

Morphological derived-environment effects in gestural coordination: a case study of Norwegian clusters

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Abstract

This paper examines morphophonological alternations involving apicoalveolar tap-consonant clusters in Urban East Norwegian from the framework of gestural Optimality Theory. Articulatory Phonology provides an insightful explanation of patterns of vowel intrusion, coalescence, and rhotic deletion in terms of the temporal coordination of consonantal gestures, which interacts with both prosodic and morphological structure. An alignment-based account of derived-environment effects is proposed in which complete overlap in rhotic-consonant clusters is blocked within morphemes but not across morpheme or word boundaries. Alignment constraints on gestural coordination also play a role in phonologically conditioned allomorphy. The gestural analysis is contrasted with alternative Optimality-theoretic accounts. Furthermore, it is argued that models of the phonetics-phonology interface which view timing as a low-level detail of phonetic implementation incorrectly predict that input morphological structure should have no effect on gestural coordination. The patterning of rhotic-consonant clusters in Norwegian is consistent with a model that includes gestural representations and constraints directly in the phonological grammar, where underlying morphological structure is still visible. On the assumption that Universal Grammar lacks faithfulness constraints on input timing, the phonology is free to include non-contrastive phonetic detail such as intersegmental gestural coordination without the danger of overgenerating impossible contrasts.

Keywords: Urban East Norwegian; Morphological derived-environment effects; Phonologically conditioned allomorphy; Rhotics; Articulatory phonology; Optimality theory

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1. Introduction

In Articulatory Phonology (Browman and Goldstein 1989, 1990, et seq.), the grammar is assumed to operate on articulatory *gestures*, which are dynamically defined along both spatial and temporal dimensions and produce a constriction in the vocal tract. Bybee (2001) argues that a gestural analysis provides more insightful and coherent descriptions of most phonological phenomena than does an analysis based on features and segments. Many alternations that have previously been explained in discrete, phonological terms can be analyzed in terms of gestural overlap and/or reduction in casual speech. Recent work in Optimality Theory (henceforth, OT) has sought to formalize principles governing the temporal coordination of gestures (Benus et al. 2004, Bradley 2002, 2004, 2005, forthcoming, Davidson 2003, Gafos 2002, Hall 2003, Zsiga 2000). Such an approach raises interesting questions about the phonetics-phonology interface and the status of gestural representations and constraints in the synchronic grammar. Should gestures be phonological primitives as well as units of articulation, or is Articulatory Phonology better viewed as a model of phonetic implementation? If gestures are primitives, should they supplant segments or coexist with them? Should the temporal coordination of gestures be specified in underlying representation, or should it be determined by the grammar?

Bearing directly upon these questions, this paper presents a case study of morphological derived-environment effects in Norwegian clusters containing an apicoalveolar tap followed by a consonant. Eastern and northern Norwegian dialects are known for the so-called Retroflex Rule (Kristoffersen 2000, *inter alia*), whereby heteromorphemic rhotic-laminal clusters appearing within the intonational phrase are realized as single apical segments (e.g., /vor-tejn/ [vo:ɹæjn] *vårtegn* ‘spring sign’). Single apicals are also found within morphemes, historically derived from rhotic-laminal clusters, although there are some lexical exceptions (e.g., *sve[rɔ]* ‘sword’, *no[r.n]e* ~ *no[.ɹ]e* ‘norn’). Before noncoronal consonants, /r/ is maintained if the cluster appears within morphemes but is variably deleted across morphosyntactic boundaries (e.g., *la[r.m]* ‘noise’ but *glede[(r) m]ange* ‘pleases many’.) Available transcriptions in the literature on Norwegian do not give sufficient phonetic detail to indicate the type of articulatory transition between the two consonants in unreduced /rC/ clusters. In this paper, I present novel acoustic data from Urban East Norwegian speech showing that such clusters typically exhibit an intrusive vowel fragment between the tap and the following consonant (e.g., *ve[r^əd]ig* ‘stately’, *va[r^əm]* ‘warm’). As I will show, this pattern finds typological support in the phonetic behavior of /r/ in other languages, such as Spanish.

After establishing the phonetic detail of /rC/ clusters, I then show how their phonological patterning can be understood in Articulatory Phonology in terms of variation in the temporal coordination of the gestures associated with each consonant. Following the alignment-based OT approach to gestural coordination proposed by Gafos (2002), I develop an account of the derived-environment effects whereby complete overlap in /rC/ clusters is blocked within morphemes but not across morphosyntactic boundaries within the intonational phrase. In maximally coarticulated clusters, blending of articulatory trajectories derives single apicals from underlying rhotic-laminal sequences, while perceptual masking of /r/ leads to the deletion of this segment before noncoronals. Gestural coordination constraints are also shown to play a role in

determining the surface distribution of allomorphs of the negation marker /-ke/. Next, I contrast the gestural OT analysis of UEN clusters with alternative gestural and non-gestural OT accounts. Furthermore, I argue that models of the phonetics-phonology interface which view timing as a low-level detail of phonetic implementation incorrectly predict that input morphological structure should have no effect on gestural coordination. The patterning of Norwegian /rC/ clusters is consistent with a model that incorporates gestural representations and constraints directly into the phonological grammar, where underlying morphological structure is still visible. On the assumption that Universal Grammar lacks faithfulness constraints on input timing, the phonology is free to include non-contrastive phonetic detail such as intersegmental gestural coordination without the danger of overgenerating impossible contrasts (Hall 2003).

This paper is organized as follows. Section 2 lays out the basic facts regarding morphological derived-environment effects in Norwegian clusters. Section 3 presents acoustic data from Urban East Norwegian speech examining the phonetic detail of /r/. Section 4 motivates the role of gestural timing in cluster realization and presents the gestural coordination framework of Gafos (2002). Section 5 develops an analysis of derived-environment effects and negative clitic allomorphy. Section 6 compares the analysis with alternatives and discusses the status of gestural representations and constraints in the phonological grammar. Section 7 summarizes and concludes.

2. Morphological derived-environment effects in Norwegian clusters

The data discussed below represent the language variety defined as Urban East Norwegian speech (henceforth, UEN; Kristoffersen 2000: 43, 55, 88, 180, 183, 312, 316, 317, 337; see also Endresen 1974, Vanvik 1972, 1973). In UEN, the realization of /rC/ clusters depends on the place of articulation of the second consonant, the presence of an intervening morpheme or word boundary, and in the case of syntactically derived clusters, the strength of the intervening prosodic boundary. In morpheme-internal environments, the laminal (denti-)alveolar series /t, d, s, n, l/ constitutes the unmarked series of coronal consonants. Surface combinations of apicoalveolar /r/ followed by laminal /t, s, n, l/ do not usually occur within the morpheme and are instead realized phonetically as single corresponding apicals [t̚, s̚, n̚, l̚], as shown in (1).¹

(1)	[svat̚]	<i>svart</i>	‘black’
	[væʂ]	<i>vers</i>	‘verse’
	[ba:r̚]	<i>barn</i>	‘child’
	[ja:l̚]	<i>jarl</i>	‘earl’

¹ Apical consonants in UEN are traditionally described as retroflex, but there is some debate as to their exact place of articulation. Vanvik (1972: 137f.) describes them as alveolar, Endresen (1985: 76) suggests that they may vary between postalveolar and alveolar, and Endresen (1991: 64) claims that they are postalveolar. More recently, electropalatographic studies by Moen and Simonsen (1997, 1998) and Simonsen et al. (2000) show considerable variation in the contact area of derived apicals [t̚, d̚] as compared to laminals [t, d]. In the present study, I follow Kristoffersen (2000: 23) in using the retroflex IPA symbols to denote apical coronals without necessarily implying a postalveolar point of contact.

However, there are lexical exceptions in which /r/-laminal clusters are pronounced intact. Kristoffersen (2000: 89) observes that surface combinations of [rd] are common and that other /r/-laminal clusters may or may not be pronounced as single apicals in some words, as shown in (2). (Note: Periods denotes syllable boundaries in phonetic transcription.)

- (2)
- | | | |
|--------------------------------------|--|----------------------|
| <i>sve</i> [rd] | | ‘sword’ ² |
| <i>no</i> [r.n]e ~ <i>no</i> [.n]e | | ‘norn’ |
| <i>Zo</i> [rn] ~ <i>Zo</i> [n] | | (names) |
| <i>Stu</i> [r.l]a ~ <i>Stu</i> [.l]a | | |

Finally, the data in (3) show that /r/ surfaces intact before noncoronal consonants within morphemes. As seen in (3b), the rhotic is subject to regressive devoicing when the second consonant is voiceless. Kristoffersen (2000: 79) states that devoicing is non-neutralizing, since it applies to the sonorant /r/, and can be variable and gradient in its application.

- (3)
- | | | | |
|----|----------|--------------|----------|
| a. | [lɑrm] | <i>larm</i> | ‘noise’ |
| | [værb] | <i>verb</i> | ‘verb’ |
| | [sɔrg] | <i>sorg</i> | ‘sorrow’ |
| b. | [skɑɾp] | <i>skarp</i> | ‘sharp’ |
| | [mæɾ.kə] | <i>merke</i> | ‘mark’ |
| | [kɔɾk] | <i>kork</i> | ‘cork’ |

In derived environments, /r/-consonant sequences exhibit a different pattern, again depending on the homorganicity of the cluster. Across morphological and syntactic boundaries, sequences of /r/ followed by laminal /t, d, s, n, l/ undergo coalescence into single apicals [t̥, d̥, s̥, ŋ, l̥], as shown in (4).³

- (4)
- | | | | | |
|----|------------|-----------|----------------|----------------|
| a. | Inflection | | | |
| | /sʌr-t/ | [sʌ:t̥] | <i>surt</i> | ‘sour’ AGR |
| | /bɑr-n/ | [bɑ:n̥] | <i>baren</i> | ‘bar’ DEF-SG |
| b. | Derivation | | | |
| | /vɔr-li/ | [vɔ:.li̥] | <i>vårlig</i> | ‘spring-like’ |
| c. | Clitics | | | |
| | /brur-s/ | [bru:s̥] | <i>brors</i> | ‘brother’ POSS |
| | /bær-n/ | [bæ:n̥] | <i>bær han</i> | ‘carry him!’ |

² The exceptionality of /rd/ in non-derived environments is limited to central parts of East Norway. In other regions, single apical realizations of historical /rd/ are common, e.g., *sverd* [svæd̥] ‘sword’ (Kristoffersen 2000: 88, 36f). The transcription of *sve*[rd] in (2) reflects the pronunciation of central UEN.

³ Some eastern and northern Norwegian varieties also have an apical retroflex flap /ɾ/ which alternates with [r] and [l] under certain conditions and may also coalesce with following laminals. An exhaustive treatment of the flap is beyond the scope of this paper, but see Kristoffersen (2000: 88-96).

d. Compounds

/vɔr-tejn/	[vɔ:.tʰæjn]	<i>vårtegn</i>	‘spring sign’
/vɔr-dag/	[vɔ:.dɑ:g]	<i>vårdag</i>	‘spring day’
/vɔr-sul/	[vɔ:.sʊ:l]	<i>vårsol</i>	‘spring sun’
/vɔr-nat/	[vɔ:.nɑt]	<i>vårnatt</i>	‘spring night’
/vɔr-luft/	[vɔ:.lʰʊft]	<i>vårluft</i>	‘spring air’

e. Across words

[hæ.tʰɛl.lɛf.sɳ]	<i>herr Tellefsen</i>	‘Mr. Tellefsen’
[də.gle:də.ŋu:.un]	<i>Det gleder noen.</i>	‘It pleases some.’
[pe:.sɛ:.rɛn.stu:.lɔ:.və]	<i>Per ser en stor løve.</i>	‘Per sees a big lion.’

With respect to the word boundary contexts in (4e), there is evidence that the coalescence of /r/-laminal clusters is prosodically conditioned. Kristoffersen (2000: 317) observes that the process applies within intonation phrases, as in (5a), but not across them, as shown by the grammaticality contrast in (5b). Coalescence can therefore be characterized as a domain-span rule applying to derived clusters within the intonation phrase.⁴

- (5) a. (pe:.sɛ:.rɛn.stu:.lɔ:.və)_{IP}
Per ser en stor løve.
 ‘Per sees a big lion.’
- b. (pe:r)_{IP} (si:.ris.bru:r)_{IP} (sɛ:.rɛn.stu:.lɔ:.və)_{IP}
 ??(pe:)_{IP} (si:.ris.bru:)_{IP} (sɛ:.rɛn.stu:.lɔ:.və)_{IP}
Per, Siris bror, ser en stor løve.
 ‘Per, Siri’s brother, sees a big lion.’

Before noncoronal consonants, morpheme-final /r/ undergoes optional deletion in unstressed syllables. Kristoffersen (2000: 180) observes that prefix-final /r/ usually deletes in informal speech before stem-initial noncoronals, and similar patterns are reported for /r/-noncoronal clusters across word boundaries. Rhotic deletion in unstressed syllables is an optional process and seems to be conditioned by extralinguistic factors such as rate and register of speech, as well as the social background of the speaker.⁵ The following data illustrate deletion across prefix boundaries in (6) and across word boundaries in (7):

(6)

/er-klære/	[æ(r). ¹ klæ:.rə]	<i>erklære</i>	‘to declare’
/for-banne/	[fɔ(r). ¹ bɑn.nə]	<i>forbanne</i>	‘to curse’
/for-klare/	[fɔ(r). ¹ klɑ:.rə]	<i>forklare</i>	‘to explain’

⁴ Throughout this paper, I assume the following prosodic hierarchy: Syllable (σ) – Foot (Ft) – Prosodic Word (PW) – Phonological Phrase (PP) – Intonational Phrase (IP) – Utterance (U) (see Inkelas and Zec 1995 and the references cited therein).

⁵ Hanne Gram Simonsen (personal communication) points out that deletion is not possible in some UEN words containing the prefixes /er-/ and /for-/, which is suggestive of lexical exceptions. In addition, the final /r/ of the auxiliary verbs *blir* ‘becomes’, *er* ‘is’, *var* ‘was’ and *har* ‘has’ is exceptional. When pronounced without stress, these verbs exhibit deletion of /r/ before both vowels and noncoronals, while coalescence applies as expected before laminals (Kristoffersen 2000: 312). I abstract away from these complexities since a meticulous examination would lead us too far afield.

- | | | | |
|-----|--|--------------------------|--------------------|
| (7) | [hæ(r). ¹ kris.tɿ.sɿ] | <i>herr Kristensen</i> | ‘Mr. Kristensen’ |
| | [dø. ¹ gle:.dø(r). ¹ mɑŋ.ŋø] | <i>Det gleder mange.</i> | ‘It pleases many.’ |

Finally, the data in (8) and (9) show that morpheme-final /r/ fails to delete before vowels, resyllabifying instead to the following onset:

- | | | | | |
|-----|---------------------|-------------------------|-------------------------|--------------|
| (8) | /er-obre/ | [æ.ru:.brø] | <i>erobre</i> | ‘to conquer’ |
| | /for-akte/ | [fɔ:.rak.tø] | <i>forakte</i> | ‘to despise’ |
| (9) | [hæ.rɑn.nø.sɿ] | <i>herr Andersen</i> | ‘Mr. Andersen’ | |
| | [dø.gle:.dø.rɑl.lø] | <i>Det gleder alle.</i> | ‘It pleases everybody.’ | |

The obligatory coalescence of heteromorphemic /r/-laminal clusters and the optional deletion of /r/ before morpheme-initial noncoronals in UEN show that these processes apply in derived environments created by morphological or syntactic concatenation. The existence of lexical exceptions to coalescence and the lack of deletion within the morpheme demonstrate the failure of such processes to apply in non-derived environments. Therefore, these sandhi phenomena may be seen as an instance of morphological Non-Derived Environment Blocking in the sense of Kiparsky (1993). Kristoffersen (2000) argues that if coalescence of /r/-laminal clusters is blocked from applying within the morpheme, then non-derived apicals must be analyzed as the underlying vestiges of historical clusters: “lexical items which formerly contained such clusters are assumed [to] have underlying apicals in the synchronic grammar” (p. 88). Therefore, the adjective *svart* ‘black’ in (1) must be represented underlyingly as /svɑt/. In contrast, the intact [rd] sequence of monomorphemic *sverd* ‘sword’ in (2) reflects underlying /rd/, whereas the alternation between *Stu[r.l]a* and *Stu[.l]a* follows from the assumption of alternate underlying forms /sturlɑ/ and /stu|ɑ/.

There are advantages to assuming phonemic apicals in UEN. The opposite position, namely that all surface apicals are derived from underlying clusters, is problematic. As discussed above, not all /r/-laminal clusters exhibit coalescence, and some show variation. Furthermore, it is not possible to derive all surface apicals from underlying clusters, as shown by words such as [ʃe:] *skje* ‘spoon’. Treating the initial fricative as derived would require the underlying representation /rse/, which violates sonority sequencing (Kristoffersen 2000: 23).

The following section presents the results of an acoustic study designed to determine the type of intersegmental transition occurring in unreduced /rC/ clusters in UEN. The phonetic patterns documented here further solidify the empirical basis of the gestural OT analysis to be developed in Sections 4 and 5.

3. Acoustic study

To understand the phonetic basis of the phonological patterning of /rC/ clusters in UEN, some discussion of the articulatory and perceptual characteristics of the apicoalveolar tap is in order. Walsh (1997: 96) notes that cross-linguistically, taps tend to prefer intervocalic position and to avoid word-edges in order to maintain sonority and

enhance perceptibility. Others have observed that in many languages, a vowel-like fragment typically intervenes between the tap and an adjacent consonant. The vocalic element has formant structure similar, although not necessarily identical, to the nuclear vowel appearing on the opposite side of the tap constriction. Descriptions of vowel fragments with /r/ abound in the Spanish phonetic literature (Blecua 2001, Bradley 2004, forthcoming, Colantoni and Steele 2005, Gili Gaya 1921, Lenz 1892, Malmberg 1965, Navarro Tomás 1918, Quilis 1970, 1988, Ramírez 2002, 2006, and Schmeiser, in press). Researchers have given a variety of descriptive labels to this fragment, including *svarabhakti*, *transitional*, *parasitic*, *epenthetic*, etc. Adopting terminology from Hall's (2003) cross-linguistic study, I henceforth refer to this phenomenon as *vowel intrusion* and to the fragments themselves as *intrusive vowels*. (The reason for this terminological choice is to distinguish vowel intrusion from true epenthesis of a phonological vowel, a distinction that will be motivated in Section 6.4.)

Walsh's (1997: 141) characterization of the tap as "a quick coronal interruption of surrounding segments" provides a perceptual basis for understanding both the distributional preferences of /r/ and the pervasiveness of vowel intrusion in clusters. Phonetic studies of Spanish report a mean duration of approximately 20 ms for the tap constriction, which may or may not involve complete lingual closure (Quilis 1970, Blecua 2001). If indeed /r/ is one of the shortest segments cross-linguistically, then the preference for flanking vowels is motivated inasmuch as they provide an optimal acoustic backdrop against which the listener can easily perceive the extra-short constriction. The presence of an intrusive vowel in consonant clusters serves the same purpose by allowing the listener to correctly tease apart the extra-short constriction of /r/ from the constriction of the adjacent consonant.

The appearance of intrusive vowels with /r/ actually reflects a broader typology of vowel intrusion behavior involving sonorants. Hall's (2003) cross-linguistic survey shows that languages vary systematically in the classes of consonants triggering vowel intrusion. Typologically, vowel intrusion happens more with liquids than with other sonorants, and more with rhotics than laterals, except the alveolar trill. Consider the following implicational hierarchy:

- (10) Vowel intrusion triggers (Hall 2003: 28)
 obstruents, if ever > other approximants, nasals > [r] > [l] > [r], [ʁ] > gutturals
 Among nasals: m > n

In a given language, if a particular class of consonants in (10) triggers vowel intrusion in clusters, then so do all consonant classes further down the hierarchy (modulo phonotactic restrictions and accidental gaps). UEN is not included in Hall's survey of languages with vowel intrusion. However, much of her data comes from secondary sources and descriptive grammars, which frequently omit aspects of phonetic detail such as the type of transition occurring between two consonants. Kristoffersen (2000) does not transcribe any intrusive vowels in phonetic sequences of a tap followed by a consonant. According to his descriptions, however, the apicoalveolar tap /r/ is "articulated by the tip of the tongue rapidly tapping against the alveoli" (p. 24), and its duration is very short (p. 79, 21f). Based on the cross-linguistic behavior of /r/ discussed above, we should expect to find similar patterns of rhotic duration and vowel intrusion in unreduced /rC/ clusters in

UEN. I am unaware of any experimental work in the phonological and phonetic literature on Norwegian that addresses these issues.

In order to investigate the phonetic detail of /ɾ/ in UEN, I carried out an acoustic analysis of speech data taken from an online Norwegian dialect database, *Nordavinden og sola* ‘The north wind and the sun’.⁶ Table 1 lists the background information of four informants whose speech is representative of the geographical region in which UEN is spoken. Text recordings by the four speakers presented the following tokens for acoustic analysis: 22 taps in (word-medial or word-final) intervocalic position, 17 clusters of /ɾ/ before a noncoronal consonant within morphemes, and 13 instances of single apicals (within or across morphemes). Tokens were segmented manually on the basis of waveform, spectrogram, and intensity plot.

Table 1: Background information for four UEN speakers

Speaker (ID)	Location, Municipality, County	Age	Gender
A (22001)	Nordstrand, Oslo, Oslo	47	Male
B (23001)	Halden, Halden, Østfold	25	Female
C (23002)	Borre, Borre, Vestfold	30	Female
D (23003)	Foldvik/Brunlanes, Larvik, Vestfold	65	Male

Figure 1 shows a prototypical intervocalic voiced tap of 21 ms in duration appearing in word-final position. A minimal degree of formant structure is maintained from the surrounding vowels, suggesting that the tap constriction does not involve a complete lingual occlusion. This type of realization was found in more than 40% of intervocalic taps in the sample, while the remainder showed a more stop-like constriction with glottal tone present but formant structure absent.

⁶ The online database [available at <http://www.ling.hf.ntnu.no/nos/>] was created and is administered by Jørn Almberg and Kristian Skarbø of the Department of Linguistics, Norwegian University of Science and Technology, Trondheim. The database contains recordings of fifty-five native-speaker informants from different regions of Norway reading a translation of the text *The North Wind and the Sun*, commonly employed in illustrations of the IPA. Background information is provided for each informant, as well as downloadable sound files and broad phonetic transcriptions, in both X-SAMPA and IPA, of the speech recordings. All relevant tokens were extracted from the recordings and analyzed acoustically with version 2.6 of the Summer Institute of Linguistics Speech Analyzer. Descriptive statistics for the duration of rhotics and intrusive vowels were calculated using the Microsoft Excel statistical package.

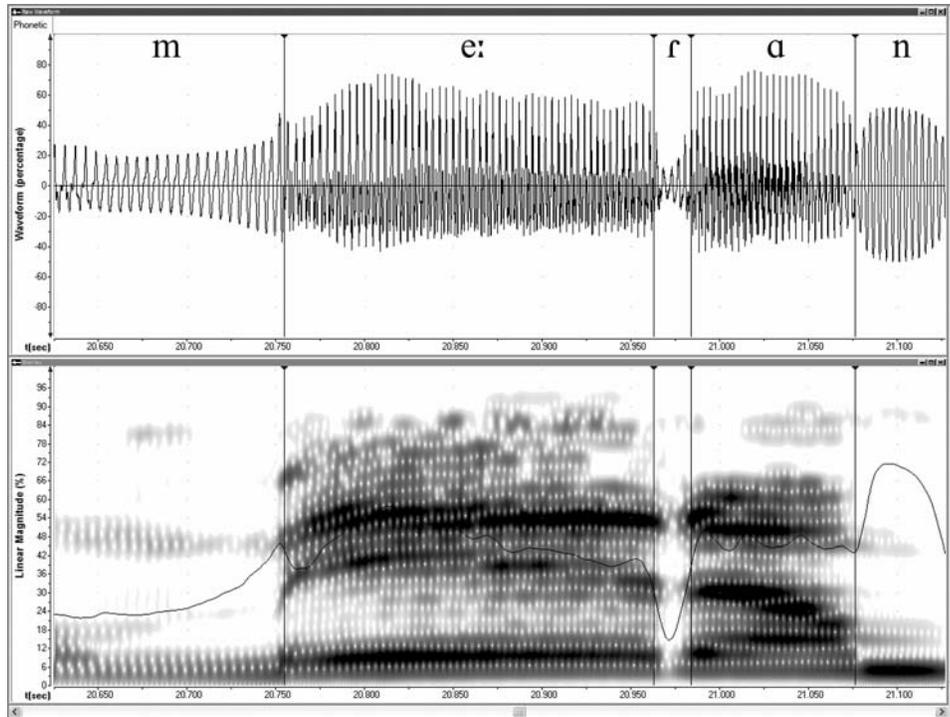


Figure 1: Intervocalic tap: *(desto) mer an (blåste)* ‘the more he blew’ (Speaker C)

Figure 2 illustrates the typical realization of morpheme-internal clusters of /r/ followed by a noncoronal consonant. The phonetic realization of /rm/ in this example shows a voiced tap constriction of 22 ms followed by an intrusive vowel of 38 ms, transcribed here as a superscript schwa [°]. A continuation of the nuclear vowel’s formant structure is clearly visible during the intrusive vowel. Of the 17 preconsonantal tokens in the sample, only one did not exhibit vowel intrusion. The rhotic in this case was a voiced approximant of 54 ms in duration, much longer than the prototypical extra-short tap. Of the 16 tokens that did show vowel intrusion, approximately 63% exhibited some degree of clear formant structure during the intrusive vowel. The remaining intrusive vowels displayed aperiodic noise instead of formants, and such noise was usually present at the 1400 Hz range and above. In some cases, noisy vowel intrusion correlated with gradient devoicing of both the tap and the intrusive vowel before voiceless noncoronal consonants, as seen in Figure 3. In other cases, noisy intrusive vowels appeared in the same segmental context even though regressive devoicing had not applied. In Figure 4, both the tap constriction and the intrusive vowel have glottal tone, and aperiodic noise is still present in the latter component. This suggests that noisy vowel intrusion is not dependent on regressive devoicing of /r/ before voiceless noncoronals.

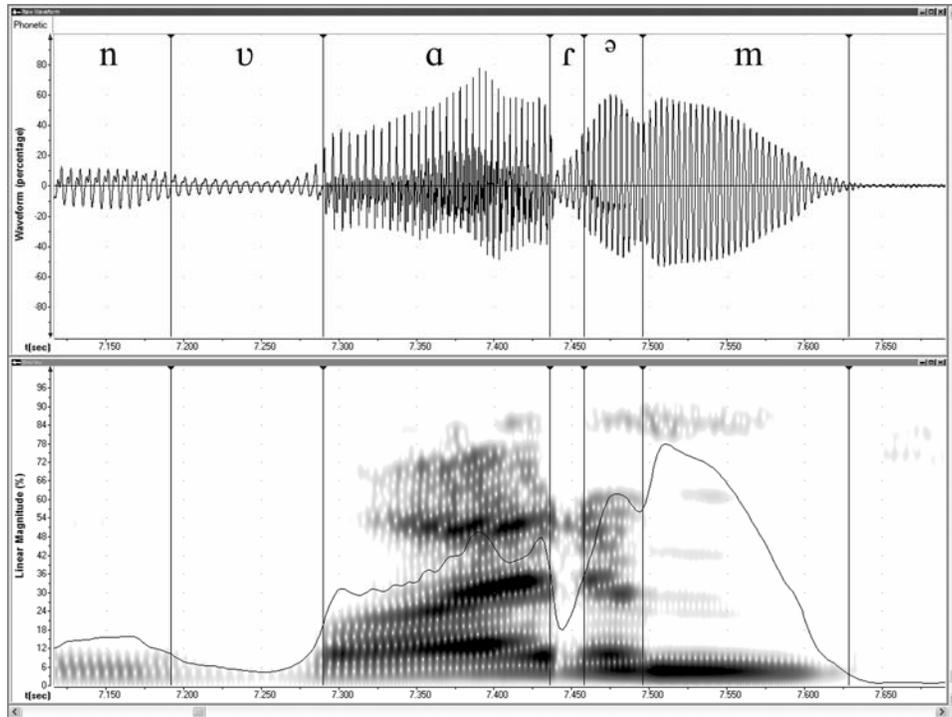


Figure 2: Voiced tap and clear intrusive vowel before a noncoronal consonant: (*e*)n varm (*frakk*) ‘a warm overcoat’ (Speaker C)

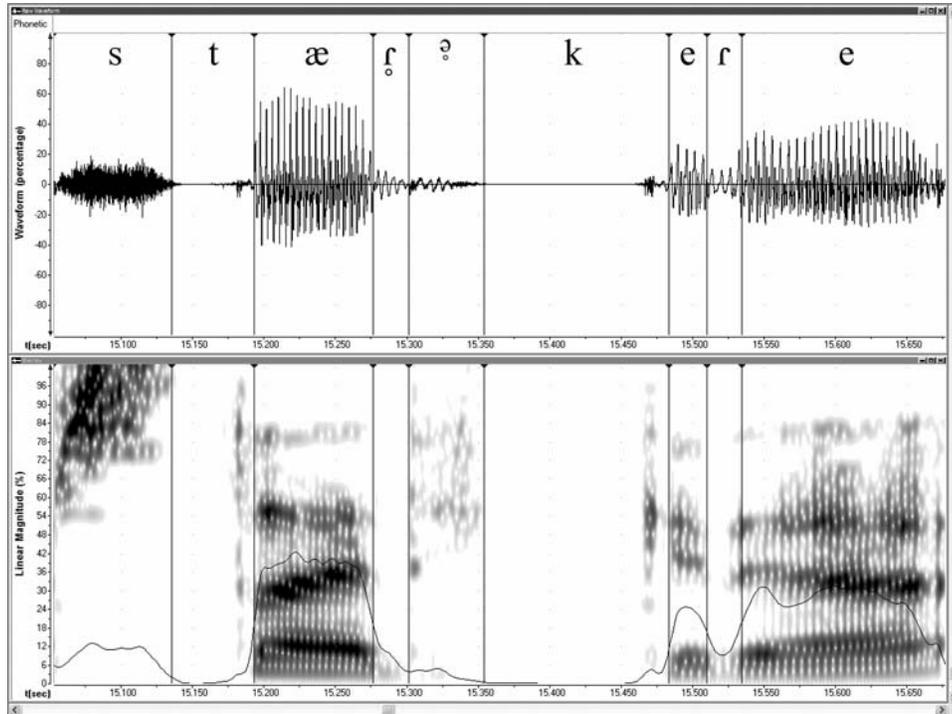


Figure 3: Partially devoiced tap and noisy intrusive vowel before a voiceless noncoronal: stærkere ‘stronger’ (Speaker C)

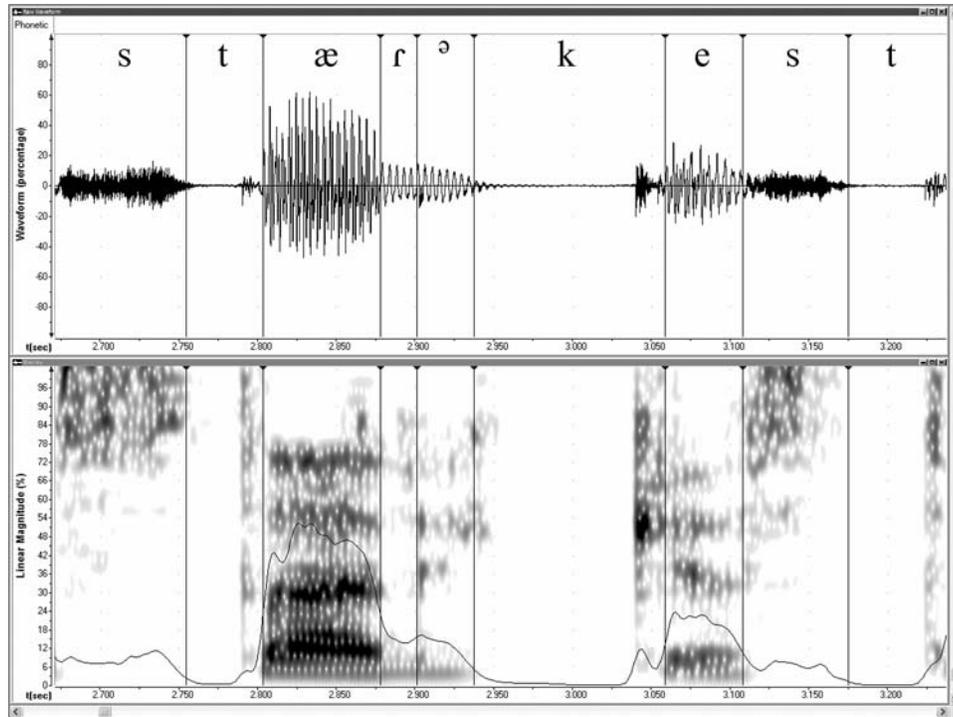


Figure 4: Voiced tap and noisy intrusive vowel before a voiceless noncoronal: *stærkest*(e) ‘strongest’ (Speaker B)

Of the 13 tokens of single apicals, none showed any trace of a preceding tap constriction or intrusive vowel. A comparison of the apical [ʃ] in Figure 5 with the laminal [s] in Figure 6 reveals a visible difference in the distribution of aperiodic energy during the fricative constriction. Also, the derived apical stop [d] in Figure 6 shows some lowering of F3 in the preceding vowel. At least in the context of morphosyntactic boundaries, these acoustic features presumably signal the derived status of apicals versus the unmarked status of corresponding laminals (see Hamann 2003 for a more complete discussion of acoustic cues in retroflexion processes). Finally, a comparison of the morpheme-internal /rk/ clusters in Figure 5 and Figure 6 shows further evidence of aperiodic noise during the intervening intrusive vowel, as well as the variable and gradient nature of regressive rhotic devoicing.

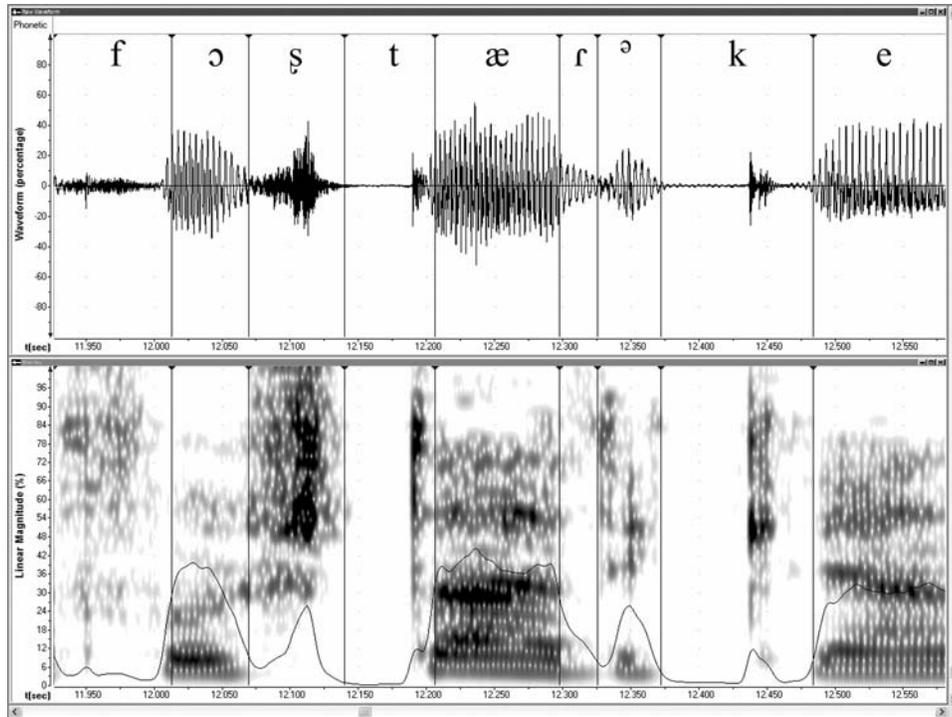


Figure 5: Derived apical fricative, voiced tap and noisy intrusive vowel before a voiceless noncoronal: *får stærke(re)* 'as stronger' (Speaker B)

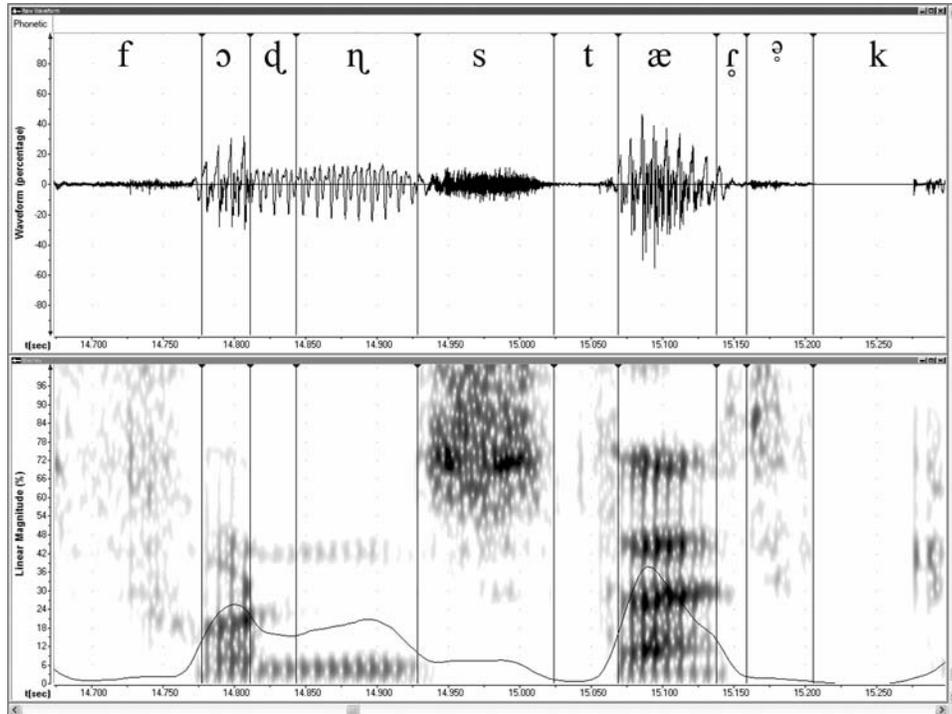


Figure 6: Derived apical stop, partially devoiced tap and noisy intrusive vowel before a voiceless noncoronal: *får dn stærk(este)* 'as the strongest' (Speaker A)

Table 2 provides descriptive statistics for the duration measurements of intervocalic taps and of taps and intrusive vowels appearing before tautomorphic noncoronal consonants. Recall from the discussion above that one of the 17 preconsonantal tokens contained a 54 ms approximant rhotic with no intrusive vowel. This particular token is not included in the duration measurements for preconsonantal taps, since the two rhotic types are not the same. Measurements of intrusive vowels include both those with clear formant structure and those with aperiodic noise in the upper spectra. The mean constriction duration for taps in the present sample is 25.27 ms between vowels and 24.44 ms before noncoronal consonants. Intrusive vowels appearing between the tap and the following consonant show an average duration of 37.56 ms, which is considerably longer than the tap constriction itself. The standard deviation of intrusive vowel duration is higher than that of the tap constriction in preconsonantal contexts (8.63 versus 2.31), suggesting greater variability in the intrusive vowels.

Table 2: Duration measurements (ms) for Speakers A-D (text reading task): intervocalic taps, taps and intrusive vowels before tautomorphic noncoronal consonants

	Intervocalic tap	Tap before tautomorphic noncoronal consonant	
		Tap constriction	Intrusive vowel
Mean	25.27	24.44	37.56
Min	19.00	21.00	18.00
Max	46.00	28.00	53.00
SD	5.77	2.31	8.63
n	22	16	16

In UEN, surface combinations of tautomorphic [rd] are exceptionally maintained in some words, and other /r/-laminal clusters may or may not be pronounced as single apicals. Neither of these cluster types happens to be represented in the text recordings that constitute the *Nordavinden og sola* database. Therefore, additional data were collected from a sentence reading task involving Speakers B and D, in which words with exceptional /rd/ clusters were embedded in the carrier phrase *Det var _____ jeg sa* ‘It was _____ I said’.⁷ These recordings provided a total of 38 tokens (19 per speaker). Only three tokens produced by Speaker D did not exhibit vowel intrusion. The rhotics in these cases were voiced approximants of 129 ms, 161 ms, and 172 ms in duration, much longer than the prototypical tap. The remaining 35 tokens all exhibited a voiced tap followed by an intrusive vowel with clear formant structure appearing before the voiced occlusion of [d]. Figure 7 shows a tap constriction of 23 ms and an intrusive vowel of 73 ms, while Figure 8 shows a tap constriction of 28 ms and an intrusive vowel of 65 ms.

⁷ I am grateful to Jørn Alberg of the Department of Linguistics, Norwegian University of Science and Technology, Trondheim, for devising the list of words containing exceptional /rd/ clusters and for conducting the recording sessions.

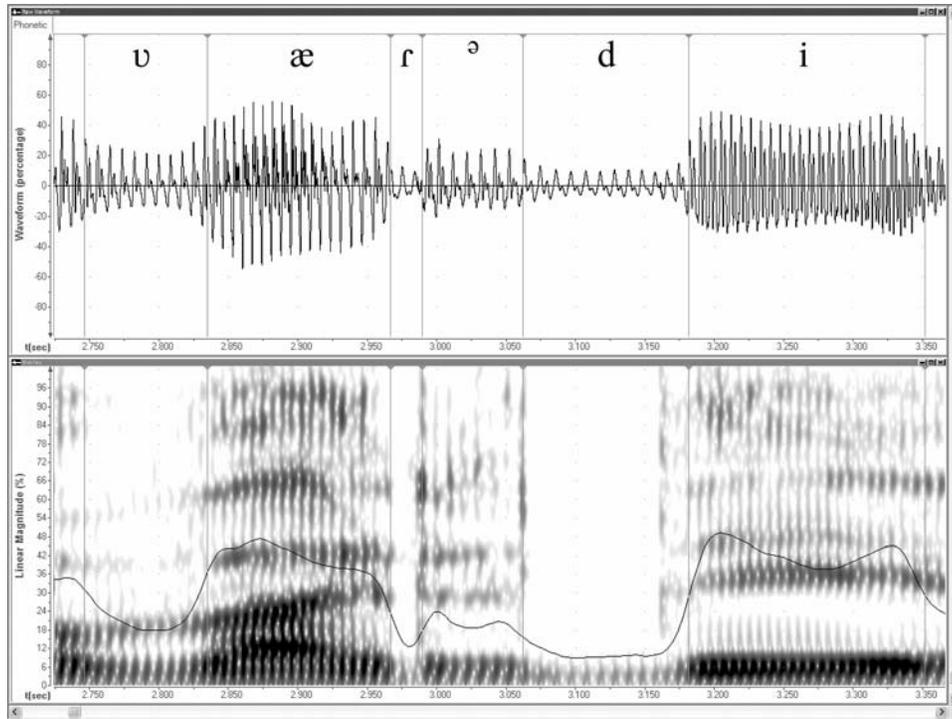


Figure 7: Voiced tap and clear intrusive vowel before /d/: *verdig* 'stately' (Speaker D)

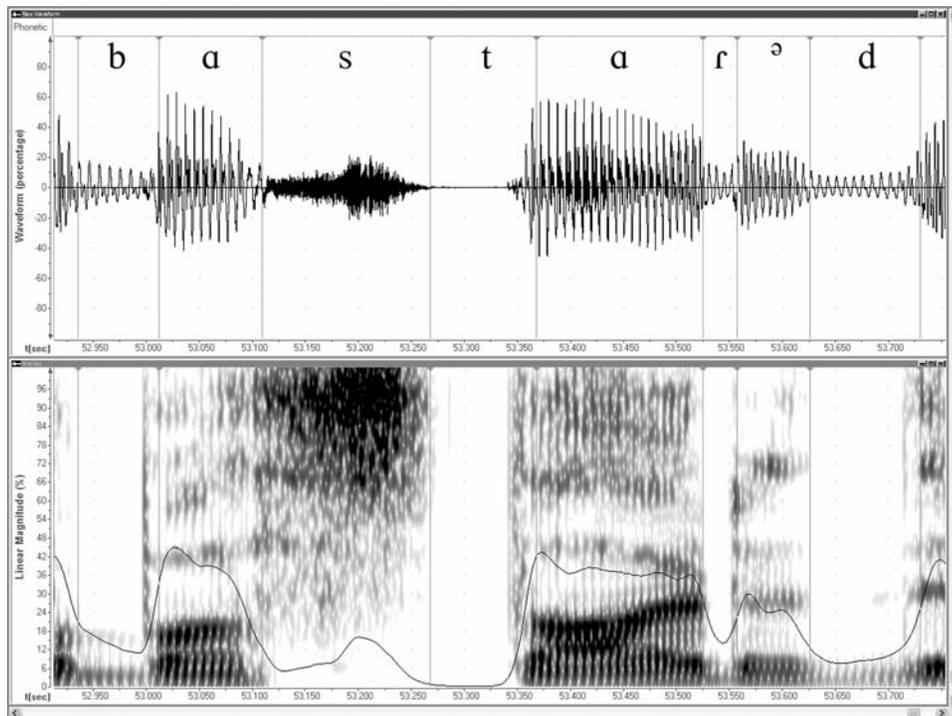


Figure 8: Voiced tap and clear intrusive vowel before /d/: *bastard* 'hybrid' (Speaker D)

Table 3 provides duration measurements for taps and intrusive vowels in exceptional /rd/ clusters based on the carrier phrase data from Speakers B and D. The mean

constriction duration for taps is 31.03 ms versus 72.51 ms for intrusive vowels. As was shown to be the case for tautomorphemic /r/-noncoronal clusters in Table 2, the standard deviation of intrusive vowel duration is higher than that of the tap constriction in /rd/ clusters (17.86 versus 9.76). Therefore, intrusive vowels tend to show greater durational variability than taps in both cluster types.

Table 3: Duration measurements (ms) for Speakers B and D (carrier phrase task): taps and intrusive vowels before tautomorphemic /d/

	Exceptional tautomorphemic /rd/	
	Tap constriction	Intrusive vowel
Mean	31.03	72.51
Min	21.00	43.00
Max	57.00	120.00
SD	9.76	17.86
n	35	35

Obviously, caution must be taken in interpreting duration measurements based on a relatively limited sample. Future studies should employ a more systematic experimental design in order to control for variables such as segmental context, stress, and word length. If these preliminary data can be taken as representative of UEN speech, then the findings reported here document the existence of intrusive vowels in morpheme-internal clusters containing /r/ and suggest trends that are in line with durational patterns found in other languages. In order to indicate vowel intrusion in UEN, I henceforth assume that phonetic sequences of [rC] are more appropriately transcribed as [r^ɪC] in narrow transcription, which abstracts away from the presence of formant structure or aperiodic noise during the intrusive vowel.⁸

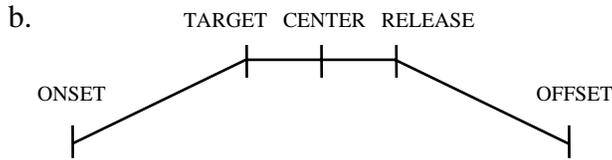
4. Constraints on gestural coordination

Articulatory Phonology provides a phonetically motivated account of intrusive vowels in terms of the temporal coordination of adjacent consonant gestures. Steriade (1990) is the first to demonstrate the utility of gestural representations in accounting for vowel intrusion phenomena in Winnebago, Late Latin, and Sardinian. She argues that vowel intrusion is the result of an overlapping vowel gesture being heard during the open transition between two consonants. In the remainder of this paper, I will argue that systematic variation in a single phonetic parameter—intersegmental gestural coordination—provides an insightful account of not only vowel intrusion but also coalescence and deletion in Norwegian /rC/ clusters. In order to formalize the competing pressures that determine gestural coordination, I assume the framework developed by

⁸ Also corroborated in the UEN data sample is the existence of vowel intrusion in complex onsets containing /r/ in second position, which is characteristic of other languages such as Spanish. As in morpheme-internal preconsonantal contexts, variable and gradient devoicing applies in the context of a preceding voiceless consonant, e.g., *frakk* [f^hrak:] ‘overcoat’ versus *andre* [and^hrə] ‘other’. See Kristoffersen (2000: 75-76) for a discussion of progressive devoicing.

Gafos (2002), which incorporates the gestural representations of Articulatory Phonology within a constraint-based OT grammar (Prince and Smolensky 1993, McCarthy and Prince 1993). Gafos proposes that gestural coordination is determined by alignment constraints of the form (11a), which make reference to temporal landmarks during the activation period of a gesture, shown in (11b):

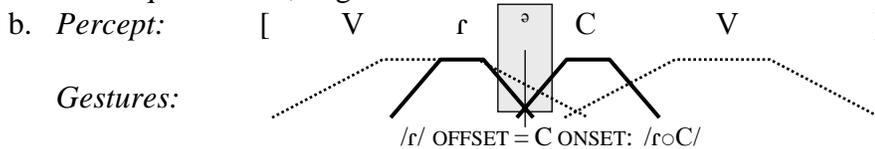
- (11) a. $\text{ALIGN}(G_1, \text{LANDMARK}_1, G_2, \text{LANDMARK}_2)$
Align landmark₁ of gesture₁ with landmark₂ of gesture₂.



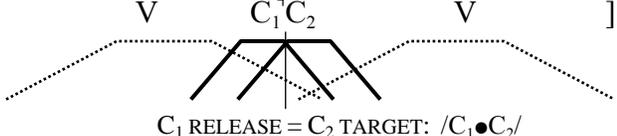
Researchers working within this framework have posited coordination relations for CV, VC, CC, and VV sequences (Benus et al. 2004, Bradley 2005, forthcoming, Davidson 2003, Gafos 2002, Hall 2003). In Bradley (2005, forthcoming), vowel intrusion with /r/ in Spanish dialects is analyzed in terms of interacting CC coordination constraints, which require either open or close articulatory transition depending on the consonants involved.

The constraint in (12a) specifies an $\text{OFFSET} = \text{ONSET}$ coordination relation in /rC/ sequences. This coordination ensures an open articulatory transition between the rhotic and the following consonant, which I represent symbolically as /r \circ C/. Following Browman and Goldstein (1990) and Steriade (1990), I assume that within a syllable, consonantal articulations are superimposed on the tongue body gesture of the vowel. Open transition allows the final portion of the tautosyllabic vowel gesture to be perceived on the opposite side of the tap constriction as an intrusive vowel, indicated by the shaded box in (12b). It is important to note that the intrusive vowel is not part of the formal representation of segments. Rather, it is the acoustic consequence of the open articulatory transition between adjacent oral constriction gestures. (The distinction between gestures and segments is further discussed in Section 6.4.)

- (12) a. $\text{ALIGN}(/r/, \text{OFFSET}, C, \text{ONSET})$ — rC-COORD
In a sequence /rC/, align the offset of /r/ with the onset of C.



The constraint favoring open transition competes with other constraints on CC coordination. The alignment constraint in (13a) favors a $\text{RELEASE} = \text{TARGET}$ coordination relation in which the initial consonant of a /CC/ cluster is unreleased. Close transition, denoted by /C₁●C₂/ in (13b), prevents vowel intrusion. Unlike rC-COORD, which targets a cluster that has an apicoalveolar tap as its initial member, CC-COORD is a more general constraint applying to any cluster of consonants.

- (13) a. ALIGN(C_1 , RELEASE, C_2 , TARGET) — CC-COORD
 In a sequence / C_1C_2 /, align the release of C_1 with the target of C_2 .
- b. *Percept:* [V C₁C₂ V]
- Gestures:* 
- C_1 RELEASE = C_2 TARGET: / $C_1 \bullet C_2$ /

As Hall (2003: 18) argues, conflicting gestural alignment constraints such as (12a) and (13a) have a functional grounding in terms of perceptibility and effort minimization, respectively. The ranking of rC-COORD » CC-COORD guarantees that the optimal gestural coordination of /rC/ clusters involves open transition and concomitant vowel intrusion, thereby ensuring clearer perceptual cues for the adjacent consonants (e.g., consonant release and formant transitions). In clusters that do not contain /r/ as their first member, the more general CC-COORD favors a greater degree of overlap and a relatively faster, more efficient overall articulation. In the framework developed by Gafos (2002), one way to capture the typology of vowel intrusion triggers in (10) is to posit a universal ranking of constraints like rC-COORD, each relativized to a different consonant class. The language-specific ranking of CC-COORD with respect to this hierarchy would determine which consonants require open versus close transition in a particular language.⁹

How should coalescence and deletion in derived /rC/ clusters be accounted for? Formal analyses of sandhi processes typically invoke spreading and/or delinking operations, the result of which is a categorical change in the associations among autosegments. A conventional view of segment deletion would involve the removal of a timing slot, resulting in the categorical absence of the segment from the phonological surface representation. For example, Kristoffersen's (2000: 96-100) analysis of the Retroflex Rule posits two separate operations of autosegmental spreading and delinking in the lexical phonology. However, Browman and Goldstein (1990) argue that in many cases of optional consonant deletion, an account in terms of gestural overlap is preferable. As an example, they cite the deletion of English final /t/ in the casual speech forms [mʌsbi] and [pəfɛkmɛm.i] versus the canonical forms [mʌst#bi] *must be* and [pəfɛkt#mɛm.i] *perfect memory*, respectively. Articulatory measurements via X-ray pellet trajectories indicate that the tongue tip gesture for /t/ is still present in the casual speech form, although its acoustic effects are hidden due to overlap with the following bilabial closure. The deletion of /t/ is only apparent, since articulatory traces of the consonant remain.

According to Browman and Goldstein (1990), gestural overlap will yield different results depending on whether the two gestures are on the same or different articulatory tiers. The prediction is that overlap of gestures engaging the same active articulator (i.e., gestures on the same articulatory tier) will produce a *blending* of gestural characteristics, which “shows itself in spatial changes in one or both of the overlapping gestures” (p. 362). The coalescence of /r/-laminal clusters into single apicals plausibly results from the blending of overlapping adjacent tongue tip gestures. Such an explanation is motivated

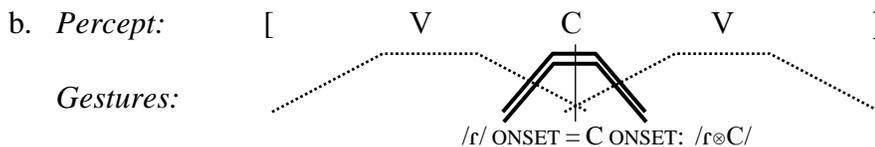
⁹ This proposal diverges slightly from that of Hall (2003: 28-30), who posits a hierarchy of *C IN V constraints penalizing the complete overlap of different types of consonant gestures by a tautosyllabic vowel gesture.

by phonetic studies of Norwegian coronal stops (Moen and Simonsen 1997, 1998, Simonsen et al. 2000), in which electropalatographic measurements show considerable variation in the contact area of derived apicals [t, d] in comparison with corresponding laminals [t, d]. While the resultant tongue tip configuration retains the apicality of /r/, variation in contact area reflects a gradient compromise between the lexically specified constriction locations of the adjacent gestures.¹⁰ Dutch provides further corroborating evidence for the gestural blending account. In non-emphatic speech, coronal plosives are often realized as apico-postalveolar after /r/, which is itself subject to elision. Plug (2002) proposes an analysis in which blending stems from greater temporal overlap between the gestures for /r/ and the following coronal.

In contrast, overlap between two gestures *across tiers* will not affect the trajectories of either gesture since different articulators can behave independently of one another. A possible consequence of cross-tier overlap is that one gesture may be perceptually hidden by another, resulting in cases of apparent deletion as in *must be* and *perfect memory*, discussed above. It is conceivable that the deletion of /r/ before noncoronals in UEN involves maximal overlap, in which the second consonant perceptually masks the extra-short tap constriction. This explanation receives some motivation from the fact that deletion in derived environments tends to occur in informal speech (Kristoffersen 2000: 180). In the Articulatory Phonology model, casual speech processes are seen as “consequences of variation in the overlap and magnitude of gestures” (Browman and Goldstein 1990: 371). Since gestures tend to overlap more in casual speech, the greater frequency of deletion in informal styles lends support to an account in terms of the overlap-induced perceptual masking of /r/ before noncoronals.

The phrasal data in (5) show that coalescence in UEN applies within but not across intonation phrase boundaries. To capture this difference, I propose the constraint in (14a), which requires a CENTER = CENTER coordination relation in /rC/ clusters that appear within the same intonation phrase. When ranked above rC-COORD and CC-COORD, this constraint requires complete overlap in such clusters, denoted by /r⊗C/ in (14b). The resulting percept depends on whether the two gestures are on the same or different articulatory tiers, as explained above. Coalescence involves blending of adjacent tongue tip gestures into a single apical constriction. Deletion involves overlap across tiers with the apicoalveolar /r/ gesture still present but perceptually hidden.

- (14) a. ALIGN(/r/, CENTER, C, CENTER) IN IP — rC-OVERLAP_{IP}
 In a sequence /rC/ within the intonation phrase, align the center of /r/ with the center of C.



¹⁰ Gjert Kristoffersen (personal communication) suggests that if there is blending in /r/-laminal fusions, then we might expect more laminal-like articulations as compared to pure apical taps. In other words, why is the apicality of /r/ retained as opposed to the laminality of the following coronal? I propose that the outcome of gestural blending is grammatically controlled, as determined by faithfulness on input apicality (see Section 5.1).

Since the tautomorphemic /rC/ clusters in (2) and (3) are necessarily internal to the intonation phrase, they fall within the purview of rC-OVERLAP_{IP}. However, coalescence and deletion are blocked in non-derived environments. To account for the blocking of complete overlap in non-derived clusters, I propose the constraint in (15), which makes reference to input morphological structure. The intuition expressed here is that the surface forms of morphemes should be similar to the underlying forms unless there is evidence to the contrary. Morphologically sensitive recoverability is violated by configurations such as (14b), in which maximal overlap of tautomorphemic consonant gestures results in the perceived deletion of one of the consonants.

- (15) RECOVERABILITY IN μ — RECOV _{μ} (cf. Gafos 2002: 318)
In a tautomorphemic sequence C₁C₂, complete overlap between the associated gestures in the output is prohibited.

Derived-environment effects are observed in the coordination of /rC/ clusters because in UEN, the recoverability constraint ranks higher than rC-OVERLAP_{IP}, prohibiting complete overlap in non-derived environments. For languages in which recoverability is outranked by overlap constraints, the prediction is that overlap-induced effects would be observed irrespective of morphological structure, applying both within and across morpheme boundaries. (See Section 6.4 for further discussion of this prediction.)

The interaction of constraints proposed in (14) and (15) is consistent with Browman and Goldstein's account of optional deletion in external sandhi, whereby the final consonant gesture is still present but perceptually hidden. Such an explanation is based on the hypothesis in Articulatory Phonology that casual speech alternations involve changes in the magnitude and/or temporal coordination of gestures but that no gestures are literally removed from the articulatory plan. To be sure, further articulatory investigation is required to determine the extent to which Norwegian morpheme-final /r/ patterns like English word-final /t/. In any event, the gestural account is still compatible with the more conventional view of deletion as the delinking of a segment. Assuming a usage-based model of phonology, Bybee (2001: 76) argues that “[p]erceived deletion of this type can lead to actual deletion. If tokens with perceived deletion are frequent, a reorganization of exemplars will occur, with the eventual effect of the loss of the final [consonant].”¹¹

¹¹ Gjert Kristoffersen (personal communication) questions how a coronal articulation can be perceptually masked by a dorsal, as in heteromorphemic /rk/. If the tongue tip and tongue body gestures are executed simultaneously, then the perceived sound would logically be a coronal-dorsal since the constriction of /k/ lies behind that of /r/ in the vocal tract. Even if the structure in (14b) represents a plausible first stage in a change, it is marked and would easily lead to the deletion process hypothesized by Bybee (2001). An alternative interpretation is that the extra-short constriction of /r/—not depicted in (14b) but nonetheless documented acoustically in Section 3—would be eclipsed by the longer constriction of the following dorsal. Given the differences in duration, the perception of a complex coronal-dorsal segment, as opposed to a simplex dorsal, does not necessarily follow from the maximal overlap configuration.

5. A gestural OT analysis of derived-environment effects

In this section, I analyze the phonological patterning of /rC/ clusters in UEN. Section 5.1 focuses on morpheme-internal cluster realization and derived-environment effects. Section 5.2 presents some additional data involving the negative clitic /-ke/ and shows how the gestural OT analysis of derived-environment effects also accounts for allomorph selection.

5.1. Vowel intrusion, coalescence, and deletion

The evaluation of morpheme-internal /rb/, as in *ve[r^əb]* ‘verb’, is shown in (16). In the tableau, a distinction is made between articulatory and acoustic representations in the output. Following the notational conventions of Gafos (2002), clusters appearing between slash brackets ‘/.../’ denote sequences of consonant gestures and their coordination relations, while corresponding acoustic forms are given in square brackets ‘[...]’. Candidate (c), with complete overlap, violates recoverability and is eliminated. The remaining candidates tie on rC-OVERLAP_{IP}, and lower-ranked rC-COORD selects the unmarked coordination in (a), with vowel intrusion. Deletion is blocked in non-derived environments because high-ranking RECOV_μ prohibits complete overlap in /rC/ clusters in the output when both consonants belong to the same morpheme in the input.

(16) Prosodic structure: (... v^ərb ...) _{IP}

/rb/	RECOV _μ	rC-OVERLAP _{IP}	rC-COORD	CC-COORD
☞ a. /r ^ə b/ [r ^ə b]		*		*
b. /r [•] b/ [r [•] b]		*	*!	
c. /r [⊗] b/ [b]	*!		*	*

Now, deletion of /r/ before a noncoronal is optional across morpheme and word boundaries, whereas coalescence of /r/ and a following laminal is obligatory. An account of this difference requires the MAX(FEATURE) constraint in (17):

(17) MAX(APICAL)

An [APICAL] specification in the input must be recovered in the output.

Crucially, MAX(APICAL) enforces preservation of the apicality of input /r/, even when the rhotic itself is not present in the auditory representation. It is insufficient to invoke a constraint demanding identical apical specification of segmental correspondents, such as IDENT(APICAL) (cf. McCarthy and Prince 1995). If input /r/ is deleted, then it has no correspondent in the output, and IDENT(APICAL) would be vacuously satisfied. Rather, identity must be evaluated directly between input and output features and not segments.

Integrating faithfulness into the analysis developed thus far, (18) illustrates coalescence in derived /r/-laminal clusters, as in /vor-dag/ [vo:ɖɑ:g] *vårdag* ‘spring day’. Since /r/ and the following consonant belong to different morphemes in the input, RECOV_μ is irrelevant. Lower-ranked rC-OVERLAP_{IP} eliminates candidates (a,b) because

the phrase-internal clusters are not completely overlapped. The clusters of the remaining two candidates are completely overlapped, resulting in the perceptual loss of the extra-short tap. The two candidates differ with respect to the percept that results from gestural blending. The laminal stop in candidate (c) fails to maintain the input [APICAL] specification of /r/ and is eliminated by its fatal violation of MAX(APICAL). Complete overlap and blending of the /r/ and laminal gestures produce the single apical in candidate (d). On the other hand, exceptional /r/-laminal clusters in morpheme-internal contexts, as in *sve*[r³d] ‘sword’, are realized intact due to high-ranking RECOV_μ (see (16), where this constraint guarantees the intact realization of input /rb/).

(18) Prosodic structure: (... vɔ:rda:g ...)IP

/r-d/	RECOV _μ	rC- OVERLAP _{IP}	MAX (APICAL)	rC- COORD	CC- COORD
a. /r ^o d/ [r ^o d]		*!			*
b. /r [•] d/ [r [•] d]		*!		*	
c. /r [⊗] d/ [d]			*!	*	*
☞ d. /r [⊗] d/ [d]				*	*

As shown in (19), coalescence does not occur if an intonation phrase boundary intervenes between /r/ and the laminal, as in *Per, Siris bror* ‘Per, Siri’s brother’. Since /r/ and the following consonant belong to different prosodic domains in the output, rC-OVERLAP_{IP} is now irrelevant. Candidate (c) violates MAX(APICAL), and (a) is chosen from the remaining candidates because it best satisfies the lower-ranked constraints. In this analysis, the unmarked coordination for /rC/ emerges in derived environments where the overlap constraint is irrelevant, just as it does in non-derived environments where overlap is rendered inactive by higher-ranking RECOV_μ (compare (19a) and (16a)). To be sure, further experimental investigation is necessary to determine the frequency of vowel intrusion across the intonation phrase boundary, where a pause is possible. The strength of this boundary may prevent adjacent consonants from establishing any temporal relationship with each other across words.

(19) Prosodic structure: (pe:r)IP (si:rɪs bru:r)IP

/r#s/	RECOV _μ	rC- OVERLAP _{IP}	MAX (APICAL)	rC- COORD	CC- COORD
☞ a. /r ^o s/ [r ^o s]					*
b. /r [•] s/ [r [•] s]				*!	
c. /r [⊗] s/ [s]			*!	*	*
d. /r [⊗] s/ [ʃ]				*!	*

Turning now to rhotic deletion before noncoronals in derived environments, I propose to account for the optionality of this process in terms of variable constraint ranking

(Reynolds 1994, Kang 1997). Variability between surface forms of *forbanne* ‘to curse’ is illustrated in (20). When rC-OVERLAP_{IP} dominates MAX(APICAL) in informal speech, complete overlap causes /r/ to be perceptually masked by the following noncoronal, as in candidate (20c). Under the opposite ranking, preservation of input /r/ becomes more important, and candidate (20d) emerges as the unmarked coordination. Positing a variable ranking between these constraints does not affect the analysis of derived-environment coalescence. As shown above, candidate (18d) violates neither of the two constraints and is optimal regardless of their relative ranking.

(20) Prosodic structure: (... fɔrbanne ...)_{IP}

/r-b/	RECOV _μ	rC- OVERLAP _{IP}	MAX (APICAL)	rC- COORD	CC- COORD
a. /r ^o b/ [r ^o b]		*!			*
b. /r [•] b/ [r [•] b]		*!		*	
☞ c. /r [⊗] b/ [b]			*	*	*

/r-b/	RECOV _μ	MAX (APICAL)	rC- OVERLAP _{IP}	rC- COORD	CC- COORD
☞ d. /r ^o b/ [r ^o b]			*		*
e. /r [•] b/ [r [•] b]			*	*!	
f. /r [⊗] b/ [b]		*!		*	*

The difference between obligatory coalescence and optional deletion is ultimately related to the difference between gestural overlap within tiers versus across tiers. Coalescence is obligatory in derived environments because when the morphologically sensitive recoverability constraint is irrelevant, gestural blending satisfies the preference for complete overlap while simultaneously preserving the [APICAL] specification of input /r/ in the derived apical. In contrast, such an optimal solution is not available when /r/ precedes a noncoronal consonant because overlap between gestures on different tiers does not result in blending. Rather, overlap between the bilabial gesture of /b/ and the tongue tip gesture of extra-short /r/ can lead only to the perceived deletion of the latter and loss of the input [APICAL] specification.¹² The optionality of deletion before noncoronals is accounted for by a variable ranking between faithfulness and overlap constraints.

¹² This account resonates well with Honorof’s (1999: 68) diachronic explanation of the weakening of the tongue tip gesture for prenasal /n/ in Castilian Spanish: “Weakened [nasal] coronals in the context of noncoronals could eventually lead to loss altogether if the release of the weakened coronal is often obscured by the noncoronal, but would not be expected to obtain at all as a consequence of overlap in the case of coronal + coronal sequences where blending results in a single release carrying potentially salient information about both consonants.”

5.2. Phonologically conditioned allomorphy

The gestural OT analysis of rhotic deletion in derived environments also provides an insightful account of an allomorphic alternation in UEN between the negative clitic /-ke/ and its corresponding full form /ike/. According to Kristoffersen (2000: 335-338), the clitic attaches to an inflected verb, and other clitics may potentially intervene between it and the verbal host. Interestingly, /-ke/ can attach only if the preceding element ends in a full vowel or /r/, but in the latter case the rhotic must undergo deletion for the output to be well-formed. Otherwise, the presence of morpheme-final /r/ in the output requires the full form /ike/. This distribution is illustrated in (21a), where NEG denotes the allomorphs {/-ke/, /ike/}. (Note: Surface [k.k] and [r.r] in Kristoffersen’s broad transcriptions represent ambisyllabic consonants, and I have added the intrusive vowel in [r^o.k] clusters, based on the acoustic findings presented in Section 3 above.) Verb-final /r/ is deleted before the clitic but surfaces intact before the vowel of the full form. Note that *[tøer^o.kə] is an ungrammatical surface form of underlying /tøer#NEG/, even though surface [tøer^o.kə] from monomorphemic /tørke/ is well formed in (21b).

- | | | | | | |
|------|----|------------|--------------------------|-----------------|-------------|
| (21) | a. | /tøer#NEG/ | [tøk.kə] ~ [tøer.ri.kə] | <i>tør ikke</i> | ‘dares not’ |
| | | | *[tøer ^o .kə] | | |
| | b. | /tørke/ | [tøer ^o .kə] | <i>tørke</i> | ‘drought’ |

As Kristoffersen points out, the deletion of /r/ before /-ke/ is not an isolated rule specific to the negative clitic. Rather, it is related to the optional deletion process that affects /r/ before heteromorphemic noncoronals, shown in (6) and (7). Deletion is also optional before the negation marker, but in this case it is the choice of allomorph that depends on speech style. Once /-ke/ is chosen in informal speech, rhotic deletion becomes obligatory. This dependency is difficult to formalize in input-oriented, derivational approaches. A rule deleting coda /r/ would create a preceding vowel-final context to which /-ke/ can attach, but deletion cannot apply until after the clitic has been added. “The clitic must in other words be able to look ahead in the derivation: it can only attach to an r-final stem in case the /r/ subsequently deletes” (Kristoffersen 2000: 337).

The look-ahead problem is effectively avoided in an output-oriented framework such as OT, since the surface distribution of allomorphs can be determined by the interaction of constraints that evaluate output forms (Kager 1996, Mascaró 1996, inter alia). An account of allomorph selection can be given on the assumption that NEG in (21a) contains two underlying representations, each of which can serve as input to a phonological mapping. Following the approach developed by Bonet et al. (2003), I assume that the two allomorphs are in a lexical precedence relation, {ke > ike}, where ‘>’ indicates the preference for the clitic over the full form. Faithfulness to the lexical precedence relation is evaluated by a universal constraint called PRIORITY, which is violated by an output in which the allomorph /ike/ is chosen instead of /-ke/. The ranking of this constraint relative to other constraints in the grammar determines the surface distribution of allomorphs.

Variability between surface forms of *tør ikke* ‘dares not’ is illustrated in (22) and (23). (Note: Henceforth, I omit high-ranking RECOV_μ since the focus is now on morphologically derived environments only.) In these two tableaux, the input contains a

verb-final /r/ followed by the set of lexically ranked NEG allomorphs. Candidates (a-c) select the preferred allomorph /-ke/, whose initial consonant gesture is coordinated with the preceding rhotic in open transition, close transition, and complete overlap, respectively. Candidate (d) selects the full form /ike/, in which case no CC coordination relation can be established between the gestures for /r/ and /k/ due to the presence of the intervening vowel. In (22), the first two candidates are eliminated by the gestural overlap constraint. The ranking of PRIORITY » MAX(APICAL) optimizes candidate (c), in which /r/ is completely overlapped and perceptually masked by the initial consonant gesture of the /-ke/ allomorph. Under the opposite ranking, it is more important to preserve the input rhotic in the output, and this is achieved via selection of the full form /ike/ in (23d).

(22) Prosodic structure: (... tærkə ...)IP

/r#{ke > ike}/	rC- OVERLAP _{IP}	PRIORITY	MAX (APICAL)	rC- COORD	CC- COORD
a. /r ^o ke/ [r ^o kə]	*!				*
b. /r [●] ke/ [r [●] kə]	*!			*	
☞ c. /r [⊗] ke/ [kə]			*	*	*
d. /rike/ [rikə]		*!			

(23) Prosodic structure: (... tær ikə ...)IP

/r#{ke > ike}/	rC- OVERLAP _{IP}	MAX (APICAL)	PRIORITY	rC- COORD	CC- COORD
a. /r ^o ke/ [r ^o kə]	*!				*
b. /r [●] ke/ [r [●] kə]	*!			*	
c. /r [⊗] ke/ [kə]		*!		*	*
☞ d. /rike/ [rikə]			*		

Positing a variable ranking of PRIORITY and MAX(APICAL) leads to an incorrect prediction when the overlap constraint is taken into consideration. In the discussion surrounding (20), it was proposed that optional rhotic deletion in derived environments can be accounted for by a variable ranking of rC-OVERLAP_{IP} and MAX(APICAL). The problem arises when, in a particular evaluation, PRIORITY dominates MAX(APICAL), which in turn dominates rC-OVERLAP_{IP}. In (24), candidates (c) and (d) are eliminated, and lower-ranking constraints incorrectly choose (a), as indicated by the [⊗] symbol. The variable ranking of the top three constraints predicts the possibility of an occasional output variant that maintains /r/ before the enclitic. However, *[tær^o.kə] is never a grammatical surface form of underlying /tær#NEG/, as (21a) makes clear.

(24) Prosodic structure: (... tærkə ...)IP

/r#{ke > ike}/	PRIORITY	MAX (APICAL)	rC- OVERLAP _{IP}	rC- COORD	CC- COORD
● [*] a. /r ^o ke/ [r ^o kə]			*		*
b. /r ^o ke/ [r ^o kə]			*	*!	
c. /r ^o ke/ [kə]		*!		*	*
d. /rike/ [rikə]	*!				

How can variable rhotic deletion be reconciled with variable allomorph selection without overgenerating outputs like *[tær^o.kə]? One possibility is to maintain the variable rankings between PRIORITY and MAX(APICAL) and between MAX(APICAL) and rC-OVERLAP_{IP} but with the proviso that the overlap constraint cannot be lowest ranked. However, this approach offers merely a stipulative solution, which goes against the spirit of factorial typology in OT. I propose that an adequate explanation requires the additional overlap constraint in (25a), which is relativized to the prosodic foot domain. On the assumption that the tendency for assimilation is greater as the participating segments share smaller prosodic domains (Mohan 1993), overlap constraints that refer to smaller domains are intrinsically higher ranked than those that refer to larger domains. The fixed ranking of overlap constraints in (25b) is sufficient to account for the UEN data, although it is plausible that other languages may make use of overlap constraints targeting consonantal gestures in different prosodic domains.

- (25) a. ALIGN(/r/, CENTER, C, CENTER) IN FOOT — rC-OVERLAP_{FT}
 In a sequence /rC/ within the foot, align the center of /r/ with the center of C.
 b. rC-OVERLAP_{FT} » rC-OVERLAP_{IP}

To see how the elaboration of overlap constraints solves the overgeneration problem, consider the prosodic representations shown in (26). If the negative clitic is assumed to adjoin at the foot level to the preceding verbal host in (26a), then the resulting /rC/ cluster is internal to the foot and, therefore, subject to rC-OVERLAP_{FT}. Kristoffersen (2000: 181) argues independently that in UEN, left edge foot assignment takes place on the root level only. The prefix /for-/ is left unfooted in (26b), and rC-OVERLAP_{FT} is irrelevant in this case because the resulting /rC/ cluster does not occur within the foot. Finally, the /rC/ cluster in (26c) is not internal to the prosodic word or the foot.

- (26) a. (... ((tærkə)_{FT})_{PW} ...)IP *tør ikke* ‘dares not’
 b. (... (fɔr(banne)_{FT})_{PW} ...)IP *forbanne* ‘to curse’
 c. (... (gle:dər)_{PW} (manŋə)_{PW} ...)IP *gleder mange* ‘pleases many’

The problematic constraint ranking is shown again in (27), with rC-OVERLAP_{FT} added at the top of the hierarchy. Candidates (a,b) are now eliminated because the foot-internal clusters are not completely overlapped. The ranking of PRIORITY » MAX(APICAL) selects candidate (c), while the opposite ranking would select (d). In the case of prefix- and

word-final /r/, rC-OVERLAP_{FT} is irrelevant because the derived clusters are not foot-internal in (26b,c). As was already shown above for prefixed forms, the variable ranking of rC-OVERLAP_{IP} and MAX(APICAL) selects either the candidate with overlap-induced deletion in (20c) or the candidate with the intact cluster in (20d).

(27) Prosodic structure: (... ((tœrkə)_{FT})_{PW} ...) _{IP}

/r#{ke > ike}/	rC-OVERLAP _{FT}	PRIORITY	MAX (APICAL)	rC-OVERLAP _{IP}	rC-COORD	CC-COORD
a. /r ^o ke/ [r ^o kə]	*!			*		*
b. /r [•] ke/ [r [•] kə]	*!			*	*	
☞ c. /r [⊗] ke/ [kə]			*		*	*
d. /rike/ [rikə]		*!				

6. Theoretical comparisons and implications

In this section, I discuss alternative OT accounts of Norwegian /rC/ clusters and consider implications of the gestural OT approach for the phonetics-phonology interface. First, possible formal analyses that invoke Local Conjunction and Root-Affix Faithfulness have difficulty accounting for rhotic deletion in all morphologically derived environments. Second, Hamann (2003, 2005) offers an analysis of Norwegian /rt/ → [t] in Functional Phonology (Boersma 1998 et seq.) but does not address rhotic deletion before noncoronals nor the blocking of derived-environment effects in morpheme-internal contexts. Third, Bradley (2002) assumes gestural representations and relies on a faithfulness constraint on input timing. However, this approach has been argued to contradict Richness of The Base and to overgenerate impossible phonological contrasts. The analysis put forth in this paper adequately captures the derived-environment effects in /rC/ clusters while avoiding the pitfalls of a faithfulness-based approach to gestural timing.

6.1. Local Conjunction and Root-Affix faithfulness

Let us examine two possible OT alternatives to UEN derived-environment effects that do not employ gestural representations or constraints. In Lubowicz (2002), morphological alternations result from the violation of locally conjoined stem:syllable anchoring and markedness constraints. Given the constraints in (28a,b) and the ranking schema in (28c), we may posit the constraint ranking in (28d) as a possible analysis of the derived-environment effects observed in UEN /rC/ clusters:

- (28) a. R-ANCHOR(Stem; σ) (Lubowicz 2002: 257)
 The rightmost segment of a stem in the input has a correspondent at the right edge of a syllable in the output.
- b. *rC
 No apicoalveolar tap + consonant sequences.
- c. [MARK_i & R-ANCHOR(Stem; σ)]_{Domain} » FAITH » MARK_i
 where MARK_i is a markedness constraint inducing the alternation
- d. [*rC & R-ANCHOR(Stem; σ)]_{AdjacentSegments} » MAX » *rC

Since there are instances of intact /rC/ clusters within the morpheme, the markedness constraint against such clusters must be ranked below the faithfulness constraint that requires maintenance of /r/ in the output, hence the ranking MAX » *rC in (28d). Following the constraint schema in (28c), *rC would be locally conjoined with stem: syllable anchoring within the domain of adjacent segments.

According to Lubowicz (2002), resyllabification of a stem-final segment violates stem: syllable anchoring, thereby activating the markedness constraint responsible for an alternation in derived environments. This account is problematic in the case of UEN clusters because the derived-environment effect does not involve concomitant resyllabification of stem-final /r/, but rather its deletion. We might view deletion as a violation of R-ANCHOR(Stem; σ) as defined in (28a), since /r/, the rightmost segment of a stem in the input, would have no correspondent at the right edge of a syllable in the output. However, this interpretation does not save the analysis because deletion also satisfies the markedness constraint *rC. Since R-ANCHOR(Stem; σ) and *rC are never simultaneously violated, the higher ranked conjunction of these two constraints is never violated, and no alternation can be produced. This problem is illustrated with the compound *værmelding* ‘weather forecast’ in tableau (29).

(29) Local conjunction cannot yield deletion of stem-final /r/

/væ:r-mɛliŋ/	{*rC & R-ANCHOR} _{AdjSeg}	MAX	*rC	R-ANCHOR
●* a. væ:rmɛliŋ			*	
b. væ:mɛliŋ		*!		*

Even if a Local Conjunction analysis could be made to work, deletion of prefix-final /r/ would still be problematic. Since R-ANCHOR(Stem; σ) applies only to stem-final segments, any segment that is not stem-final in the input will vacuously satisfy this constraint. No higher ranked conjunction involving R-ANCHOR(Stem; σ) can be violated by changing prefix-final /r/, thus leading to an incorrect outcome similar to (29a).

Let us consider another approach to the deletion of prefix-final /r/. McCarthy and Prince (1995) propose a universal metaconstraint of ROOT-FAITH » AFFIX-FAITH whereby faithfulness to input specifications is greater within roots than within affixes. If the markedness constraint *rC is ranked between MAX-ROOT and MAX-AFFIX, then the deletion of prefix-final /r/ versus its faithful realization in roots can be accounted for as follows:

(30) Faithfulness in roots versus deletion in prefixes

	MAX-ROOT	*rC	MAX-AFFIX
☞ a. /larm/ → larm		*	
b. /larm/ → lam	*!		
c. /for-banne/ → fɔrbannə		*!	
☞ d. /for-banne/ → fɔbannə			*

However, the Root-Affix faithfulness account falls short when an initial compound member ends with /r/ and the second compound member begins with a non-coronal consonant:¹³

(31) Root faithfulness cannot yield deletion of stem-final /r/ in compounds

/væ:r-meliŋ/	MAX-ROOT	*rC	MAX-AFFIX
☞ a. væ:rmeliŋ		*	
b. væ:meliŋ	*!		

In contrast to the non-gestural OT alternatives sketched above, the derived-environment effects in UEN follow straightforwardly under the gestural OT account. Since $RECOV_{\mu}$ is inactive across morphological and syntactic boundaries, the preference for gestural overlap is free to exert its effects, thereby producing both coalescence and deletion. Within morphemes, $RECOV_{\mu}$ protects input /rC/ clusters from complete overlap in the output, and lower-ranked constraints ensure the default coordination that produces vowel intrusion. To be fair, a comparison with only two non-gestural alternatives does not prove that no classic OT analysis will work as well as the gestural analysis developed in this paper.¹⁴ However, the comparison does highlight some difficulties facing Local Conjunction and Root-Affix faithfulness when applied to morphological derived-environment effects in UEN clusters.

6.2. Functional Phonology and retroflexion in a rhotic context

In recent work on the phonetics and phonology of retroflexes, Hamann (2003, 2005) proposes an analysis of the process deriving [ɽ] from input /rt/ in Norwegian, couched within Boersma's (1998 et seq.) Functional Phonology framework. The analysis employs an articulatory markedness constraint penalizing movement made by the tongue tip from

¹³ In articulating a theory of head dominance, Revithiadou (1999) derives the effects of Root-Affix faithfulness from the ranking HEAD-FAITH » FAITH, whereby lexical accents sponsored by morphological heads are given priority over other accents within the word. However, a ranking such as MAX-HEAD » *rC » MAX does not remedy the deletion problem, as tonal accent in UEN compounds is controlled by properties of the first compound member (Kristoffersen 2000: 263). If indeed /væ:r/ in (31) enjoys headship status, then MAX-HEAD would incorrectly forbid deletion as does MAX-ROOT. Thanks to Jason Riggle for discussion on this point.

¹⁴ See McCarthy (2003a), who proposes to account for morphological derived environment effects, among other phenomena, using comparative markedness constraints.

the articulation of a tap to a following coronal stop. In UEN, this markedness constraint outranks a faithfulness constraint requiring the perceptual specifications of the input segment /r/ to be maintained in the output. Other high-ranking faithfulness constraints prevent deletion of the stop and loss of the [LOW F3] specification of /r/. This ranking maps input /rt/ to the apical [t] in the output, which maintains both the stop articulation and the rhotic's [LOW F3] specification at the expense of losing the rhotic segment itself.

In order to rule out surface [rt] clusters, Hamann employs an articulatory markedness constraint that targets tongue tip movement. This constraint has nothing to say about clusters in which /r/ precedes a noncoronal, since articulation of the second consonant does not involve the tongue tip. Therefore, the coalescence of /r/-laminal clusters is necessarily seen as distinct from the deletion of /r/ before noncoronals. In contrast, the gestural analysis developed in this paper appeals to a single mechanism—gestural overlap—in order to account for the perceptual loss of the extra-short tap in both types of cluster. Hamann's markedness constraint is not relativized to any specific prosodic domain, which incorrectly predicts across-the-board coalescence of /rt/. The gestural overlap constraint in (14a) targets only those /rC/ clusters that are internal to the intonation phrase. In addition, phonologically conditioned allomorphy involving the negative clitic /-ke/ provides evidence for the necessity of the additional overlap constraint in (25a) targeting foot-internal clusters.

Hamann (2005) analyzes the diachronic change whereby morpheme-internal /r/-alveolar sequences in Old Scandinavian became underlying apicals in contemporary UEN, as in the example /svart/ > /svat/ *svart* 'black'. Once the trill /r/ had become an apicoalveolar tap, Old Scandinavian speakers would have produced forms such as [svart] due to a low ranking of the markedness constraint against /rt/ clusters. Stochastic variation in the ranking of markedness relative to the faithfulness constraint against rhotic deletion would have produced occasional output variants such as [svat], "which might lead a learning child to postulate an underlying retroflex form instead of the original rhotic + alveolar" (Hamann 2005: 40). Since none of the constraints employed by Hamann makes a distinction between derived and non-derived clusters, it is difficult to explain why coalescence in contemporary UEN is obligatory in derived environments but blocked in non-derived environments. To get [vo:r.dɑ:g] but never *[vo:r.dɑ:g] from heteromorphic /vor-dag/ 'spring day', a fixed ranking of markedness above faithfulness is required. However, just the opposite ranking is necessary to handle the exceptional cases in which tautomorphic clusters surface intact in (2). In the gestural account proposed here, the derived versus non-derived distinction is adequately captured by the RECOV_μ constraint. Since this constraint is irrelevant across morpheme and word boundaries, the remaining constraints obligatorily map input /r-d/ to output [d]. In non-derived environments, RECOV_μ blocks complete overlap and allows input clusters to surface intact, with vowel intrusion guaranteed by lower-ranked coordination constraints.

How might we account for the emergence of phonemic apicals in a gestural coordination approach? It is not feasible to posit a variable ranking between RECOV_μ and the gestural overlap constraint, for this would potentially overgenerate rhotic deletion in non-derived contexts. It is unclear from the available literature whether, for example, [værb] and [væb] were possible output variants of /værb/ 'verb' at the time when [svart] and [svat] were variants of /svart/, as discussed above. I would like to suggest that vowel intrusion was relevant in the diachronic change that produced phonemic apicals within

morphemes. Specifically, I hypothesize that a variable ranking between rC-COORD and CC-COORD led to variation in the surface coordination of tautomorphemic /rC/ clusters. Acoustic forms such as [væɾ^əb] and [svær^ət], with vowel intrusion, alternated with [væɾ^ɪb] and [svær^ɪt], with no audible release. It is plausible that language learners would have mistakenly postulated an underlying apical for the unreleased homorganic cluster in [svær^ɪt], given the absence of a perceptually enhancing intrusive vowel to effectively tease apart the extra-short tap from the following coronal stop. Although similarly unreleased, heterorganic [r^ɪb] must have been less susceptible to misparsing by learners because of the difference in place of articulation of the consonants. If indeed the perceptual distance between [r^ɪt] and [t] is smaller than the distance between [r^ɪb] and [b], then this would explain how phonemic apicals could have arisen within morphemes while /r/-noncoronal clusters remained intact.

6.3. Faithfulness and lexically specified gestural coordination

Adopting Cho's (1998a,b) approach to morphological derived-environment effects in Korean palatalization, Bradley (2002) develops an analysis of Norwegian clusters that incorporates gestural representations and constraints. In Korean, /t/ is palatalized before /i/ only in environments derived by morphological concatenation: /mati/ → [madi] 'knot' versus /mat-i/ → [maɟi] 'the eldest'. (Note: Obstruents are voiced intervocalically by an independent process.) Cho's central hypothesis is that the timing relationship between adjacent gestures is less variable within a *single* lexical entry than across *different* lexical entries. While the timing between two gestures in the same lexical entry is preserved in the output, "the timing between two gestures created by morpheme concatenation is not lexically specified and is therefore potentially subject to any phonological change which can be produced by varying gestural overlap" (Cho 1998b: 5). On the assumption that palatalization stems from greater overlap between the gestures for /t/ and /i/, the derived-environment effect can be explained as follows. Lexically specified timing for the /ti/ sequence in monomorphemic /mati/ is preserved in the output, precluding palatalization. However, the /t-i/ sequence in heteromorphemic /mat-i/ has no lexical timing specification, which permits the two gestures to overlap, thus yielding surface palatalization.

The derived-environment effects in UEN receive a similar analysis. The gestures in tautomorphemic /rC/ belong to the same lexical entry and are coordinated in such a way as to produce open transition and vowel intrusion. This lexically specified timing relation is preserved on the surface, producing intact [r^əC] clusters. However, the same gestures in heteromorphemic clusters have no lexically specified timing relation because they belong to different lexical entries. In derived environments, the gestures for /r/ and the following consonant may overlap, producing a phonological change. Assuming lexical specification of gestural coordination requires a faithfulness constraint on input timing, which conflicts with a markedness constraint favoring maximal overlap:

- (32) a. IDENT(timing) (cf. Cho 1998b: 6)
 Intergestural timing belonging to the same lexical entry must be preserved in the output.

- b. OVERLAP (cf. Cho 1998b: 37)
 Adjacent consonantal gestures must be overlapped.

The ranking of IDENT(timing) » OVERLAP has the effect of prohibiting gestural overlap in tautomorphemic /rC/, as shown in (33). Faithfulness to input timing is irrelevant across morphosyntactic boundaries, and lower-ranked markedness favors complete overlap in (34c). Although not shown here, coalescence of /r/ with a following laminal requires the MAX(APICAL) constraint in (17a) in order to preserve input apicality of the rhotic as the result of gestural blending in the output.

(33) Gestural overlap blocked in tautomorphemic clusters

	/rOb/	IDENT(timing)	OVERLAP
☞ a.	/rOb/ [r ^o b]		*
b.	/r●b/ [r [•] b]	*!	*
c.	/r⊗b/ [b]	*!	

(34) Overlap-induced rhotic deletion in derived environments

	/r-b/	IDENT(timing)	OVERLAP
a.	/rOb/ [r ^o b]		*!
b.	/r●b/ [r [•] b]		*!
☞ c.	/r⊗b/ [b]		

The IDENT(timing) analysis has been further extended to dialectal variation in Spanish complex onsets (Bradley and Schmeiser 2003) and to coda rhotics in Highland Ecuadorian Spanish (Bradley 2004). All of these works assume that input morphemes already have their gestural timing relations fully and reliably specified 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—intersegmental gestural coordination—is incorporated directly into the phonological representation in the input. In a critique of Cho (1998a,b) and Bradley (2002), McCarthy (2003a, 7f) points out that the assumption of fully specified inputs runs counter to the Richness of The Base in OT, according to which “the lexicon cannot be relied on to consistently and reliably encode predictable details of structure, such as the timing of gestures.” Since there are no grammatical restrictions on the input, a consonant cluster in a form at this level of representation may have a number of different coordination relations, or none at all. Systematic aspects of surface coordination must be determined by the grammar through differences in constraint ranking.

Hall (2003: 14-16) makes another argument against IDENT(timing) based on phonological contrastiveness. If Universal Grammar had a faithfulness constraint on input timing, then some language might rank it above *all* gestural alignment constraints,

thereby overgenerating a contrast based on gestural coordination. As explained above, Richness of The Base predicts that the input might contain morphemes which differ solely in the coordination of gestures comprising a consonant cluster. High-ranking IDENT(timing) would preserve these different coordinations in the output, as made evident by a comparison of the winners in (33a) and (35b). The prediction here is that a surface contrast should be possible between a form containing [r^ob], with open transition and vowel intrusion, and an otherwise identical form containing [r^ɪb], with close transition and no vowel intrusion.

(35) Input gestural coordination preserved in the output

	/r●b/	IDENT(timing)	OVERLAP
a.	/r ^o b/ [r ^o b]	*!	*
b.	/r●b/ [r ^ɪ b]		*
c.	/r ^o b/ [b]	*!	

Contrary to what IDENT(timing) predicts, it seems that gradient differences in intersegmental timing are not contrastive in any language. Hall's (2003) cross-linguistic survey shows that in each language, vowel intrusion either always happens or never happens in a given environment (modulo variability due to fast/casual speech). This places the intrusive vowel on a par with consonant release, which plays an important role in perceptual licensing of contour segments although it is never phonologically contrastive per se (Steriade 1993). It seems unlikely that any language would have minimal pairs based solely on minute differences in the phonetic timing of adjacent consonant gestures. The problem has a parallel in syllable structure. Most phonologists agree that syllabification in itself is not contrastive, given that no language permits a tautomorphemic contrast between *pa.ta* versus *pat.a* or *pa.kla* versus *pak.la*. McCarthy (2003b) proposes to account for this gap on the assumption that faithfulness is not sensitive to underlying syllabification (also see Kirchner 1997). Inputs may be syllabified in various ways or perhaps not at all, but this is ultimately irrelevant to surface syllabification, which is determined entirely by markedness interaction (e.g., ONSET, NOCODA, *COMPLEX, etc.). Similarly, Hall (2003) argues that UG contains no faithfulness constraints on underlying gestural coordination and that surface coordination must result from interacting markedness constraints alone. Input gestures may be temporally coordinated in various ways or perhaps not at all, but the absence of faithfulness to input timing ensures that timing itself will never be contrastive.¹⁵

The account of Norwegian clusters developed in this paper avoids the difficulties associated with IDENT(timing). Since the type of articulatory transition between consonants is determined entirely by surface-based alignment constraints, the account is

¹⁵ An anonymous reviewer suggests that banning faithfulness constraints on non-contrastive features might be viewed as a stipulation. However, the same criticism can be leveled against other frameworks. In distinctive feature theory, a feature can be posited only when contrastive in at least one of the world's languages. Universal non-contrastiveness plausibly results from physiological limits of the human perceptual apparatus. Phonological theory must encode this in some fashion, whether by excluding distinctive features or by prohibiting faithfulness constraints on non-contrastive properties.

consistent with Richness of The Base. Since there is no longer a faithfulness constraint on gestural coordination, the problem of overgenerating a phonological contrast disappears.¹⁶ In the analyses of Cho (1998a,b) and Bradley (2002), IDENT(timing) is responsible for the blocking of derived-environment effects that result from gestural overlap. The present account also allows input morphological structure to influence gestural coordination in the output but in a way that avoids the problems inherent in the faithfulness-based approach. RECOV_μ in (15) is violated when two consonants in an output cluster are completely overlapped if these consonants also belong to the same morpheme in the input. Unlike IDENT(timing), morphologically sensitive recoverability does not refer to gestural coordination in the input. Therefore, potential timing-based contrasts in the input are always neutralized at the surface.

6.4. Implications for the phonetics-phonology interface

It is a commonplace assumption among phonologists that phonology and phonetics constitute distinct but derivationally related components of the grammar (see Liberman and Pierrehumbert 1984, Keating 1990, Cohn 1990). In this model, underlying forms are typically assumed to be devoid of non-contrastive properties such as syllabification or temporal relations between articulatory gestures. The phonological component derives a syllabified surface representation that is categorical, qualitative, and timeless, and phonetic implementation then supplies gradient, quantitative aspects of non-contrastive detail to yield a fully specified phonetic representation. This is essentially the approach of Zsiga (2000), who argues that the phonology acts upon abstract features and segments, which are then mapped to gestures that are coordinated by language-specific alignment constraints in phonetic implementation. Another common assumption is that underlying morphological structure is not present in the input to the phonetic component. The erasure of morphological boundaries at the end of each transformational cycle in SPE and the Bracket Erasure Convention of Lexical Phonology both predict that morpheme boundaries should be invisible to the phonetics.

The division between phonetics and phonology entails that morphological structure cannot influence intersegmental gestural coordination. On this view, however, it is difficult to explain why overlap-induced phonological changes in derived environments are not also observed in morpheme-internal contexts. If phonetic implementation has no access to underlying morphological structure, then an alignment constraint requiring complete overlap of /rC/ clusters in some prosodic domain should apply in across-the-board fashion within that domain, regardless of morphosyntactic boundaries. The morpheme-internal clusters in (2) and (3) would be expected to pattern the same as the derived clusters in (4) through (7). This problem does not arise in a unified model that incorporates gestural representations and coordination constraints directly into the phonology (Benus et al. 2004, Bradley 2005, forthcoming, Davidson 2003, Gafos 2002, Hall 2003). In the analysis developed in Sections 4 and 5, the blocking effect achieved by

¹⁶ In phonological frameworks that take a systemic view of contrast, it is insufficient to ban IDENT(timing), either because no underlying representation is assumed (Flemming 1995) or because generalized systemic faithfulness exists as an independent constraint in the grammar (Padgett 2003a,b,c). See the discussion in Bradley (2005), who argues that imperceptible contrasts based on gestural timing must be universally ruled out by inviolable perceptual distinctiveness constraints.

RECOV_μ is possible only because this and other gestural coordination constraints are able to interact at the same level in the phonological grammar, where underlying morphological structure is still accessible.

The inclusion of RECOV_μ in the phonological grammar predicts that languages may differ in the ranking of this constraint relative to constraints requiring overlap of certain cluster types. When recoverability outranks overlap constraints, derived-environment effects should be observable, as in Norwegian /rC/ clusters. Under the opposite ranking, overlap-induced phonological changes should occur both within and across morpheme boundaries. This prediction is potentially borne out in the Spanish of Havana, Cuba, in which coda liquids participate in several intricate patterns of neutralization, retroflexion and place assimilation, both within and across word boundaries (Harris 1985, Padgett 1995). Before coronal consonants, liquids are neutralized via retroflexion, to which the following coronal assimilates progressively. Before non-coronals, coda liquids assimilate regressively in all features but voicing. The distinct patterning of preconsonantal liquids suggests a possible parallel to the overlap account of UEN coalescence and deletion.¹⁷ Further experimental investigation is necessary to determine whether the complexities of Havana Spanish liquid-consonant clusters may be subsumed under the gestural approach advocated here.

An anonymous reviewer suggests an alternative account of derived-environment effects in which gestural coordination constraints do not make direct reference to underlying morphological structure. One possibility is that morphological information is encoded in the prosodic representation and that gestural coordination constraints refer only to the latter. Since many syllable positions have been proposed at word edges, morpheme-final consonants could be syllabified, for example, as a nucleus, coda, appendix, or onset. Internal and morpheme-edge consonants could occupy different syllabic positions and thus exhibit different gestural patterning. The analysis proposed in this paper employs gestural overlap constraints that target /rC/ clusters appearing within different prosodic domains, namely the intonation phrase (14a) and the foot (25a). These constraints might be reformulated so that they affect only those consonant clusters in which the first member occupies a different syllabic position by virtue of being morpheme-final. This would eliminate the need for RECOV_μ to refer directly to underlying morphological structure. In fact, Hall (2003: 49-52) does propose that gestural alignment constraints must be able to refer to syllable structure, since in languages such as Dutch and Finnish, vowel intrusion in sonorant-consonant sequences is dependent on the tautosyllabic versus heterosyllabic status of the cluster. However, this difference does not seem to matter for derived-environment coalescence in UEN. Heteromorphemic /r/-laminal clusters are realized as single apicals both within syllables in (4a,c) and across syllable boundaries in (4b,d,e). To make syllable structure function as a surrogate for morphological boundaries would ideally require motivation beyond the need to account for derived-environment effects in /rC/ clusters. While Kristoffersen (2000: 137-138) does propose language-specific *patch-up* rules of Appendix Formation and /s/-incorporation to syllabify segments left over by core syllabification, I am unaware of any

¹⁷ Padgett (1995) is the first to consider the possibility of an overlap account for Havana Spanish clusters, although he ultimately rejects such an analysis in favor of a phonological feature spreading rule (see the arguments given on pp. 120-121).

independent arguments for the differential syllabification of /r/ versus other consonants in morpheme-final contexts.

Any proposal to place gestural coordination within the purview of the phonology must also account for the facts that motivate a phonology-phonetics division. Evidence that gestural coordination belongs in a distinct phonetic implementation component comes from the observation that vowel intrusion is in many ways invisible to the phonology, which tends to count the intrusive vowel and tautosyllabic vowel it copies as one. That is, vowel intrusion does not create a new syllable, unlike true phonological epenthesis of a nuclear vowel. Hall (2003: 43-45) provides several diagnostics for distinguishing between vowel intrusion and phonological vowel epenthesis. Native speakers are typically unaware of intrusive vowels. Intrusive vowels are invisible to phonological processes that count segments and syllables (e.g., stress assignment, word games, syncope, allomorph conditioning, and reduplication). Phonological vowel epenthesis disregards the nature of the segments comprising the cluster, whereas vowel intrusion can be sensitive to consonant type.

Several facts regarding vowel intrusion with /r/ in UEN are consistent with the diagnostics outlined by Hall. While explicit discussion of intrusive vowels in tap-consonant clusters is remarkably absent from impressionistic descriptions in the literature, the acoustic study of UEN speech presented in Section 3 documents their systematic presence in unreduced /rC/ sequences. Although the duration of intrusive vowels may sometimes approximate that of unstressed full vowels, there is evidence that the phonology of UEN still treats the phonetic sequence [r^hC] as a cluster of adjacent consonants. First, as shown in (3b) and instrumentally in Figure 3 through Figure 6, /r/ is subject to regressive devoicing before voiceless noncoronals. If the intervening vocalic element were syllabic, then this would seem to imply a typologically unusual type of voicing assimilation whereby voicelessness spreads across a preceding vowel only if the target is /r/. Second, as we saw in the discussion of phonologically conditioned allomorphy in Section 5.2, the negative clitic /-ke/ can attach to a preceding word only if that word ends in a full vowel or /r/. In the latter case, the rhotic must delete in order for the output to be well-formed. If the vocalic element in [r^h.k] were syllabic, then enclisis should be possible without concomitant deletion of /r/. In the analysis illustrated in (27), rC-OVERLAP_{FT} correctly ensures deletion because the foot-internal /rk/ sequence patterns as a consonant cluster and is therefore subject to the overlap constraint. Finally, informal observations based on the same speech data analyzed in Section 3 suggest that while vowel intrusion is systematic in clusters containing /r/, it is absent from clusters involving other consonants, such as nasal-obstruent and obstruent-obstruent. This suggests that the vocalic elements appearing in Figure 2 through Figure 8 are sensitive to consonant type, as predicted by the hierarchy of vowel intrusion triggers in (10).¹⁸

Assuming the standard division between phonology and phonetics, invisibility can be explained by the fact that vowel intrusion arises in phonetic implementation, where syllabification and stress constraints are no longer operative and where segments cease to be relevant after features are mapped to gestures. As Hall points out, however, invisibility need not imply a derivational mapping of features to gestures. She argues instead for a

¹⁸ See Bradley (2005) for additional arguments that Spanish intrusive vowels pattern as phonologically invisible in stress assignment and language games. See Hall (2003) for arguments from other languages.

unified model in which gestures are associated to segments, which in turn group together into higher prosodic constituents such as syllables, feet, prosodic words, and so on. If the constraints responsible for segmental and syllable-based phonological phenomena refer only to segmental and prosodic structure, then it follows that these constraints will be insensitive to any percepts arising from specific gestural coordination relationships. As made evident in (12b), intrusive vowels are the acoustic consequence of non-overlapping consonant gestures and are not part of the formal representation of segments. In short, the invisibility of vowel intrusion requires not a *derivational* difference between phonological and phonetic components but rather a *representational* difference between segments and gestures in the phonological component.

7. Conclusion

As Bybee (2001: 57) notes, “[c]ases in which morphological status interacts with variable phonetic processes constitute important evidence against modularization. Phonetic implementation cannot be relegated to a derivative role in which it has no access to the lexical or morphological status of the elements upon which it works.” In this paper, I have analyzed derived-environment effects in Norwegian clusters in terms of gestural recoverability and coordination constraints that are relativized to morphological and prosodic domains, respectively. Alternative gestural approaches that view coordination as a low-level aspect of phonetic detail cannot account for the influence of morphological structure on the phonetic realization. This problem does not arise in a unified model that incorporates gestures into the phonological representation along with alignment constraints governing their coordination (Benus et al. 2004, Bradley 2005, forthcoming, Davidson 2003, Gafos 2002, Hall 2003). Such a model predicts that gestural coordination is potentially sensitive to morphology, as Gafos (2002: 327, 13f) points out: “If, as claimed here, temporal coordination is part of the representation, then we may expect to find morphology that expresses itself, partially or totally, through that aspect of the representation (‘temporal morphology’).” In the analysis developed here, the morphological affiliation of segments is expressed primarily through differences in the temporal coordination of gestures, with complete overlap giving rise to phonological change in derived environments.

As we have seen, there is no danger in assuming phonetically rich gestural representations in the phonology as long as they coexist with segments (Hall 2003). The fact that intrusive vowels are not part of the segmental representation accounts for their invisibility to phenomena that refer to higher levels of prosodic structure. Since faithfulness is not sensitive to gestural coordination, contrasts based solely on differences in timing are universally ruled out—even if such differences happen to be present in the input. The combination of gestural representations and constraints in an OT grammar provides a unified account of the Norwegian data that captures the interaction among morphological, prosodic, and gestural structure without overpredicting the range of possible phonological contrasts.

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