) and (b) it does not, and thus no violation is incurred.

Figure 3 Three patterns of gestural overlap for consonant + tap clusters



The following tableau illustrates how candidates a. and b. are both optimal, when IDENT (TIMING) outranks OVERLAP:

Tableau 4 IDENT (TIMING) outranks OVERLAP for outputs with an IV

/CɾV/		IDENT (TIMING)	OVERLAP
☞ a.	CvɾV		*
☞ b.	C^{ə}ɾV		*
c.	CɹV	*!	

Finally, if we were to rerank the constraints so that OVERLAP outranked IDENT (TIMING), the optimal candidate would be c., given that this constraint favors maximal overlap, which entails no IV. Though this study is novel in that it considers outputs that differ in IV duration, the two constraints employed are not able to discern candidate a. from b. IDENT (TIMING) incurs violation for outputs that exhibit maximal overlap (where both consonants are perceptible, but with no intervening IV); however, IDENT (TIMING) is not capable of discerning shorter IV duration from longer IV duration, given that the onset for C_2 begins before the Phase Window.

Bradley's (2006a) analysis utilizes a modification of Gafos's (2002) ALIGN constraints in which vowel intrusion before a tap is specifically noted in the constraint, as in the following figure:

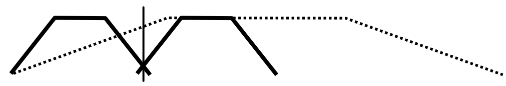
[7] I refer the reader to Colantoni and Steele (2007) for a very strong analysis of Spanish IVs in OT, though it is not based on a gestural approach and does not distinguish IVs in terms of their duration. I do not include it within the discussion as my focus is on gesture-based analyses in OT.

Figure 4 ALIGN constraint and coordination for /Cɾ/ cluster

a. ALIGN(C, OFFSET, /ɾ/, ONSET)

In /Cɾ/, align the offset of C with the onset of /ɾ/.

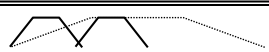
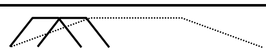
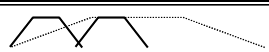
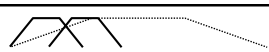
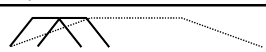
b. *Coordination:* C OFFSET = /ɾ/ ONSET



Percept: [C ə ɾ V]

Bradley offers alignment relationships for coarticulation, citing Gafos's (2002, pp. 283-287) notion that CENTER = ONSET can produce different acoustic results depending on the consonant gestures involved. The following tableau illustrates how the constraint ALIGN (C, CENTER, /ɾ/, ONSET) will favor coarticulation with heterorganic /pɾ/ but not for homorganic /tɾ/.

Tableau 5 Open transition in heterorganic /pɾ/ versus close transition in homorganic /t̪ɾ/ (adapted from Bradley, 2006a, p. 28)

	ALIGN (C, CENTER, /ɾ/, ONSET)	ALIGN (C, OFFSET, /ɾ/, ONSET)	ALIGN (C_1, RELEASE, C_2, TARGET)
a.  [pvɾV]	*!		*
b. ☞  [p^{ə}ɾV]		*	*
c.  [pɹ̥V]	*!	*	
d.  [t̪vɾV]	*!		*
e. ☞  [tɹ̥V]		*	*
f.  [tɹ̥V]	*!	*	

Notice in the above tableau that the alignment constraint, ALIGN (C, center, /ɾ/, onset) will result in different realizations for the /Cɾ/ clusters; that is, in 5b. an IV is present between the /p/ and /ɾ/, whereas the same alignment for /t/ and /ɾ/ in 5e. will not result in an IV, but rather in coarticulation.

In his discussion, he also notes *how* intrusive vowels can gain phonological full-vowel status over time; see Quilis (1981, pp. 341-342) for examples, such as the following:

(7) *trabilla* → *tarabilla* 'belt loop'
[t^{ə}ɾa.βí.ʝa] → [taɾa.βí.ʝa]

To gain phonological full-vowel status, as in the above example, Bradley (2006a) views the two gestures distancing themselves from each other (i.e. no intersection of gestures) to the point that a full vowel is realized phonologically (p. 26).

In sum, we currently have a gesture-based OT account for Spanish /Cɾ/ clusters that can capture vowel intrusion, coarticulation, and a diachronic, full-vowel realization. What is lacking in our analysis of Spanish /Cɾ/ clusters are constraints that distinguish vowel intrusion in terms of IV duration. In what follows, I offer alignment constraints to capture gradient vowel intrusion and offer a different perspective on the alignment relationships for the above categories.

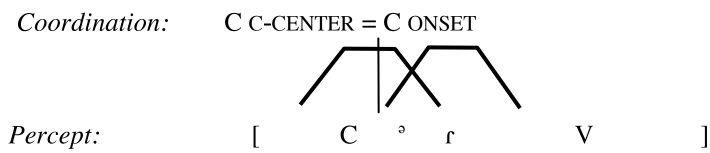
4. The current analysis

4.1. Vowel intrusion

To offer a full continuum of constraints relating to Spanish /Cɾ/ clusters (i.e. from coarticulation to full-vowel status), I argue that the duration of the intrusive vowel must be considered given recent findings on its variability. Recent studies (Colantoni & Steele, 2005, 2007; Kilpatrick, Kirby, & McGee, 2006; Ramírez, 2002, 2006; Schmeiser, 2006, 2007, 2009) differ in their findings in terms of which prosodic and segmental factors affect IV durational variability. However, they all agree that longer intrusive vowel duration is evidenced after voiced consonants (e.g. [gɾ]) than voiceless ones (e.g. [pɾ]). There currently does not exist however the mechanism through which we can evaluate these candidates. That is, we can evaluate coarticulation as compared to vowel intrusion, but we cannot evaluate two different outputs with statistically-significant differences in timing.

For the discussion, I utilize as a base Gafos's (2002) RECOV (ERABILITY) constraint which requires that in a CC ordering, complete overlap between the two consonants is prohibited. Differing from Bradley (2006a), who uses the alignment of ALIGN (C, offset, /ɾ/, onset) to represent an intrusive vowel, I refer to Gafos's (2002) CC-COORD = ALIGN (C, c-center, C, onset), using the term, RECOV (AVERAGE) to denote a cluster with an average IV mean duration, as in :

Figure 5 RECOV (AVERAGE) constraint for average IV mean duration in Spanish



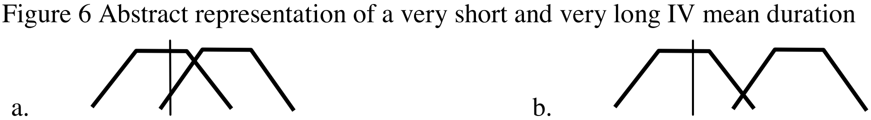
In the above example, we see an example of a canonical intrusive vowel. In order to capture gradient intrusive vowel duration, I abandon the notion that alignments can only be made from landmark to landmark (i.e. punctate). I put forth the constraints RECOV (MIN) and RECOV (MAX) to capture shorter and longer duration, respectively:

(8) a. notably short duration: RECOV (MIN): Two gestures must intersect *between* C^1's release and CC-INTERSECT.

b. notably long duration: RECOV (MAX): Two gestures must intersect *between* C^1's CC-INTERSECT and release offset.

The following illustrates these constraints in abstract terms:

Figure 6 Abstract representation of a very short and very long IV mean duration



In (a.) we view an intrusive vowel that is very short in duration. Each consonant of the cluster is minimally recovered. In (b), we view a much longer intrusive vowel and each member of the cluster is maximally recovered. In this procedure, I consider the acoustic duration of the IV to be an indirect measure of gestural overlap (Schmeiser, 2006; Bradley, 2006a).

In the specific case of C^1 voicing, which evidences longer mean IV duration, a gesture-based OT tableau for a [dᵊɾ] cluster would be the following:

Tableau 6 A gesture-based OT tableau for a [dᵊɾ] cluster

/dᵊɾ/	RECOV (MAX)	RECOV (AVERAGE)	RECOV (MIN)
a. dīɾ	*!	*	
b. dᵊɾ	*!		*
☞ c. dᵊᵊɾ		*	*

Note that ‘ī’ and ‘əə’ are arbitrarily chosen to represent very short and very long IV mean duration, respectively. In the case of longer IV duration, RECOV (MAX) crucially outranks the other RECOV constraints in that maximum recovery of the IV is maintained by less gestural overlap; that is, the two gestures dissimilate given that both the /d/ and the /ɾ/ are voiced (Colantoni & Steele, 2005, 2007; Schmeiser, 2006). In the case of voiceless C1, however, the consonant is less similar to the tap in terms of voicing and a very short duration is observed:

Tableau 7 A gesture-based OT tableau for a [tᵊɾ] cluster

/tᵊɾ/	RECOV (MIN)	RECOV (AVERAGE)	RECOV (MAX)
☞ a. tīɾ		*	*
b. tᵊɾ	*!		*
c. tᵊᵊɾ	*!	*	

In the above tableau, RECOV (MIN) preserves the shortest IV mean duration, given that the cluster, comprised of a voiceless obstruent and a voiced tap, is not in jeopardy of being recovered by the listener. An added benefit to this analysis is that we are now able to capture differences in terms of manner and place of articulation. More specifically, when there are three categories to consider, the constraints used are able to capture the different durational tendencies. In the case of place of articulation, Schmeiser (2006, 2007, 2009) observes a continuum along which intrusive vowel duration follows; that is, labials evidence the shortest IV duration, followed by coronals and finally velars.

4.2. No vowel intrusion

Blecua (2001) has illustrated with spectrographic analysis that lack of an intrusive vowel does not entail coarticulation. For this reason, I argue that the following alignment constraint is appropriate for /Cɾ/ clusters that evidence neither an intervening vocalic element nor coarticulation:

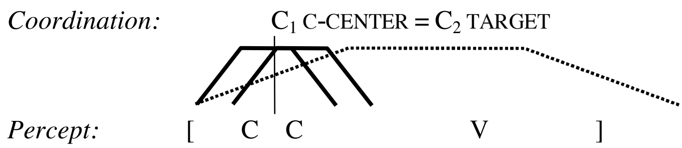
Figure 7 NV/NC: ALIGN(C, RELEASE, C, TARGET)

Coordination: C_1 RELEASE = C_2 TARGET

Percept: [C C V]

With specific regard to coarticulation, however, I argue that C^2's target must be aligned with C^1's C-center. In this representation, the onset of the second consonant commences before the release of the first consonant and overlaps along the gestural plateau (i.e. between the target and release), and is viewed in the following manner:

Figure 8 COART: ALIGN(C, C-CENTER, C, TARGET)



Of these two cases in which no IV is attested, NV/NC means that there is 'no vowel-like fragment' (i.e. NV) and there is 'no coarticulation' (i.e. NC). That is, though quite rare, a /Cɾ/ cluster in Spanish without an IV still evidences the tap; COART (ICULATION), however, differs in that it assumes the loss of the tap realization in favor of the approximant (see (c) in Figure 3 above).

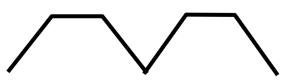
4.3. Diachronic full-vowel status

An advantage of this analysis is that we can illustrate how the intrusive vowel can become a full vowel over time. For the reader's convenience, I repeat the example orginally listed in (7):

(9) *trabilla* → *tarabilla* 'belt loop'
[t^{ə}ɾa.βí.ʝa] → [taɾa.βí.ʝa]

I argue that full vowel status is achieved when the two gestures no longer intersect. This notion is formalized in the following alignment constraint:

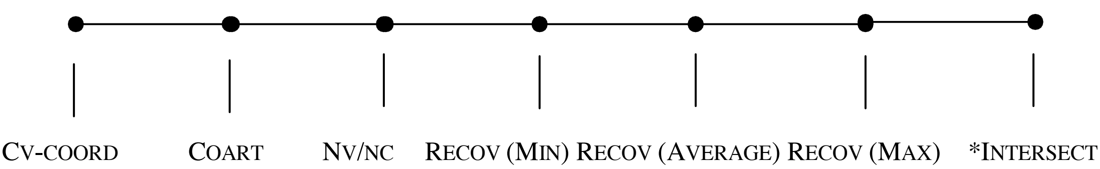
Figure 9 *INTERSECT: ALIGN (C, OFFSET, C, ONSET)



In this alignment, a full offset followed by a full onset in a Spanish /Cɾ/ cluster results in an IV that is perceived as a full vowel by the listener over time, as in (9). Though the gestures may spread further apart, they need not do so for the IV to gain phonological full vowel status over time.

In this section, I offered an analysis that enhances our usage of a gesture-based OT approach for Spanish intrusive vowels. By offering constraints based on actual duration of the intrusive vowel, we are now able to formalize the *full* continuum of realizations that occur in Spanish /Cɾ/ clusters:

Figure 10 A continuum of inter-gestural overlap for a C-C sequence



From left to right, CV-COORD is a constraint that aligns the two consonants together, thus resulting in elision of the second element. I did not discuss this constraint in the current study, given my emphasis on the intergestural phasing of the two gestures when both are present; in Schmeiser's (2006) study, he finds tap deletion to occur in less than one percent of Spanish /Cɾ/ clusters (p. 48). COART aligns the two gestures along the plateau, thus resulting in coarticulation (with no IV); NV/NC aligns release of C1 with the target of C2 such that there is no IV, however both the obstruent and tap are pronounced; the three RECOV constraints allow an analysis which considers a range of IV mean duration; finally, *INTERSECT aligns the offset with the following onset, causing the listener to reinterpret the IV as a full vowel over time.

5. Conclusions

Kingston (1992) correctly notes that "models are valued more for what they predict, particularly what they predict not to occur, than what they describe" (p. 60). If this is the case, what does this say about phonetically-based OT? Should future research attempt to create constraints that can *predict* low-level, gradient, non-contrastive elements in a language or should it restrict itself to only contrastive elements? If the speaker is altering IV mean duration due to matters of perceptibility, a model, though abstract, should seek to represent these alterations in the form of different constraints.

The current study has added to the growing body of work on this topic by adding constraints that allow us to formally discuss the full spectrum of realizations for Spanish /Cɾ/ clusters. Given that the IV is of such short duration (18 to 25 ms: Quilis, 1981), a gestural approach is a logical framework as it allows us to illustrate minute timing between two consonants. Linguists' attempts to formalize Spanish IVs within OT have been quite thorough; the current study adds to these attempts by adding constraints that will allow us to discuss all realizations of the Spanish /Cɾ/ cluster at a formal level.

Finally, I note one apparent weakness with the current analysis. The reader might have noticed in the previous section that the voiceless dental stop, /t/, is listed under Tableau 8 as producing the shortest IV mean duration. Within the hypothesis of obstruent voicing, this is true, however when we view a different category, for example place of articulation, /t/ is a coronal and thus falls within the category of average IV mean duration. Thus, we must ask, how that is a gesture can be both very short and average in mean duration. There are two explanations for this apparent inconsistency. First, the duration of the IV in Spanish is quite variable (Gili Gaya, 1921), and thus it is the case that in one word, the IV will be very short after a /t/ and yet average or longer (or non-existent) after a /t/ in another word (see Pierrehumbert (2002) for a theoretical framework that addresses word-level phonetics). Second, however, is that mean IV duration tends to pattern along a continuum based on manner of articulation, place of articulation and voicing (Schmeiser, 2006). Future work on Spanish IVs within a gesture-based OT approach ought to consider these segmental limitations on mean duration when offering new constraints to the analysis.

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