Defining Phonological Rules over Lexical Neighbourhoods: Evidence from Canadian Raising

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1. Introduction

Recent years have seen a heightened interest in incorporating a wide range of nonphonological factors, including phonetic, morphological, lexical, syntactic, social, and usage factors, into explaining phonological phenomena (see, for example, Beddor *et al.*, 1986; Browman & Goldstein, 1989; Keating, 1990; Ohala, 1990, 1993; Flemming, 2001; Hume & Johnson, 2001; Pierrehumbert *et al.*, 2001; Gordon, 2002; Beckman & Pierrehumbert, 2003; Bod *et al.*, 2003; Bybee, 2003; Guy, 2003; Padgett, 2003; Hall *et al.*, 2004, among others). This interest seems to stem from the idea that "phonology" involves the study of linguistic sound systems and *whatever factors affect these systems*, regardless of more traditional notions of modular grammar.

One aspect of this trend has been an interest in lexically based accounts of grammar in general and phonology in particular (e.g., Lahiri & Marslen-Wilson, 1991; MacDonald *et al.*, 1994; Goldinger, 1997; Bybee, 2000; Pallier *et al.*, 2001; Beckman & Pierrehumbert, 2003; Hay *et al.*, 2003). This paper provides further evidence for the idea that the understanding of phonological patterns can be usefully informed by looking at phonological neighbourhoods in the lexicon; that is, by considering word similarity. The focus of investigation is "Canadian raising," a cover term for the distribution of the vowels [ai] and [ʌi] in certain dialects of English, including many spoken in Canada. It will be shown that the traditional phonological accounts of Canadian raising as a categorical process, governed by the voicing of the following segment and stress patterns, are not in fact sufficient to account for the actual patterns of Canadian raising for at least some speakers. In addition to these factors, phonological neighbourhoods also play a role in shaping the distribution of [ai] and [ʌi]. Section 2 gives a brief overview of Canadian raising and its role in the phonological literature, and outlines an elicitation study carried out to look at the modern pattern of Canadian raising in a particular Ontario community. Section 3 then describes the results of this study, and section 4 discusses how the results can be modelled making reference to phonological neighbourhoods. Finally, section 5 presents conclusions.

2. Background on Canadian raising

Canadian raising is a phonological process in which the distribution of the vowels [ai] and [ʌi] is traditionally assumed to be predictable by phonological rule. (The term also applies to the distribution of [au] and [ʌu], but these phones will not be discussed in this paper.) As the name implies, it is usually assumed that [ai] and [ʌi] are allophones of a single underlying phoneme, /ai/, which is "raised" to [ʌi] in certain phonological contexts. Although there have been several different formulations of the specific rule, making use of either syllable structure (e.g. Paradis, 1980; Chambers, 1989) or foot structure (e.g. Kiparsky, 1979; Jensen, 2000) to govern the distribution, the basic formulation of these rules is the same. An example is shown in (1).

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(1) Canadian raising (Paradis, 1980; adopted by Chambers, 1989):
/ai/ → [ʌi] / ___ C
[-voice]
(if C is in same syllable, using syllabification of Kahn, 1980)

This rule, and others like it, makes two key assumptions: first, that there is a categorical difference between the output of the rule when it applies (i.e., [ʌi] in the rule in (1)) and the variant that does not undergo the rule (i.e., [ai]); and second, that the rule will apply in all and only words where its phonological environment is met (i.e., in any word where /ai/ occurs and is followed by a tautosyllabic voiceless consonant; for example, "tight" is pronounced as [tʌit] while "tide" is pronounced as [taid]). Especially crucial in this second assumption is the idea that *only the phonological environment* will play a role in determining which variant, [ai] or [ʌi], appears in any given context. Furthermore, knowing the phonological environment will always be sufficient to uniquely predict the choice of variant.

In the phonological literature, Canadian raising is often used as a prime example of a traditional phonological rule; it is also often used as an example of how phonological opacity can arise, because of its interaction with other rules such as flapping (see, for example, Chambers, 1973; Bromberger & Halle, 1989; Bermúdez-Otero, 2003). Despite its wide use, however, there have been few rigourously controlled production studies of modern Canadian English to determine whether the patterns of Canadian raising first reported in Joos (1942) and later in Chambers (1973) are still representative of today's speakers. Many phonological accounts simply rely on earlier studies, which themselves often rely upon the intuitions of native speakers, including the author of the particular study, rather than performing acoustic analyses on recorded data to determine the actual distribution of the high and low variants of /ai/.

To partially offset this trend, an in-depth production study was carried out in Meaford, Ontario, a small community approximately 100 miles north of Toronto. The goal of the study was to determine what the distribution of [ai] and [ʌi] is, at least in certain words in a certain community. A more complete description of the study and its results are reported in Hall (submitted); an outline of the study and its results is presented here as background for the subsequent discussion of these results in rethinking the nature of phonological rules.

Three male participants over the age of 65 were chosen as a subset of the original 20 participants in order to control for age and sex. All three had grown up in and lived the majority of their lives in Meaford. They were recorded performing two tasks. The first was a read narrative, during which the participants read a passage describing a set of pictures they had previously examined. There were 78 different words whose canonical pronunciations include the vowel /ai/ embedded in the passage, some repeated several times. The second task was a read wordlist. Each participant read a randomized version of the same list of 554 words, 299 of which were /ai/ words and 255 of which were fillers. The /ai/ words were controlled for following segmental context, stress, syllable structure, and frequency (based on the CELEX corpus, Baayen *et al.*, 1995). The list also included words that are commonly cited in the literature on Canadian raising (e.g., "write," "writer," "ride," "rider") and words that are phonologically or morphologically related to other words on the list (e.g. "sight," "cite," "citation").

Once the recordings were made, the /ai/ vowels from each of the words in the two tasks were delimited in Praat (Boersma & Hayes, 2001). The values of the first two formants were used as a phonetic correlate of Canadian raising, and were measured at the point of maximum F1 (i.e., the lowest part of the vowel), using an automatic Perl script written by Elliott Moreton (p.c.). (For discussion of the choice of measurements, see Hall, submitted.)

3. Results

The results of this study question both of the assumed predictions of traditional phonological rules like that given in (1). Recall that the first prediction is that there is a categorical distinction between the two variants, [ai] and [ʌi]. If this were the case, the phonetic measurements of the words with /ai/ should fall into two distinct clusters – although there would be some variation in the pronunciation of either vowel, they would be clearly separate from each other. The actual distribution of F1 and F2

values, however, which is shown in Figure 1, presents quite a different picture. Although there is variation within each speaker, there is no clear distinction between [ai] and [ʌi] for any of the words.

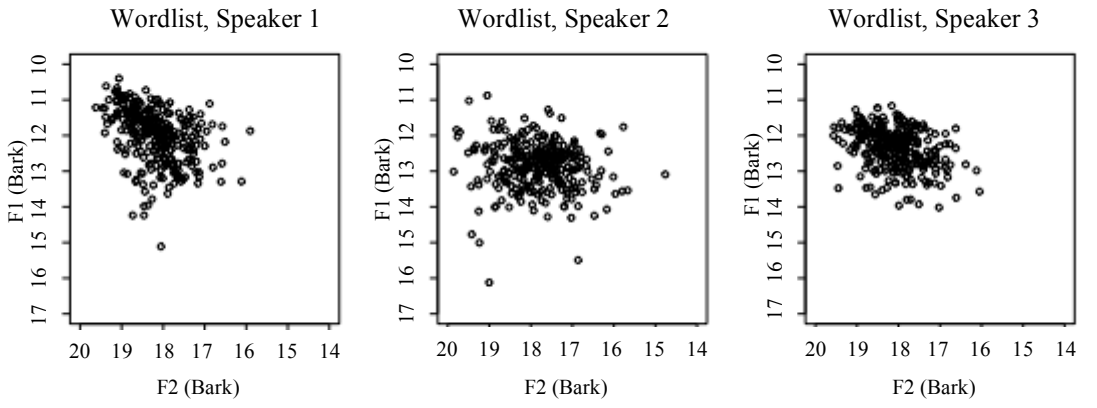

Figure 1: Actual distribution of F1 and F2 values for each of the words on the wordlist, for each of the three speakers

Furthermore, the predictions of traditional models like that in (1) do not accurately predict the distribution of vowels even within these undifferentiated clusters. The words that are predicted to contain the higher [ʌi] variant and those predicted to contain the lower [ai] variant overlap almost completely, as shown in Figure 2. Given this overlap, it is impossible to tell just from looking at these measurements which vowel, [ai] or [ʌi], any given word contains. Clearly, it is not just a matter of writing a rule that states that one variant "becomes" the other variant in a particular context.

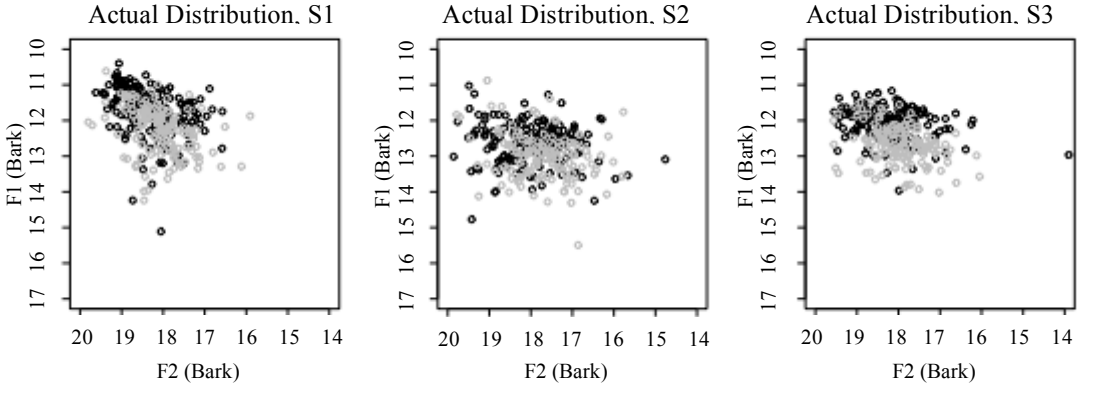

Figure 2: Overlap of tokens predicted to be "high" (black circles) and "low" (grey circles), for each of the three speakers

Perhaps even more troubling is the fact that, even if the data are artificially divided into [ai] and [ʌi] sections, the traditional predictions fall short. One way of dividing the data is to look at the top and bottom quartiles, such that the highest and frontest 25% of tokens in terms of F1 and F2 can be labelled as [ʌi] and the lowest and backest 25% can be labelled as [ai], as is shown in Figure 3. Dividing the data this way rather conservatively ignores the dense middle 50% of the tokens, treating these words as being ambiguous between "high" and "low." This categorization, however, still leaves the traditional models with unexplained data: while 69% of the words in each of the highest and lowest quartiles for each speaker matched the traditional phonological predictions (i.e., had high vowels when they were expected to have high vowels, as in "dicey" [dʌisi], or low vowels when they were expected to have low vowels, as in "high" [hai]), an alarming 31% of the data were in the "wrong" place according to the predictions of traditional phonological rules. More specifically, 18% had low vowels

when they were predicted to have high vowels (e.g., "like" [laik]), and 13% had high vowels where they were predicted to be low (e.g., "gigantic" [dʒʌigæntɪk]). Although the specific words that violated the predictions differed across the speakers, all three showed these proportions of matching and mismatching words.

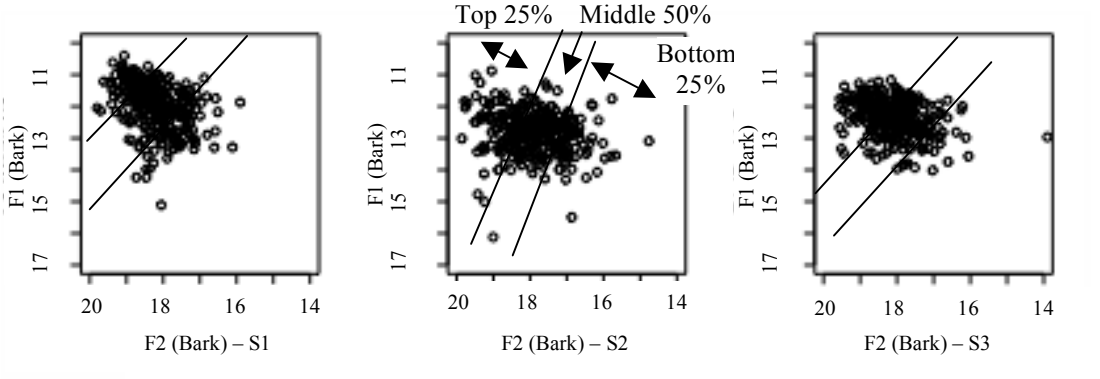

Figure 3: Upper and lower quartiles for each of the three speakers

4. Defining phonological rules over the lexicon

Traditional rules of Canadian raising take into account the voicing of the segment following the target /ai/, the syllabification of the word, and the word's stress pattern to determine the quality of an /ai/ vowel in the word. Clearly, however, such approaches are missing some crucial factor or factors that account for the 31% of the "mismatched" data in §3.

The proposal here is that words that are phonologically similar to each other will pattern together, regardless of the specific predictions of the traditional phonological rules regarding [ai] and [ʌi]. At least as a first pass, phonological similarity will be defined over pairs of adjacent segments – *biphone* sequences – containing /ai/ and the segment that immediately *precedes* it (e.g., /bai/, /dai/, /sai/, /#ai/). This definition of similarity is not to discount other levels of phonological similarity, including the biphone pair that consists of the following segment (the segment that is of course the main focus of traditional accounts of Canadian raising) as well as larger domains of similarity such as longer sequences of matching phonemes (triphones, etc.), overall word shape, prosodic similarity, etc. This choice has some precedence in the results of earlier studies such as Raymond *et al.* (to appear). This study showed the importance of looking at the joint frequency of biphones in predicting phonological processes by demonstrating that greater biphone frequencies correlate with higher rates of word-internal [t]/[d] deletion in American English.

For all three of the speakers examined here, many of the seemingly "aberrent" words do pattern together in terms of biphone similarity. For example, almost[1] all words with the biphones /dai/, /dʒai/, and /sai/ have a *high* vowel (or one that falls in the middle, ambiguous 50%), regardless of the rest of the phonological predictions for these words. So, for instance, "dicey," "diverted," and "didactically" all were produced with the sequence [dʌi], even though "diverted" and "didactically" are predicted to have the [ai] variant because of both the voicing of the following consonant and the fact that the vowel appears in an open syllable. Figure 4 shows this "neighbourhood effect" graphically by showing where five /dai/ words actually fall in the F1/F2 distribution for each of the speakers. Not only are all five words clearly in the highest 25% of the first speaker's productions, but there is absolutely no correlation between the traditional predictions and the actual distribution of the words – those that are traditionally predicted to have the low variant (depicted graphically with a solid black square)

[1] There were a few exceptions to most of the generalizations in this section. Speaker 1 had one word ("dying') that contained a [dai] sequence; Speaker 3 had one word with a [lʌi] biphone ("balalaika," produced as [bʌlʌika]); Speakers 1 and 3 each had one word containing a [sai] biphone ("scientist" and "side," respectively), while Speaker 2 had two ("launching-site" and "cytologist").

sometimes occur with a vowel that is actually higher and fronter than those that are predicted to have a high vowel (depicted graphically with a solid black triangle). Although there was more ambiguity with the productions of the other two speakers, it is still clear that the traditional predictions and the actual productions are not correlated, and that /dai/ words tend to be produced with a high vowel, regardless of traditional predictions.

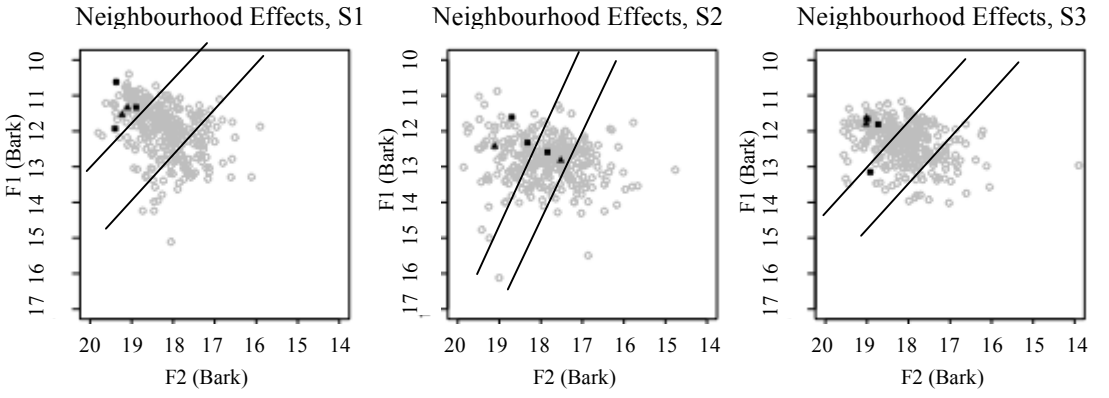

Figure 4: Neighbourhoods with the /dai/ biphone for each of the three speakers; black triangles are words predicted under traditional models to have a high vowel, black circles are words traditionally predicted to have a low vowel

Similarly, "gigantic," "gigantically," and "angina" were all produced with the sequence [dʒʌi], even though none of these are predicted to have the high variant, and the words "sight," "exciting," "bauxite," "Siberia," "psychology," and "psychological" were all produced with the sequence [sʌi], despite the prediction of [ai] in "Siberia" and "psychology."

Of particular interest is the fact that there are biphone neighbourhoods that go in the opposite direction, as well – for example, all words on the wordlist with the /lai/ biphone were produced with a low vowel (or again, one that was in the ambiguous middle 50% of the data), regardless of the predictions of traditional phonological rules. For example, "like," "life," "collide," and "July" were all produced with the sequence [lai], even though every theory of Canadian raising would predict high vowels in "like" and "life."

Furthermore, although there was some inconsistency across speakers, there were consistent biphone neighbourhoods within speakers. For example, for Speaker 1, words with the /hai/ biphone all contained low (or ambiguous) vowels – words like "high," "hypothesis," "hype," and "hypercritical" all contained the sequence [hai], even though "hype" and "hypercritical" are traditionally predicted to have high vowels. Similarly for Speaker 2, words with the biphone /nai/ were produced with a high (or ambiguous) vowel; for example, "united," "nitroglycerine," "ninth," "nine," and "nineteen" all contained the sequence [nʌi], even though "ninth," "nine," and "nineteen" are predicted to have low vowels.

The claim is that these patterns are not just coincidental but rather are a clue to the "unexpected" distribution of [ai] and [ʌi] for these speakers. By adding in the effects of biphone neighbourhoods as a predictive factor in Canadian raising, a large portion of the data that at first seemed to be aberrant can now be accounted for. Of the 31% of the data that was originally classified as "mispredicted," 86% patterns together in these biphone neighbourhoods for Speaker 1; 67% for Speaker 2; and 59% for Speaker 3. These percentages, while reflecting the percentage of the mismatched cases that can be explained, were calculated by considering *both* matching and mismatched words and considering a neighbourhood to be "high" or "low" only if it held true for words in both groups – that is, none of the originally "correct" predictions are made incorrect by looking at the biphone neighbourhoods considered in these calculations.

Clearly, then, the segment preceding /ai/ is playing a significant role in the modern distribution of Canadian raising patterns, at least for these three speakers. There are several potential reasons for this. For example, recall that for all speakers, words with /dai/, /dʒai/, and /sai/ biphones were produced

with high vowels. Perhaps, then, the generalization should be made that when /ai/ is preceded by a coronal, or a coronal obstruent, it has a tendency to be produced as [ʌi]. This generalization may in fact be phonetically motivated – the high, front location of the tongue for a coronal could make it more difficult to achieve a fully low and back [ai] directly following it. This generalization is of course completely analogous to the generalization that can be made about /ai/ and the *following* segment. For example, /ait/ and /aip/ sequences tend to have high vowels, while /aid/ and /aib/ sequences tend to have low vowels; this is not necessarily because of the [t], [p], [d], or [b] per se, but (as in traditional accounts) attributable to the voicelessness of [t] and [p] and the voicing of [d] and [b]. That is, the patterns are generalizable across the sets of biphone neighbours.

In addition to the phonetic motivation for these patterns of biphone neighbourhoods, it is also important to consider the role of lexical frequency. Not all the biphone neighbourhoods can be explained by appealing to phonetic factors such as coarticulation, and so other factors must also be taken into consideration. Concretely, suppose that, for any given biphone neighbourhood such as /dʒai/, a particular neighbourhood "anchor" is chosen by the speaker. This anchor is any given word in the neighbourhood that is for some reason particularly salient; for example, it could be the most frequent word in the neighbourhood. It would then be possible for the traditional phonological rules to apply as expected to this particular word; the other words in the neighbourhood could then "follow the lead" of the anchor, regardless of how the traditional rules would apply to them. If, for example, the CELEX corpus frequencies were accurate for the speakers in this study (an assumption that is admittedly questionable, given the rather scientific nature of many of the texts in CELEX and the rather low levels of education of the three subjects presented here), then the neighbourhood anchor in the /dʒai/ neighbourhood would be "meningitis," as it is the most frequent word that contains the /dʒai/ biphone. The traditional phonological rules apply as expected in this word and predict that it will be produced with the high vowel [ʌi]. Then *all* words in this neighbourhood follow suit, and words like "gigantic" and "angina" are also produced with [ʌi], despite the fact that traditional rules would predict low vowels in these words, all else being equal. Recall, of course, that this is in fact exactly the pattern found in the data – all /dʒai/ words for all speakers were produced with a high vowel.

Under this analysis, the neighbourhood anchor could be chosen on any grounds (i.e., not necessarily frequency). This aspect of the analysis means that different speakers are in fact *predicted* to choose different anchors based on their own indivudal lexicons, which is again precisely what was found in this data – not only were the actual patterns of distribution varied across the different speakers, but the usefulness of incorporating biphone neighbourhoods also varied across speakers.

Looking at the overall picture of Canadian raising, then, several generalizations emerge. First of all, the traditional phonological factors that are said to influence raising clearly do play a role in determining the distribution of [ai] and [ʌi] – the voicing of the following segment and patterns of stress and syllabification accounted for 69% of the data. In addition to these factors, however, the identity of the preceding segment (or perhaps some particular feature of the preceding segment, such as place of articulation) also plays a crucial role. None of these factors are "perfect" predictors – no single factor can fully predict the vowel in every word, and indeed, the pressures of different factors may conflict (as in the case of "dinosaur," for example, where the preceding [d] enforces the "high" [dʌi] neighbourhood but where the voicing of the following segment enforces the low [ain] neighbourhood). That is, these factors all compete with each other, and the final output is the result of this competition.

The question then becomes, of course, how can all of these facts be incorporated into a model of grammar? The facts that need to be accounted for are the non-categorical distribution of /ai/ vowels in the phonetic space; the importance but not complete determinism of syllabification and voicing of the following segment as well as the identity of the preceding segment; and the variability across speakers coupled with the consistency within speakers.

One promising model of grammar that can incorporate all of these facts is an "exemplar" model (see, e.g., Goldinger, 1997; Johnson, 1997; Pierrehumbert, 2001, 2003). In such a model, adapted from pattern recgonition and categorization models in psychology, all tokens of utterances that a speaker encounters are stored in the lexicon. "Grammar" emerges from generalizations about similarity across the lexicon. The fact that different notions of similarity can be entertained – similarity of the preceding segment, similarity of voicing of the following segment, similarity of syllabification, etc. – is not

problematic in such a model and in fact leads to the very prediction that there will be multiple factors competing to have an influence on the production of any given word. These competing factors, then, *all* can contribute to the actual phonetic output, and the gradient distribution of /ai/ vowels is the perfectly natural outcome of this competition. Furthermore, factors such as frequency can easily be brought into the model: since all tokens of utterances are stored in the lexicon, keeping track of the number of occurrences of each token is not difficult. Finally, and perhaps most compelling, is the fact that this model specifically predicts interspeaker variability and intraspeaker consistency. This is because every speaker will have encountered different tokens and is free to make different generalizations about similarity across the tokens they have encountered. It would in fact be very strange in such a model if speakers were all acting exactly the same way. Furthermore, the fact that not all of the data has been explained with the specific factors discussed here is also not surprising. Other factors, such as larger domains of phonological similarity; duration of segments invovlved; semantic and morphological relatedness of words; age, sex, and socioeconomic status of the speaker; etc., can all be incorporated into this model as elements affecting the generalizations made by speakers and thus the grammar that emerges from the speakers' lexicons.

It should be noted that other models of Canadian raising cannot account for all of these facts. Clearly, the traditional rules of Canadian raising are insufficient in that they falsely predict a categorical distribution of [ai] and [ʌi], and they only account for 69% of the data when artificial categoricality is imposed on the gradient distribution. It is also not possible to simply claim that the traditional rule is "optional" – optionality only explains underapplication, and says nothing about cases in which a high vowel occurs unexpectedly.

Other models of phonology in which morphologically related words pattern in the same way regardless of other expectations – i.e., various "Paradigm Uniformity" approaches (see e.g. Benua, 1995; McCarthy, 1999; Steriade, 1999) – also cannot account for all of the generalizations seen here. First of all, they treat such patterns as somehow "aberrant" in the general course of phonology, rather than as an extension of the general mechanisms of grammar. Second of all, they only allow morphological relatedness to play this type of role, rather than allowing phonological similarity of, e.g., biphones, to have an impact. Thirdly, and related to this second point, there is no clear way in these approaches of predicting variation across speakers – such patterns are all attributed to morphological paradigms, and individual experience or the generalizations drawn by a specific speaker play no role in determining grammar.

5. Conclusions

In conclusion, it is clear that patterns in the sound systems of languages – i.e., phonology – must take into account many more factors than have traditionally been assumed. It is not sufficient to rely only on natural classes of phonological sounds to describe categorical distributions of clearly distinct phonemes. This point has been vividly demonstrated with the case of Canadian raising, a phenomenon which has long held a place in the phonological literature as a typical example of phonology in action. Rather than being a clear-cut case of one underlying phone "becoming" another phone in well-defined phonological environments, however, it has been shown that the distribution of the vowels [ai] and [ʌi] in the speech of three Ontarians today crucially depends at least on other measures of phonological similarity such as the segment preceding the /ai/ and probably on many other factors as well. It has been proposed that the best way of modelling these multifaceted interactions is with an exemplar model of the lexicon, where grammar is an emergent characteristic of an individual speaker's generalizations over the linguistic experiences he has encountered.

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