

CANADIAN RAISING AND THE REPRESENTATION OF GRADIENT
TIMING RELATIONS*

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Although autosegmental notation has often been thought of as the best means of expressing the phonetic motivation behind phonological patterns, it differs from phonetics in one crucial way: its representation of the timing relations among elements is categorical rather than gradient. In this paper it is argued that the description even of categorical phonology sometimes requires reference to gradient timing relations. The focus is on the familiar phenomenon of Canadian Raising (CR), where the variation in diphthong height is categorical, and yet whose phonetic motivation appears to be vowel shortening, which is gradient. Autosegmental notation cannot describe this relationship without falsely implying that vowel shortening also involves categorical timing relations. By contrast, a phonological theory assuming that all phonological representations involve gradient timing relations, such as phonetically-motivated Optimality Theory, has no problem representing both categorical CR and gradient vowel shortening as part of a single system.

1. Introduction.

As the application of autosegmental theory spread from tonal phenomena (Goldsmith 1976) to consonant and vowel duration (e.g. Leben 1980) to feature theory (e.g. Clements 1985) to psychological processing models (e.g. Lahiri and Marslen-Wilson 1991), its growing success led some phonologists in the early 1990s to suggest that the issue of phonological representation was essentially settled, so much so that phonological theory 'is now in a position to turn its attention to other, equally difficult matters' (Goldsmith 1993:23). The field that was dominated from the late 1970s through the 1980s by questions of representation now began to concentrate on the nature of constraint interaction, specifically as formulated in Optimality Theory (Prince and Smolensky 1993).

Although Optimality Theory (OT) is ostensibly unaligned in debates over representation, some phonologists nevertheless recognize that it lends itself to a radical view where phonological forms are represented with the level of detail formerly associated with phonetics (e.g. Flemming 1995, Hayes 1995, Jun 1995, Kirchner 1995, Silverman 1996, Steriade 1996). Such a move would clearly nullify not just autosegmental theory, but feature theory in general.

This paper represents a small contribution to this literature in the form of a consideration of the autosegmental approach to a familiar phonological phenomenon: CANADIAN RAISING (CR). First introduced to theoretical linguistics by

Joos 1942, CR became a star of early generative literature with the discussion in Halle 1962 of its curious interaction with flapping. What has been less extensively discussed, however, is how curious the pattern is in and of itself, with one consequence being, as I argue, that CR cannot be represented insightfully in any conceivable autosegmental notation. An OT analysis, on the other hand, allows us to capture this old friend far more accurately than it ever has been before.

The problem with the autosegmental analysis of CR, I show, lies in its phonetic motivation. This may seem odd, since one of the common rhetorical arguments for autosegmental notation is that it provides a plausible interface with phonetics (see e.g. Goldsmith 1976, Clements 1985, Hayes 1986, Sagey 1986, McCarthy 1988). However, autosegmental notation, regardless of how it may be revised in the future, will always differ from phonetics in one crucial way: it is CATEGORICAL. That is, both the fundamental elements of autosegmental notation (features, nodes, moras) and the timing relations among these elements (association lines) are discrete. Phonetics, as is well known, is not like that. It is an uncontroversial claim that timing relations in phonetics are not categorical, but GRADIENT: the gesture of one articulator typically overlaps with that of another to a degree that varies from context to context along a continuous physical scale (e.g. Browman and Goldstein 1992; Zsiga 1993).

Consider, for example, the nasalization of vowels before nasal consonants (see Cohn 1990). In an autosegmental analysis, we would spread the feature [+nasal] leftward from the consonant to the preceding vowel. In the output, the [+nasal] feature is associated with the vowel in the same way it is associated with the nasal consonant; both are 'equally nasalized'. In the phonetics, however, vowel nasalization may take quite a different form. It may indeed be the case that the velum is lowered roughly with the onset of the vowel, causing it to receive as much nasalization as the following consonant, but in many cases what actually happens is that the velum lowering begins gradually within the vowel portion of the syllable, giving rise to a gradually increasing amount of nasalization on the vowel. This sort of nasalization, because it involves gradient timing relations between the nasalization gesture and the vowel gestures, must be a phonetic phenomenon, and cannot be represented with categorical autosegmental notation.

That such phonetic phenomena are part of a speaker's knowledge of a language's sound system, and not merely an automatic consequence of the physics of articulation, is also widely recognized, as languages may vary in the degree to which a gradient phenomenon occurs (Keating 1985, Fowler 1990). Cohn 1990, for instance, discusses differences between the degree of vowel nasalization in French and English, and Chen 1970 shows how gradient variations in vowel duration (a phenomenon to be much discussed below) differ across languages.

The central purpose of this paper is to show that the description even of categorical phonology sometimes requires reference to gradient timing relations, as with CR, suggesting that autosegmental notation is at best insufficient for its representation. I start by showing that phonological theory has an obligation to describe CR by demonstrating that it is neither 'mere phonetics' nor an idiosyn-

cratic dialectal anomaly; CR turns out to be an example of lexicalized phonology that apparently emerged as a side-effect of vowel shortening. It turns out to be possible to translate this insight into autosegmental notation, but with an undesirable consequence: we predict that both CR and vowel shortening will be categorical. A phonetic study shows that while CR is indeed categorical, vowel shortening is not.

By contrast, as I show at the end of the paper, a phonological theory that assumes all phonological representations involve gradient timing relations, such as phonetically-motivated OT, has no problem representing both categorical CR and gradient vowel shortening as part of a single system. I therefore conclude that something like this approach is required for an accurate description of CR.

2. Canadian Raising

The basic data on CR are found in Joos 1942 and Chambers 1973, with the most famous analysis being Halle 1962, but there is also a healthy literature extending far beyond these (e.g. Kaye 1990; Chambers 1989; Vance 1987; Paradis 1980; Thomas 1991). In the variety of CR examined by Chambers 1973 in Ontario, the generalization involves the complementary distribution of the low diphthongs [ay] and [aw] in open syllables and before voiced consonants, and the raised diphthongs [ʌy] and [ʌw] before voiceless consonants.¹

(1) a. [after (1) in Chambers 1973:115]

[ʌy]	[ʌw]
type	tout
tight	south
tyke	mouse
rife	couch
rice	

b. [after (2) in Chambers 1973:116]

[ʌy]	[ay]	[ʌw]	[aw]
knife	knives	house	houses
life	lives	mouth	mouths
wife	wives	spouse	espouse
advice	advise		
device	devise		

The alternations in (2) below show that CR interacts with stress, applying only if the diphthong appears in a syllable with more stress than the following syllable, if there is any.

As Paradis 1980 demonstrates, these facts can be accommodated by assuming first that CR observes the syllable structure produced by stress-induced resyllabification, whereby a consonant following a stressed syllable becomes ambisyllabic and thereby closes the stressed syllable (see Kahn 1976), and second, that

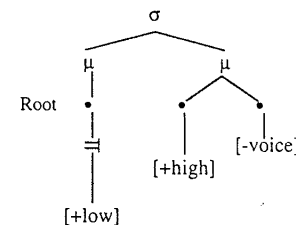
second, that CR requires the voiceless obstruent to be tautosyllabic with the affected diphthong. Thus the diphthong is raised in words like *microphòne* because there /k/ is the coda of the first syllable, but not in *mìcrómeter*, where /k/ is not a coda.

(2) [after (12) in Chambers 1973:125]

[ay]	[ʌy]
citátion	cíte
icónoclàst	ícòn
mìcrómeter	mícròphòne
títanic	títan
mìcròscopist	mícròscòpe

Translating Paradis's insight into more current autosegmental notation (including the concepts of feature geometry and underspecification, which allow us to conceive of raising as the deletion of [+low]), we obtain the description of CR given in (3).

(3) Canadian Raising (autosegmental version)



Unfortunately, although this description uses autosegmental formalism, it cannot exploit its unique properties because CR does not involve the spreading of features. Thus no explanation is given for why [+low] should delete in this environment, and in particular, what connection there could be between low vowels on the one hand and voiceless consonants, diphthongs, and closed syllables on the other. The result is that autosegmental notation provides no more constrained a representation of CR than would linear notation; for instance, both would allow rules that delete [+low] in open syllables, a pattern that does not arise, as we will see later.

Of course, the instructive value of CR as a problem for autosegmental phonology would be undermined if CR proved not to be phonology at all, but merely phonetics, or at the other extreme, a phonetically unnatural relic of a dead sound change. Neither, however, is the case.

CR cannot be pure phonetics, since it is at least partially lexicalized. First, many native speakers of Canadian English show lexical exceptions to CR, for instance pronouncing *Cyclops* with [ay] whereas the prosodically identical *psy-*

leveling, such as *house* and *houses*, which for some speakers both contain [aʷ] (Taylor Roberts, personal communication). Third, there are instances of raised diphthongs before voiced coda consonants, implying that the raised forms are marginally contrastive, as in *spider* with [ʌy] versus *cider* with [ay] (Myers 1993), or *tiger* with [ʌy] in the Western New York variant of CR (Vance 1987). Fourth, as we will see in a later section, phonetic evidence shows that CR is categorical, not gradient, which is what is expected of a lexical pattern. Finally, it is notable that CR is not surface-true, being 'ordered before' the prototypical postlexical pattern of flapping in all living dialects (Chambers 1973, Kaye 1990).

It is also wrong to consider CR a quirk of a single dialect, and thus irrelevant to phonological theory as a whole. Many English dialects, sometimes quite far afield, have patterns that target diphthongs (i.e. not /a/ alone), specifically low diphthongs (i.e. not /oy/ or /ey/), and only in closed syllables. Moreover, with only one exception that I am aware of (the 'brogue' spoken on Ocracoke Island off the coast of North Carolina), all of these CR-like patterns place the raised diphthong before voiceless consonants, not voiced ones.²

It may be objected that the prevalence of CR-like patterns in English is simply due to relics of the Great English Vowel Shift, and so instead of many independent patterns we may have only one, which may indeed have been a phonological quirk. In particular, the CR-like pattern in Scottish English is known to result historically from the general lowering of /i:/ to /ʌy/, followed by the lowering of /ʌy/ to /ay/ only in certain environments (rather than generally, as happened in other English dialects). Thus one might imagine a scenario whereby the substantial number of Scottish immigrants to Canada reintroduced their semi-vowel-shift back into a dialect that had previously lost it. Nevertheless, CR is distinct in several ways from the Scottish pattern, and in fact its unique characteristics were already found in the speech of Canadians born as long ago as 1861 (Thomas 1991). This suggests that Scottish English may have been nothing more than the catalyst for native tendencies towards CR that are inherent in all dialects of English. Moreover, Trudgill 1986 points out that CR-like patterns are found in other places, such as the Caribbean, where there never has been significant Scottish influence.

If CR is not unnatural, what then is its phonetic basis? The key observation is that CR occurs only in environments that shorten vowels, namely in closed syllables and before voiceless consonants (see Chen 1970 and Kluender, Diehl and Wright 1988 for reviews of the phonetic literature on vowel shortening).³ Given this, it is easy to hypothesize why the low diphthongs in Canadian English raised in these short environments. As Chambers (1973:119) observes, '[vowel shortening] placed pressure on the low tense (that is, diphthongized) vowels, since the "distance" ... between the low central onset and the peak of the upglide (whether front or back) is the greatest for these vowels'. In order to reach the high targets /y/ and /w/ in a shorter amount of time, the gesture for the /a/ started a little bit higher.

The circumstantial evidence for this hypothesis is quite compelling.⁴ First, consider the effect of various coda consonants on the duration of long syllable nuclei (including /ay/ and /aw/) in a dialect of North American English that does not have CR, shown in the first two columns of the following table. Vowel length variation is clearly gradient; there are no strictly separated 'long' and 'short' categories. Note that voicing has the greatest influence on vowel duration, but that within the voiceless or voiced obstruent sets, the stop/fricative distinction is also relevant. The effect of /r/ falls in the middle of the ranking.

Now match this ranking with the diphthong variant that appears in each context in different dialect regions, as is done in the table for Canada and Western New York. In both cases, it is the 'short' environments that permit the raised diphthongs, with the variation being due solely to the classification of /r/.⁵

- (4) Distribution of low and raised diphthongs in two English dialects (vowel length data from Peterson and Lehiste 1960)

VOWEL LENGTH			
Environment	(msecs)	Canada	Western NY
_t	210	ʌy	ʌy
_s	269	ʌy	ʌy
_r	296	ay	ʌy
_d	318	ay	ay
_z	390	ay	ay

This hypothesis allows us to understand why CR only affects diphthongs (because the offglide is a high target) and why only low diphthongs (because of the contrast with the high offglide) and why only in closed syllables (because this context shortens the diphthongs). Moreover, in the one case where we do know something about the history of a CR-like pattern, in Scottish English, it is known that the vowel length change preceded the vowel quality change, and even today it is the duration effect that is most salient to native speakers (see e.g. McClure 1977, Allan 1985, McMahon 1991).

In short, CR is a genuine, phonetically natural phonological pattern. Nevertheless, autosegmental notation in its current form appears unable to describe it insightfully. In the next section I show that this is true even if we revise autosegmental notation to incorporate vowel shortening into the analysis.

3. Vowel shortening in autosegmental notation

Before we can make use of vowel shortening in a revised autosegmental analysis of CR, we must first abstract a bit from the complex phonetic facts, about which surprisingly little is known. For instance, there is still disagreement about the causes of vowel shortening before voiceless consonants (compare Fowler 1992 and Kluender, Diehl, & Wright 1988 for opposing views). The best we can do is choose one plausible hypothesis and build from there.

The hypothesis I adopt here is that shortening is compensatory. This idea rests on the observation that voiceless consonants are inherently longer than voiced ones (Chen 1970, Luce and Charles-Luce 1985). This intrinsic difference in length then translates into a (roughly) complementary length difference in preceding vowels due (mostly) to coarticulatory overlap: the target endpoint of the vocalic gesture lies beyond the onset of the coda consonant, so if the consonant is intrinsically longer, the acoustic effect of the vowel will be comparably shorter. A similar explanation for the shortening of vowels before consonant clusters, which are longer than singleton consonants, is offered by Munhall, Fowler, Hawkins & Saltzman 1992.

Compensatory shortening and lengthening are quite easily expressed in autosegmental notation as the reassignment of a timing unit from one autosegment to another. For example, in a moraic analysis of compensatory lengthening (e.g. Hayes 1989), the deletion of a coda consonant allows for the spread of the vowel features from the first mora to the now unassociated second mora. The shortness of the input vowel is represented by its association to a single mora, while the increased length of the output vowel is represented by associating the vowel features to two moras.

We cannot use precisely this analysis for the representation of vowel shortening before voiceless consonants because it would make two false predictions. First, we would have to say that the inherently longer voiceless consonants are bimoraic in order to contrast them with the shorter (and thus monomoraic) voiced consonants. This would permit syllables with four moras if the vowel is also long, a situation disallowed in all versions of moraic theory. Second, if vowel shortening involves moras, we expect that vowels in different voicing environments should differ in length to the same degree as inherently long and short vowels contrast in length. Actually, a study on Dutch found that variation due to voicing context only involves differences of 20 to 30 milliseconds, whereas lexically distinctive long and short vowels differ by about 100 milliseconds (Jongman, Sereno, Raaijmakers, & Lahiri 1992).

Thus if we want to describe this variation as autosegmental compensatory shortening, we need to posit a timing unit smaller than the mora.⁶ Suppose we dub this unit 'Q' (for quantity) and stipulate that a mora may dominate up to two. Inherent differences in consonantal duration are represented by further stipulating that the Root node of a voiced consonant links to a single Q while that of a voiceless consonant links to two. Compensatory shortening then gets the desired submoraic difference in vowel duration: vowels before voiced consonants are linked to at most two Q slots, while those before voiceless consonants are linked to three. I will not take space to describe this proposal in full, but it turns out that it allows for a very elegant autosegmental representation of CR as the delinking of [+low] when both this feature and the [+high] of the offglide are dominated by the same mora. In other words, the observation that CR finds its origins in the temporal compression of low and high vocalic gestures can in principle be formalized in autosegmental notation.

The crucial observation, though, is this: any conceivable autosegmental analysis that recognizes the role of vowel shortening in CR must encode both CR and vowel shortening with categorical units. If vowel shortening in Canadian English is gradient, as it is in the North American dialect described above, autosegmental theory will not be able to capture its connection with CR, no matter how radically it may be revised in the future. The autosegmental approach thus seems to predict that vowel shortening in Canadian English will be categorical.⁷

4. Vowel shortening in Canadian English

Because no study had been done on vowel length variation in Canadian English (Jack Chambers, personal communication), an informal one was undertaken to test this crucial claim. Three female undergraduates at York University in Toronto, native speakers of English who were born in the Metro Toronto area, were recorded reading aloud a list that included the words *tight*, *dice*, *tide*, *stripe*, *strife*, *price*, *pride* and *prize*. Each word was read three times, creating nine tokens of each word, which were then treated as if they were independent for purposes of the statistics.⁸ These words allowed for a comparison across four phonological categories defined by the features [\pm voice] and [\pm continuant]. Measurements were taken of vowel duration (defined as the onset and offset of periodicity in the waveform, except for words with prevocalic /r/, where onset was defined as a rise in F3) and of F1 (at a point one-third through the vocalic portion of the syllable).

There were two predictions to test. The first was that differences in F1 (an indication of vowel height) would be significantly different only across the voiced and voiceless categories; differences in [continuant] should have no effect. This would be taken as evidence that CR itself is categorical with respect to a single feature (namely [voice]). Second, if vowel length variation is categorical with respect to this same feature (as the Q analysis predicts), we expect the same results with vowel duration. Thus, for instance, there should be a significant difference in vowel duration between *dice* and *tide* and between *price* and *prize*, but not between *tight* and *dice*, *stripe* and *strife*, or *pride* and *prize*.

Results are shown in the following table. To simplify the exposition, I have used the following conventions: 'A < B' means that A is significantly lower than B ($p < .05$ in a two-tailed paired t-test), while 'A = B' means that A and B are not significantly different ($p \geq .05$).

(5) a. Vowel F1 comparisons in Hz (with standard errors)

<i>tight</i>	= <i>dice</i>	< <i>tide</i>		
624(16.1)	631(19.7)	904 (60.2)		
<i>stripe</i>	= <i>strife</i>	<i>price</i>	< <i>pride</i>	= <i>prize</i>
607 (7.8)	612(11.4)	600 (7.5)	746 (39.6)	772 (42.2)

b. Vowel duration comparisons in msec (with standard errors)

<i>tight</i>	< <i>dice</i>	< <i>tide</i>
151(5.6)	188 (3.1)	215 (8.6)

<i>stripe</i>	< <i>strife</i>	<i>price</i>	< <i>pride</i>	< <i>prize</i>
94 (7.3)	116(5.0)	125 (8.0)	160 (10.5)	223 (11.6)

We see from the table that CR is indeed categorical, in that it respects only differences in voicing, giving rise to two discrete categories of diphthongs in terms of their height. Thus there is no difference in vowel height between *stripe* and *strife*, or *pride* and *prize*, but there is between *price* and *pride* (as well as between *price* and *prize*).

By contrast, vowel shortening is gradient; the diphthong in *stripe* is shorter than that in *strife*, and the diphthong in *price* is shorter than that in *pride*, which in turn is shorter than that in *prize*. The crucial phonetic prediction of the Q analysis, or indeed any autosegmental analysis of CR that relates CR to vowel shortening, is thus false. Apparently a gradient phonetic pattern is the 'cause' of a categorical phonological pattern, a situation that is impossible to express in autosegmental notation.⁹

5. Phonetically-driven Optimality Theory.

The way out of this dilemma is to rethink the role of phonological notation. Autosegmental notation attempts, as McCarthy (1988:85) writes about feature geometry, to 'describe common phonological phenomena with a simple, almost minimal set of operations'; that is, the power of phonological theory should be constrained by inherent limitations of the notation itself. This view of phonological notation was already challenged by McCawley (1973 [1979:210]), who pointed out that 'no mathematician criticizes a notation on the ground that it allows one to write the sentence $2 + 2 = 59$ '. This analogy makes it clear that the alternative to building inherent constraints into notation, which, as I have argued, does not work in the case of CR, is to constrain phonology from without, as sentences like ' $2 + 2 = 59$ ' are filtered out by independent mathematical modules like number theory. The alternative to the autosegmental enterprise, therefore, would be a theory where phonological representations have few or no inherent limitations in level of detail, but rather are kept in check by independent phonetic constraints.

The devices of OT allow this concept to be implemented formally within generative phonology for the first time (e.g. Flemming 1995, Hayes 1995, Jun 1995, Kirchner 1995, Silverman 1996, Steriade 1996). Phonetically-driven OT supplements the usual principles of OT with the proposals that the set of ranked constraints includes explicitly phonetic statements, some of which maintain perceptibility and some of which enforce ease of articulation. Crucially, phonological inputs and outputs are considered to be highly detailed, involving among other things all the complexity of gradient timing relations traditionally associated only with phonetics. Categoricity is not an inherent property of phonological representations, but instead emerges from constraint ranking; a language with a categorical (or even contrastive) distinction in vowel duration will rank a subset of phonetically explicit vowel duration constraints much higher than the rest. A single set of phonetic constraints is therefore all that is needed to impose both gradient and categorical patterns on inputs.¹⁰

Thus we may posit a family of constraints affecting vowel duration, ranked as shown in accordance with the phonetic facts discussed in earlier sections. The constraints requiring vowels to have a duration above a set minimum enforce perceptibility, while the others are presumably motivated by 'ease of articulation'.¹¹

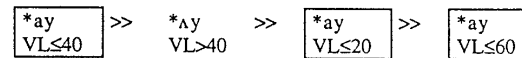
(6) Families of constraints affecting vowel length

- a. *VL<x Vowel length cannot be shorter than x% of the maximum
*VL<20 >> *VL<40 >> *VL<60 >> *VL<80
- b. *[F] Before a [F] segment the preceding vowel cannot
VL>x be longer than x% (of some maximum length)
- *Z >> *D >> *S >> *T
VL>80 VL>60 VL>40 VL>20

The constraints affecting diphthong 'raising', shown below, are of the same general type. Notice the important fact that they make explicit reference to the presumed connection between vowel duration and the distribution of low and raised diphthongs. The only formal difference here from the vowel duration constraints is that as CR is categorical in Canadian English, a subset of one family of constraints (here the 'ease of articulation' constraints) is ranked much higher than the others. By way of illustration here, the cut-off point for the appearance of the [ay] variant is arbitrarily set at a vowel duration 40% of maximum.

(7) Families of constraints affecting diphthong raising

- a. *Ay [Ay] cannot appear if the vowel length is
VL>x greater than x% of its maximum
- b. *ay [ay] cannot appear if the vowel length is
VL≤x less than or equal to x% of the maximum



Given these constraints and their ranking, we find that we can describe vowel shortening as gradient and CR as categorical within a single formal analysis. I illustrate this with a tableau showing the effect on diphthongs before voiceless stops, in which the optimal candidate is a syllable with a raised, very short diphthong.¹² Although space prevents me from giving the three other relevant cases, it should be easy for the reader to see how diphthongs before voiceless fricatives will be raised but not quite as short, diphthongs before voiced stops will be low and a little bit longer still, and diphthongs before voiced fricatives will be low and longest of all.

Despite the inherent appeal of describing in this way the dependence of categorical CR on gradient vowel duration, it would be premature to say that the long-mysterious relationship between phonology and its phonetic motivations has been suddenly made blindingly obvious. For instance, how should ruleless

(8)

Input: ayT	*ay VL≤40	*Ay VL>40	*Z >80	*D >60	*S >40	*T >20	*VL <20	*VL <40	*VL <60	VL <80
ayT VL = 20	*							*	*	*
ayT VL = 40	*					*			*	*
ayT VL = 60						*				*
ayT VL = 80						*				
AyT VL = 20								*	*	*
AyT VL = 40						*			*	*
AyT VL = 60		*				*				*
AyT VL = 80		*				*				

OT describe the apparently counterfeeding ordering relation between CR and flapping? It's easy enough to set the mechanics of an analysis in motion. For example, Reiss 1997, following a suggestion of Bruce Hayes, points out that counterfeeding can be modeled in OT with constraint disjunction, whereby one assumes that no violation is incurred if a candidate satisfies at least one of a pair of constraints; in the case considered here, this will mean that a raised diphthong may appear before a voiced consonant if and only if that consonant is a flap. There is much work to be done before the details of a phonetically motivated OT analysis of the CR-flapping interaction can be worked out, however, because little is known about the effect of flaps on vowel duration in English dialects; for instance, Fox and Terbeek 1977 found that their American speakers showed a small but significant difference in vowel duration in pairs like *patting/padding*, while Huff 1980 found no such difference with his New York City speakers. Since to my knowledge no phonetic study of this sort has been done on Canadian English, it's impossible to determine what role vowel shortening may play in the appearance of raised diphthongs before flaps. In addition, a complete OT analysis of flapping itself has yet to appear in the literature, related as it is to the

intricacies of metrical and syllabic structure; see Hong 1997 for a recent discussion.

The role of stress in CR also poses challenges for the OT analysis sketched here. I've argued that a voiceless consonant only triggers CR when the diphthong is in a stressed syllable because in this environment the consonant closes the syllable and thus shortens the diphthong; CR doesn't occur in an unstressed syllable before a stressed syllable with a simple onset because in this environment the diphthong is an open syllable, and is thus longer. The problem is that, as is well known, stress itself lengthens vowels. The data in Davis and Summers 1989, for example, show that in American English, stressed vowels before voiceless consonants may be up to 70 milliseconds longer than their unstressed counterparts. Although that study did not examine Canadian English, nor the diphthongs [ay] and [aw], the stress effect on vowel duration may well be similar in dialects with CR. In a sense this is another case of counterfeeding; the analysis must be modified so that vowel duration effects caused specifically by stress 'do not count' in the evaluation of the vowel-quality constraints.

6. Conclusions

This paper has attempted to make a thorough case that autosegmental theory is powerless (actually, overly powerful) in the face of a phonological pattern as familiar to the generative literature as CR. I argued that the fundamental problem was unsolvable if we maintain the autosegmental assumption that all phonologically relevant phonetics can be (ultimately) encoded in categorical notation. I then showed how an alternative model where phonetics directly constrains phonological outputs is much more successful in capturing the essential qualities of CR and its relation to vowel shortening. Contrary to what was thought only a few short years ago, there is still much work to be done in the study of phonological representations.

NOTES

* This version of a well-battered paper has benefited from assistance over the years from Pam Beddor, Jack Chambers, San Duanmu, Matt Gordon, Jimmy Harnsberger, Mike Hammond, James and Leslie Milroy, John Ohala, Taylor Roberts, Donca Steriade, Alice Turk, and reviewers for this journal, not all of whom will be happy with how I have misunderstood or ignored their suggestions. I would also like to thank John DiZazzo of the York University Language Laboratory in Toronto for providing recording facilities and equipment.

¹ These are what will be given as the surface forms of what will be termed the 'raised' diphthongs throughout this paper, though the precise phonetic realization varies somewhat among speakers and dialects with CR-like patterns. The term 'raised' is used merely to pick out the mid-vowel diphthongs that are in complementary distribution with the low diphthongs; no claim about which form is underlying is intended.

² See Wolfram and Schilling-Estes 1995 for discussion of Ocracoke; other CR-like patterns are found in Virginia, Martha's Vineyard and in Scottish English (Chambers 1973), Western New York (Vance 1987), Ohio, Pennsylvania and Minnesota (Thomas 1991), Michigan (Dailey-O'Cain forthcoming), and the Caribbean (Trudgill 1986).

³ Again, the use of the convenient and familiar term 'vowel shortening' is not meant to imply a claim of directionality; the process may involve vowel lengthening instead, or a purely surface-level complementary distribution of vowel durations.

⁴ For an opposing view, see Thomas 1991.

⁵ Interestingly, this does not work with Scottish English (the /d/ environment requires the raised diphthong, while the /l/ environment requires the low one). This may result from the fact that the North American dialects actually have /l/ rather than /l/, but any effect of this difference on vowel duration is impossible to test since Scottish English has a categorical vowel duration pattern in addition to the usual gradient one (McClure 1977, McMahon 1991).

⁶ There is precedence for such submoraic timing units in the autosegmental analysis of consonant closure parameters of Steriade 1991, 1992a,b.

⁷ It is possible, however, as a reviewer has suggested, that while the CR vowel quality categories correspond with discretely represented durational categories, gradient duration values are also assigned depending on the phonetic environment. In fact something like this seems to be a fair description of Scottish English, where McMahon 1991 has argued that vowel duration variation has both a categorical component (characteristic of this dialect) and a gradient component (common to all English dialects). If this were true of all cases of CR-like patterns, the autosegmental approach would be quite convincing, but this is precisely because the conclusion we'd be forced to, that vowel duration variation has a categorical component in Canadian English but not in American English, seems somewhat counterintuitive. Thus if we do not find evidence for such a component in Canadian English, Occam's razor leads us to assume that it's not there.

⁸ In spite of this irregularity, I do not expect that more careful studies will lead to substantially different conclusions.

⁹ The problem may also be conceived of as a rule-ordering paradox, where a gradient rule (vowel shortening) precedes a categorical one (CR). See Anderson 1975 for other examples.

¹⁰ With the change in paradigm we must also change the interpretation of 'categorical' from 'built out of discrete elements' to simply 'nongradient', i.e., variation of a phonetic factor does not cover all possible points along a physical scale, but instead falls into discrete, sharply peaked subdistributions (see Pierrehumbert 1994 for discussion of this concept). Thus vowel nasalization is 'categorical' in this sense if the velum is always lowered roughly simultaneously with the onset of a nasalized vowel, never at all the other possible points within the vowel.

¹¹ Throughout the discussion, 'Z' represents voiced continuants, 'D' voiced stops, 'S' voiceless continuants, and 'T' voiceless stops.

¹² Among the constraints not shown here is Faith [ay], which of course must be ranked below the highest-ranked constraint violated by the optimal candidate.

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