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On the status of redundant features: The case of backing and rounding in American English*

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This paper discusses a theory of redundantly specified phonological features as variable phonetic enhancement features (Stevens et al. 1986). It reports on an articulatory study of the American English vowel backing contrast and redundantly specified rounding contrast, showing how the theory of enhancement applies to this case. Analyses show tongue backing to vary considerably, while the presence of (redundantly specified) rounding acts to compensate for cases of reduced tongue backing. Lip rounding thus accounts for a consistent lowering in F2. The redundant specification of rounding makes the backness/rounding distinction more robust to coarticulatory influences. These results are discussed with respect to various theories of phonological features and feature geometry.

1. Introduction: Enhancement features

Stevens, Keyser, and Kawasaki (1986) lay out a theory of phonological features in which languages employ features from a universal set in two different ways. Each language employs some features from this set to minimally distinguish lexical items; this is a distinctive use of the feature. Cases often arise in which a particular feature is never employed all by itself to contrast lexical items, but rather, it always occurs in conjunction with another, distinctive feature. For reasons of compactness of description, various linguists, e.g. Halle (1958, 1964), have proposed that, at some level of the linguistic grammar, only one of the features needs to be specified. The other of the two features is redundant, and can thus be filled in by rule.

While the phonological literature on redundancy of featural specifications is quite large, there has been relatively little consideration of these phonologically-based distinctions in feature usage from a phonetic standpoint. Stevens *et al.* add the phonetic property of variability to the phonological, informationally-based diagnostic of redundant and distinctive features. They state that, while distinctive features serve directly to convey lexical distinctions, redundant features serve to enhance the salience of the distinctive features. Thus, an alternative term for redundant features is enhancement features. As a corollary to this claim, they suggest that distinctive features are invariantly

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present in speech, while enhancement features are more variable, being employed especially in situations where the distinctive feature may be obscured by some attribute of the context in which the feature appears.

The present paper reports on aspects of some American English speakers' production of back vowels and semi-vowels which shed light on the relationship between distinctive and redundant features. Stevens *et al.*'s theory of enhancement features has four aspects which are important for the present study. First, enhancement features phonetically increase the salience of the distinctive features to which they are redundantly specified. The presence of an enhancement feature makes activity associated with a distinctive feature more effective in producing an acoustic contrast. Second, enhancement features may, over time, take over the role of the distinctive feature to which they are redundantly specified. Enhancement features may become distinctive features, and conversely, distinctive features may take on an enhancement capacity, or simply disappear. Third, enhancement features can be identified for a particular language by the fact that they are informationally unnecessary. All lexical contrasts can be communicated by the specification of other distinctive features, and enhancement features, then, can be filled in by rule in the phonological grammar. Fourth, enhancement features also differ from distinctive features in that they are more variable. According to Stevens *et al.*, distinctive features will always occur in the phonetic expression of a particular lexical item; enhancement features will occur especially in conditions where the distinctive contrast might be obscured by context. This paper examines how these four aspects of this version of enhancement theory apply to the case of rounding and backing in American English.

2. An example: Tongue backing and lip rounding in American English

The first example of an enhancement feature/distinctive feature pair considered by Stevens *et al.* is that of [back] and [round]. [back] refers articulatorily to a retracting of the tongue body, and [round] refers to the protrusion of the lips. Stevens *et al.* show that rounding is a reasonable example of an enhancement feature for backing, by showing that the acoustic correlates of backing and rounding are complementary. Backing, especially with the tongue body raised toward an oral constriction, has the effect of lowering the second formant (F_2). Rounding, the protrusion of the lips, has a similar depressing effect on F_2. They point out that, by rounding the lips, the F_2 lowering will be increased enough for the first formant (F_1) and F_2 to closely approximate, thus increasing the salience of the general lowering of the vowel's timbre. In a similar vein, they argue that another feature, labiality, the approximation of the lips, may have an enhancing relationship with backing, at least for high vowels. Again, the approximation of the lips, like backing and rounding, lowers F_2. This relationship is readily apparent in the electronic analog modeling of vocal tract acoustics reported in Stevens *et al.*, just as it is in other more general works, such as Stevens and House (1955), Fant (1960), and Maeda (1990).

Considering the case of American English in particular, the second aspect of enhancement theory, mentioned above, is also evident. The roles of backing and rounding seem to be in a process of change. Northern midwestern dialects, such as those which will be examined in more detail below, have both rounding and backing in non-low back vowels. However, other dialects are well on their way towards either eliminating the redundant rounding specification, or switching the contrast to one of rounding and eliminating the newly redundant backing specification. A dialect typical of Anglo southern California exhibits little or no rounding of back non-low vowels. Thus, here the redundant rounding feature is being eliminated. In contrast, some speakers of the southern midwest seem to be loosing the backing contrast. Figure 1 shows tongue movement trajectories taken from an X-ray microbeam database, such as that analyzed below. The speaker in this case is from St. Louis. Shown here are the movement trajectories of one token of the nonsense sequences, "keek" (above) and "kook" (below). As can readily be seen, the tongue pellet movement trajectories lie in identical horizontal locations within the oral cavity. This indicates that the horizontal tongue positioning in the sagittal plane for the two sequences is nearly identical, and thus there is no retraction distinction between the two vowels. A retraction distinction would show up as a shift to the left in the lower panel of Figure 1. The difference between the two sequences lies in the protrusion of the lips – shown to the right in the figure. The lips during the vowel in "kook" are more anterior, indicating an increased rounding of the vowel. Thus, the distinction between these two sequences is more accurately described as between [kik]

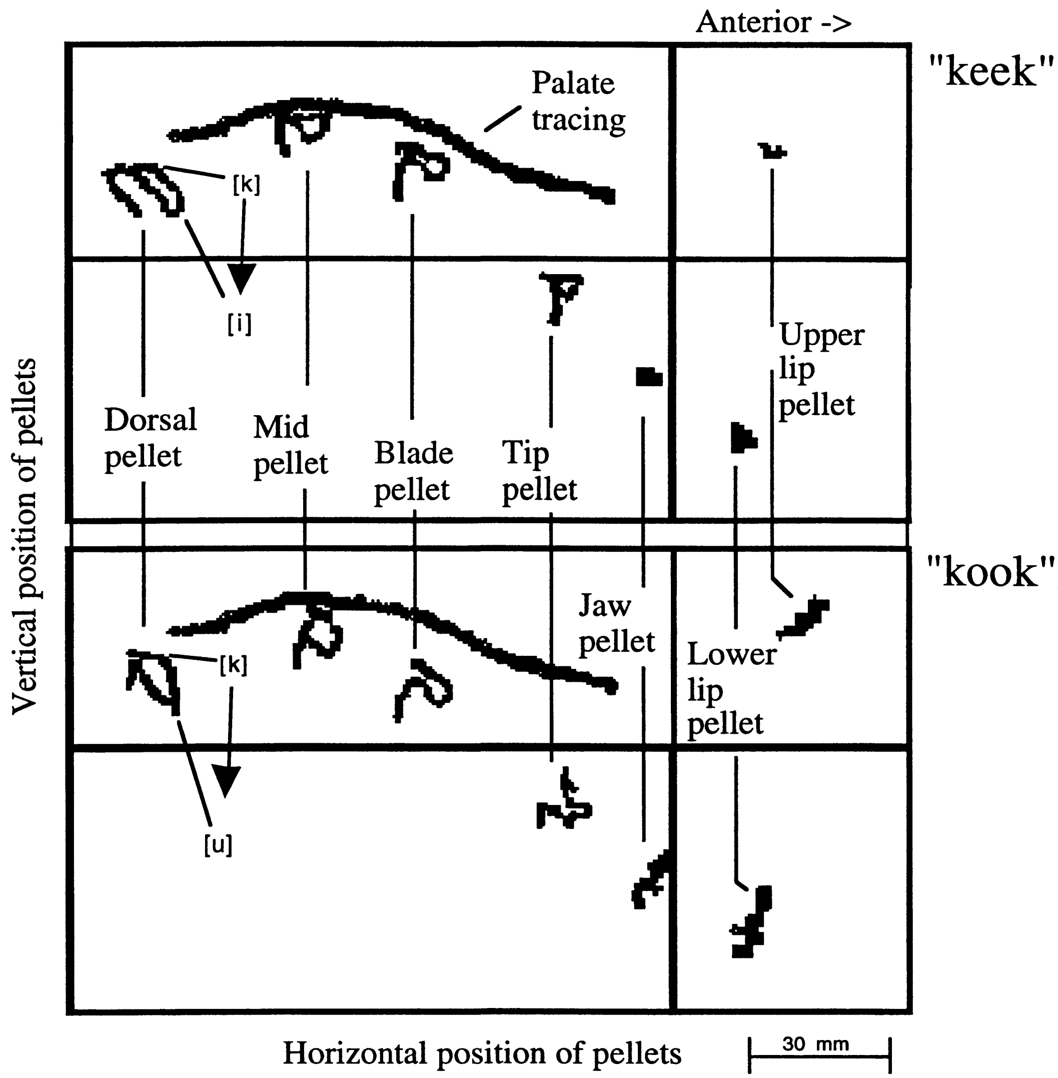

Figure 1. Pellet movement trajectories for the utterance, "keek" (top panel), and "kook" (bottom panel), produced by a speaker of a southern midwest dialect of American English (St. Louis). The horizontal location of the tongue pellets for the two utterances is very similar, while the horizontal position of the lip pellets differs.

and [kyk], not between [kik] and [kuk], as in the northern midwestern dialects, and not between [kik] and [kuk], as in the Anglo southern California dialects.

Considering again the case of the northern midwestern dialects, which have both phonetic rounding and tongue backing, the question arises as to which feature, [back] or [round], is redundant. To answer this question, consider the featural specifications given in Table 1. The specifications are reflective of claims made in Chomsky and Halle

(1968); many more recent phonological works assume these or their equivalent autosegmental representations. This description is, however, overspecified, and thus some of the specifications are not necessary to contrast each vowel. There are several possible ways of compacting the representation, so some criterion must be used to determine which analysis should be assumed. Usually, the optimal compaction is determined as that which needs the smallest number of specifications over the whole set of vowels (as argued for in Halle 1958). Stevens *et al.*, however, describe the process as limiting the number of features which must be used, rather than the number of specifications. In the case of general midwestern American English, it is not possible to eliminate either the rounding or the backing specifications, since the mid, lax vowels contrast minimally in both features. [ɛ] and [ʌ] contrast minimally in the feature [back], and [ʌ] and [ɔ] contrast minimally in the feature [round]. However, the specifications of the vowel [ɔ] are debatable in the general American case, and more important, the vowel [ɔ] has merged with the vowel [a] in most of the western and western mid-western dialects of American English. Thus, in these dialects it is possible to compact the underlying feature set by eliminating the feature, [round], filling in the values with rules given in (1) - (5). For this dialect of American English, backing and rounding are a distinctive and enhancing feature, respectively.

	HIGH	LOW	BACK	ROUND	TENSE
i	+	-	-	-	+
e	-	-	-	-	+
a	-	+	+	-	+
o	-	-	+	+	+
u	+	-	+	+	+
ɪ	+	-	-	-	-
æ	-	+	-	-	-
ɛ	-	-	-	-	-
ʌ	-	-	+	-	-
ɔ	-	-	+	+	-
ʊ	+	-	+	+	-

Table 1. Feature specifications for American English vowels.

(1) [+high, +back] --> [+round]

(2) [-high, +back, -low, +tense] --> [+round]

(3) [-back] --> [-round]

(4) [+low] --> [-round]

(5) [-high, tense] --> [-round]

3. An experiment: the articulation of [ow]

Given that rounding and backing conform well to three of the four aspects of Stevens *et al.*'s theory mentioned above, their theory predicts that the articulation of the backing specification by the tongue body should be invariant, while the articulation of the rounding and labiality features should be more variable. Following, I shall present aspects of an analysis of articulatory records of some western northern American English speakers which suggest that redundant specification of a contrast makes that contrast more robust. Other aspects of the theory should be refined, however, especially the claim that distinctive features are invariantly present in speaker behavior.

The corpus of X-ray microbeam data was gathered at the University of Wisconsin (Nadler, Abbs and Fujimura 1987). X-ray microbeam systems use a narrow beam of X-rays to record the movement in the sagittal plane of metal pellets attached to speakers' articulators. The corpus which I will discuss consists of the x- (horizontal) and y- (vertical) positions of seven pellets, three located on the tongue, one each on the upper an lower lip, and two indexing movement of the jaw. Of interest for the present are pellets placed mid-sagittally on the vermilion border of the upper and lower lip, and the rear-most of the tongue pellets, placed approximately 40 mm from the apex of the tongue as measured with the tongue extended. The lip pellets should index the actions associated with rounding and labiality. The rear-most tongue pellet indexes movement of the tongue dorsum as it is used to make velar constrictions for high back vowels. In addition, a time-aligned digital acoustic record of each utterance was recorded.

The speakers recorded in this corpus were all speakers of some northern midwestern dialect of American English, and, thus, had diphthongs whose nuclear component was fairly far back – as opposed to more southern dialects of midwestern American English where the nuclear component in this diphthong is much more centralized. To assess the variability in the production of this vowel, it appeared in varied segmental environments as well as with different amounts of stress. The speakers were cued to recite one of eight target words in the frame sentence, *I said, "Put the ______ on the table."* The target words were *toe, toes, toast, toasts, tote, totes, toad,* and *toads.* To vary the amount of stress on the target words, the subjects were given miniature discourse conditions in which they were to respond to someone mishearing the sentence. For example, to elicit a rendition of the sentence with nuclear (sentence) accent on *put*, the subjects were given the following dialogue:

Did you say, 'Throw the toes on the table'?
I said, 'PUT the toes on the table.'

There were three accentual conditions. Speakers placed nuclear accent on the target word, before the target word (precluding accents on the target word), and after the target word. In the last condition, the speakers consistently placed a prenuclear accent on the target word; thus, the target word appears with three levels of stress: nuclear accented, prenuclear accented and postnuclear (unaccented).

4. Redundant features and coarticulatory robustness

The top of Figure 2 plots the movement of the rearmost tongue pellet during a nuclear accented rendition of the target word. In this figure, as in other ones in this paper, anterior is to the right. The motion displayed here for the vowel is what one would expect, if one assumes that the vertical motion of the tongue dorsum is roughly correlated with the height of F_1 and the horizontal motion of the dorsum is correlated with the height of F_2. As is illustrated schematically in the lower part of the figure, one expects a lowering of the dorsum for the relatively high F_1 in [o], followed by a raising of the dorsum for the lower F_1 in the offglide (hereafter transcribed as [w]). In addition, one expects a retraction motion of the dorsum for the F_2-lowering in [w]. This retraction should occur after the lowering motion, yielding the circular motion exhibited in the top of Figure 2.

However, this motion was not always present in this speaker's renditions of the target word. Figure 3 shows the dorsal motion for three other renditions of the same word by

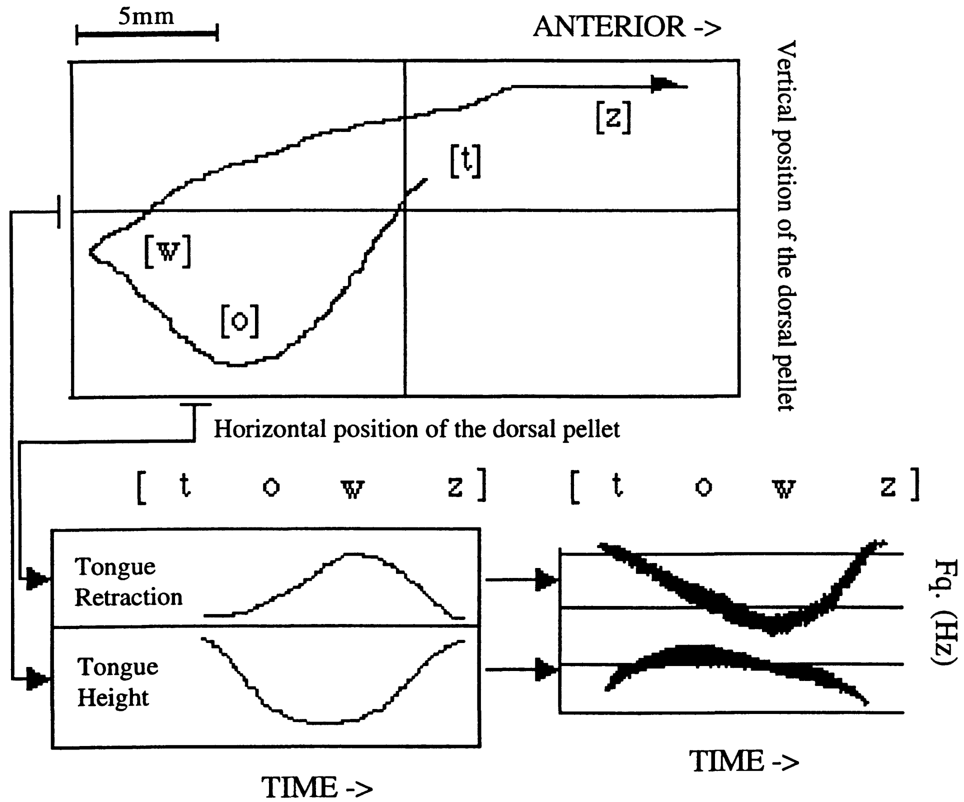

Figure 2. A tongue dorsum movement trajectory for an utterance of the word toes by speaker MB (upper panel). Below is an schematic illustration of the expected formant movement patterns associated with such a dorsal motion.

the same speaker. The top panel shows one of many cases in the corpus in which there is no apparent raising and retraction of the dorsum for velar constriction in [w]. There simply is no velar constriction motion corresponding to the off-glide. It is tempting at this point to simply say that the [w] has been deleted in these cases. However, there are two arguments against this approach. The first is evident in the lower two panels of Figure 3 which show two more tokens of the same word by the same speaker. These tokens show that the disappearance of the velar constriction motion is a gradient effect – here are two tokens with less and less raising and retraction of the dorsum. Deleting the off-glide would yield a categorical distinction, rather than a gradient one. The movement patterns in this corpus show that the velar off-glide is apparent in the dorsal movement to a variable degree.

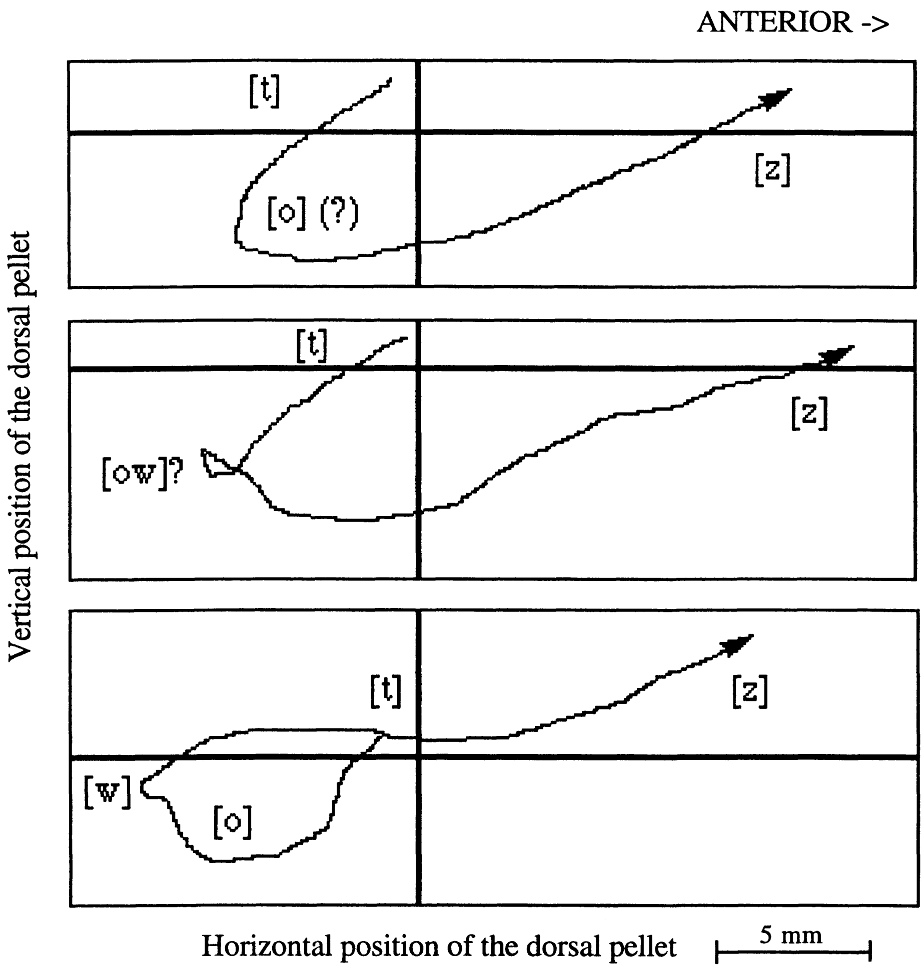

Figure 3. Tongue dorsum movement trajectories for three utterances of the word *toes* by speaker MB. Scale is as in Figure 2.

The second argument against positing a deletion of the [w] is even more revealing and shows another way in which the notion of enhancement is useful. The top panel in Figure 4 is a spectral representation of the utterance shown in the top panel of Figure 3. The bottom panel in Figure 4 is of the utterance shown in the top panel of Figure 2. Especially of interest here is the fall in F_2 for the offglide, even though there was no apparent velar constriction motion for the offglide in this token. Thus, even though articulatory tongue backing is not present in all of the tokens, the primary acoustic correlate of phonological backing was present.

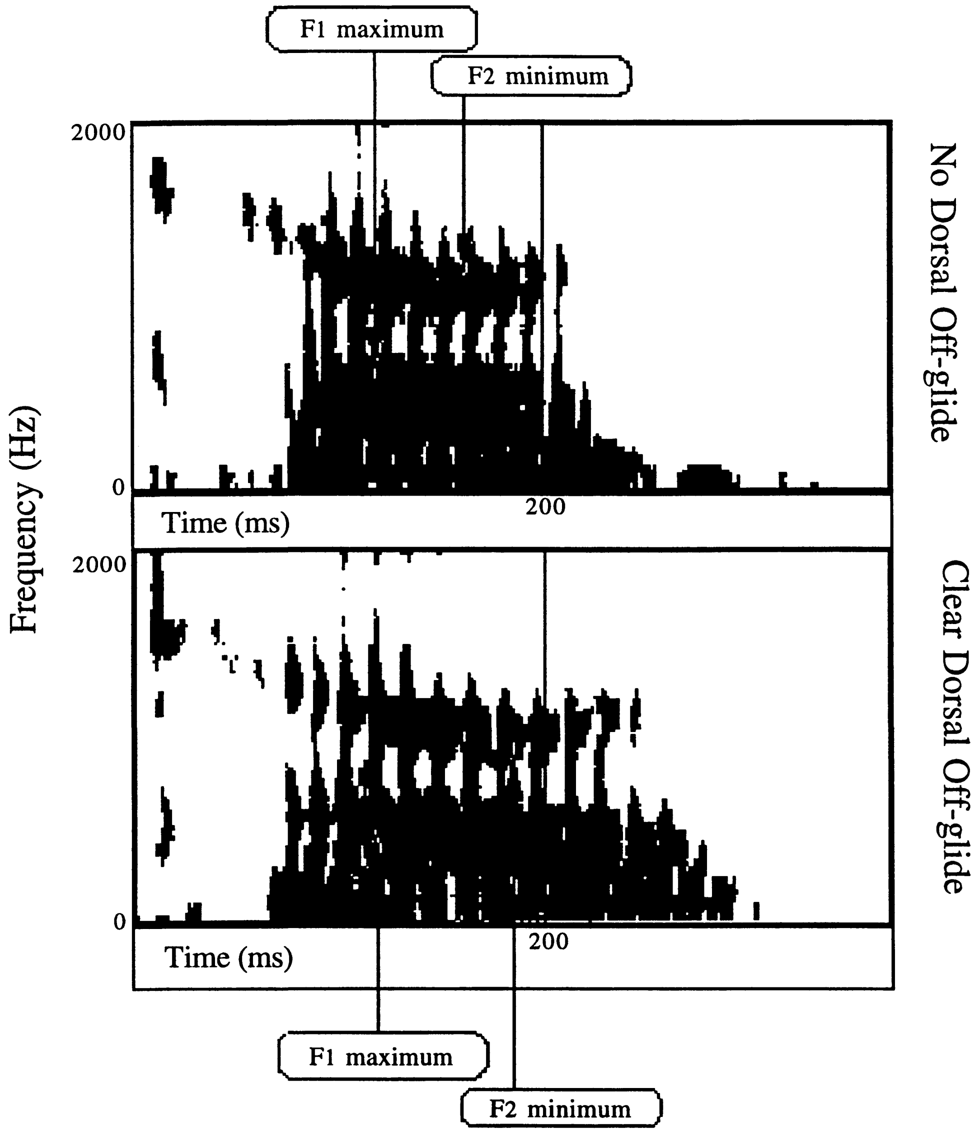

Figure 4. Broad-band spectrograms of the utterance shown in the top panel of Figure 3 (above) and the top panel of Figure 2 (below). Also shown here are timing marks for the two acoustic events discussed in this paper, the F_1 maximum and the F_2 minimum.

To more carefully assess the relationship between the observed motion of the dorsal pellet and the height of F_2, the timing of various acoustic events was measured and correlated with the timing of the tongue dorsum retraction. From spectral displays, such as Figure 4, the value and timing of the highest point in the F_1 trace, and the lowest point in the F_2 trace were estimated. The location of the F_1 maximum and F_2 minimum were confirmed by consulting LPC time slices, calculated with a window size of 20 ms.

Maximum values of F_1 and minimum values of F_2 were measured as peaks in the LPC time slices. In all of the cases for each of the speakers the F_2 minimum came later in time than the F_1 maximum. This was the case even though many of the dorsal motion trajectories, such as that shown in the top panel of Figure 3, had a retraction maximum which preceded the time of maximum lowering.

Figure 5 plots the timing of the F_2 minima relative to the timing of a dorsal index of the occurrence of the offglide, usually the timing of maximum dorsal retraction.[1] Both the events are relative to the timing of a dorsal index of the [o], usually the timing of maximum dorsal lowering. The speaker is the same as that shown in Figures 2 and 3. Tokens with simultaneous dorsal retraction and F_2 lowering would appear along the diagonal line, which indicates the function, $x = y$. Tokens above the line indicate an F_2 lowering occurring after the dorsal retraction; tokens below the line indicate F_2 lowering occurring before the dorsal retraction. In many of the cases, the F_2 minimum corresponds closely in time with the dorsal retraction, as is evident in the clustering of points around the $x = y$ diagonal. However, there are cases in which the F_2 minimum comes considerably later in time than the dorsal retraction, as is evident in points lying above the diagonal. Many of these are cases such as that in the top of Figure 3, in which there was no apparent dorsal motion for the [w] off-glide.

Figure 6 suggests that the F_2 lowering in these cases is due to labial activity. Figure 6 plots for the same speaker the deviation of the time of F_2 lowering from the time of dorsal retraction against the deviation of the time of the maximum lip protrusion from the time of dorsal retraction. There is a fairly strong correlation between the timing of the two events. When the F_2 lowering occurs much later than the dorsal retraction, the labial protrusion maximum occurs later as well.

A reasonable interpretation of these results is that there are many cases in which demands of the neighboring alveolar consonants on the positioning of the tongue body, when weighed against the demands of the velar off-glide, result in a more advanced positioning of the tongue dorsum. Hence the off-glide is gradiently being obscured according to the temporal proximity and strength of the neighboring alveolar consonants. In these cases in which the velar motion is obscured, however, the distinctive fall in F_2

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[1] In cases in which maximum retraction was reached before maximum lowering, such as in the upper and lower trajectories in Figure 3, the dorsal event for both [o] and [w] was a forty-five degree combination of retraction and lowering. Thus, all of the points in Figure 5 with x approximately equal to zero had the trajectory shape of the upper and lower ones in Figure 3.

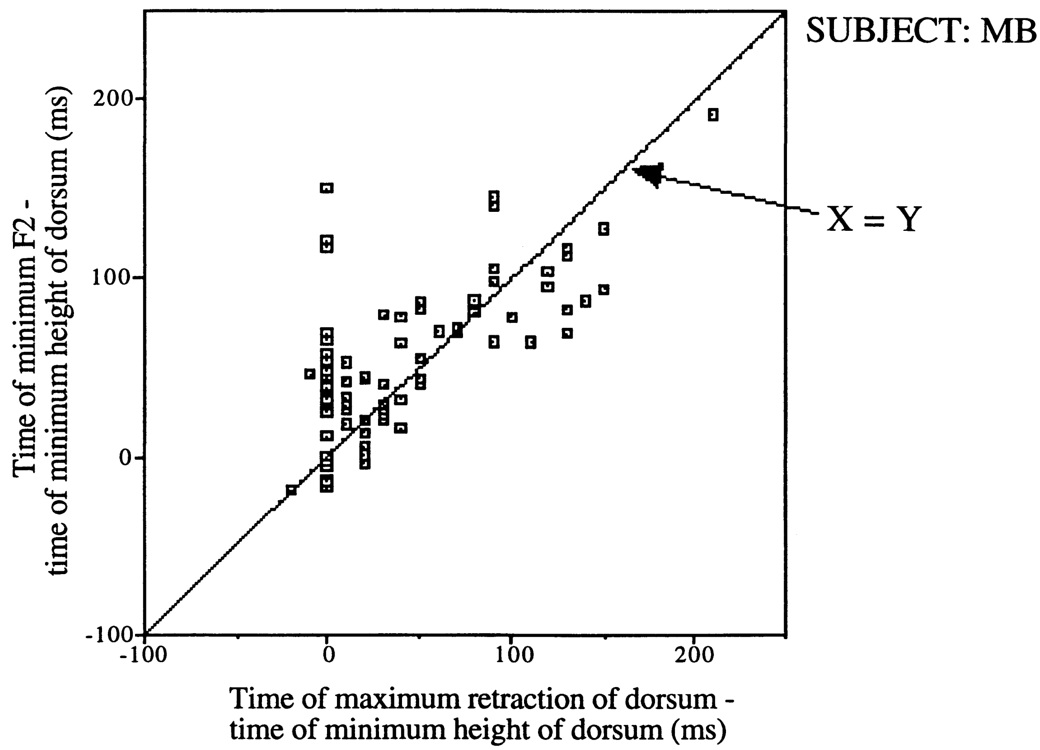


Figure 5. The timing of the F2 minimum plotted against the timing of maximum dorsal retraction. If the F2 minimum were synchronous with the maximum dorsal retraction (as would be the case if dorsal retraction were uniquely and directly causing the F2 lowering), all tokens would lie on the x = y function.

remains, because there is a redundant specification of labial rounding which remains relatively unperturbed by the alveolar consonants. This is because alveolar consonants do not make demands on the placement of the lips (with the possible exception of [s]).

These data suggest that redundantly specifying a contrast not only increases the acoustic salience of the contrast, but also makes the contrast more robust to coarticulatory influences. In the present case, the redundant specification of lingual and labial activity gives the speaker more options in maintaining the contrast in the face of the conflicting motor demands of neighboring consonants.

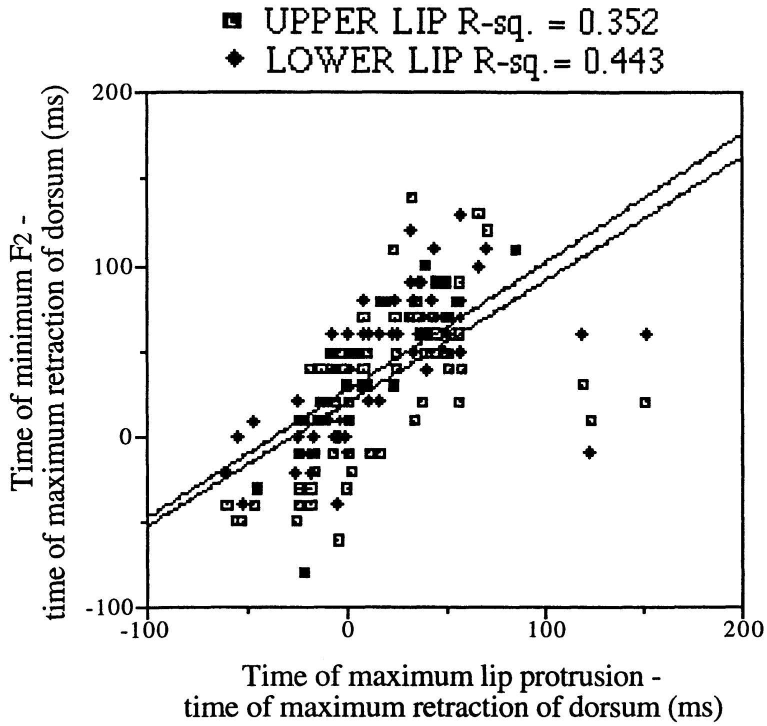


Figure 6. The temporal deviation of the F_2 minimum from the time of maximum dorsal retraction plotted against the temporal deviation of the time of maximum upper lip protrusion from the time of maximum dorsal retraction.

5. A phonetic relationship between rounding and backing

These results present a problem for the analysis of rounding and backing as an enhancement/distinctive feature pair in that the articulatory correlate of backing specifications is not invariantly present in speakers' lingual activity, even though [back] should be the distinctive specification. One possible explanation for this aspect of the results is that the rounding specification is the invariant, distinctive feature, while the backing specification is the optional enhancement feature. Perhaps, the unit being studied here should be treated as a consonant, and therefore the redundancy analysis above may not be appropriate for the present case.

Switching the redundant and enhancement roles of backing and rounding does not alleviate the problem, since the rounding is not invariant either. What is more, the variation is related to variation in rounding is related to the variation in the amount of dorsal retraction. Figure 7 plots the most protruded position of the lips against horizontal position of the tongue dorsum for two of the three speakers. Speaker MB exhibits a negative correlation between tongue retraction and lip protrusion. Speaker SD exhibits a positive correlation between retraction and protrusion. The third speaker shows the same pattern as Subject SD.

Theories of phonetic variability, such as Lindblom's Hyper- and Hypoarticulation (H+H) theory (Lindblom 1983, 1990), would predict this positive correlation between retraction and protrusion. Lindblom posits a continuum between hyper- and hypo-articulate speech. Hyperarticulate speech – found in more formal settings, and in noisy conditions – is characterized by increased speaker activity in producing distinctions. In the present case, this would mean more tongue retraction and simultaneously more lip protrusion. Indeed, Stevens *et al.* (1986) allow for this kind of variability in redundant features, when they note that redundant features may be particularly called upon when there is contextual danger to the communication of the distinction, conditions which Lindblom would expect to give rise to hyperarticulate speech.

The bottom plot of Figure 7 (subject SD) shows this positive relationship between lip protrusion and dorsal retraction. When the tongue body is further retracted (evident in a more negative, posterior position), the lips are further protruded (evident in a more positive, anterior position). This is also the result one expects due to variation associated with stress – stress in English acts to increase the movement of articulators toward distinctively specified positions (de Jong, Beckman and Edwards 1993). Due to this stress-related effect on the overall amount of retraction and protrusion, separate regressions were calculated for each stress category. For this subject, the positive relationship also holds within each stress category. This effect can be interpreted as a result of background variation along Lindblom's H+H scale occurring even within stress categories.

The top plot (subject MB), however, shows a different and more interesting relationship. Here, there is a negative relationship between lip protrusion and tongue advancement – the less tongue retraction (evident in a more positive, anterior location of the tongue pellet), the more protrusion (evident in a more positive, anterior location of the lip pellets). This speaker shows a tendency to increase rounding in those situations where retraction has been reduced. This relationship can be interpreted as indicating a compensatory relationship between labial protrusion and dorsal retraction; that is perturbations of the movement of one articulator are being counter-balanced by activity in another articulator. Similar results are evident in analyses of this speaker's renditions of the word, *put*, as well as in speakers analyzed by Perkell, Matthies, Svirsky and Jordan

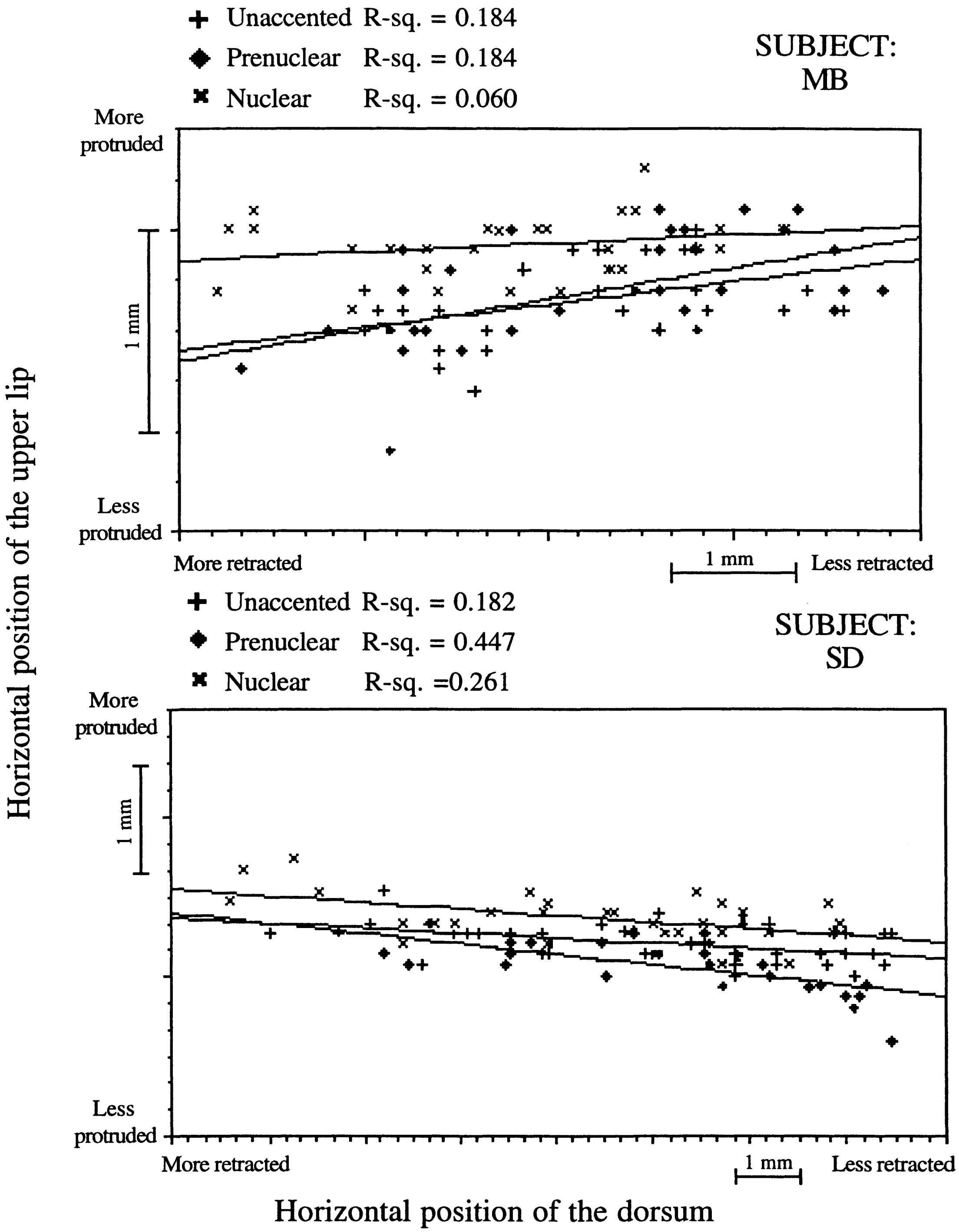


Figure 7. The horizontal position of the upper lip plotted against the horizontal position of the tongue dorsum for two of the speakers. All position values are with respect to a consistent reference point.

(1993). This raises problems for enhancement theory as Stevens *et al.* (1986) describe it. Neither feature, round nor back, is invariantly present at the level of articulation. Both features vary. Thus, it is not clear that there is any phonetic distinction between enhancement and distinctive features.

6. Labial-dorsal compensation and featural specifications

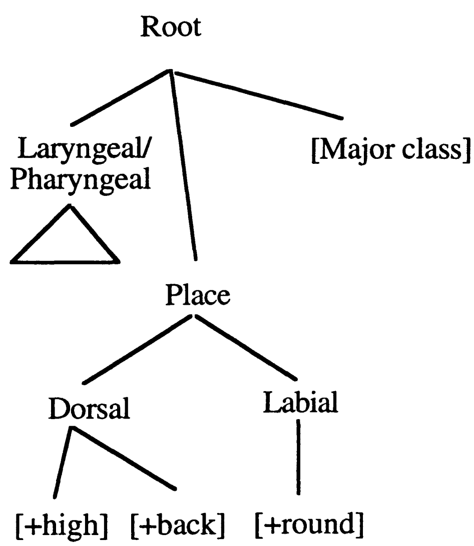
Compensatory relationships between articulatory positions, such as those shown here, have also been demonstrated for articulatory sub-components of an articulatory complex, such as the jaw and lower lip, or the upper and lower lip for labial closures (e.g. as shown in Abbs, Gracco and Cole 1984; and Shaiman 1989) or the tongue blade and the jaw in coronal articulations (e.g. in Kelso, Tuller, Vatikiotis-Bateson and Fowler 1984). These kinds of complementary relationships have provided a basis for recent theories of speech production, such as Task Dynamics (Saltzman and Munhall 1990), which treat the various speech articulators as being yoked together around the attainment of articulatory goals. Both the jaw and the lip contribute to the approximation of the lips; both the jaw and the tongue blade contribute to the attainment of alveolar closures.

However, labial-dorsal compensation differs from these earlier cases. Each of these earlier examples indicates a yoking of articulators centered around the articulation of a particular feature – [labial] for jaw and lip, [coronal] for jaw and tongue blade. The labial and the dorsal activity studied here, however, are thought to be behaviors associated with two separate features, [round] and [back]. Labial-dorsal compensation suggests that activities associated with different features may be phonetically yoked in the same fashion as articulatory structures are yoked together for the production of a single feature.

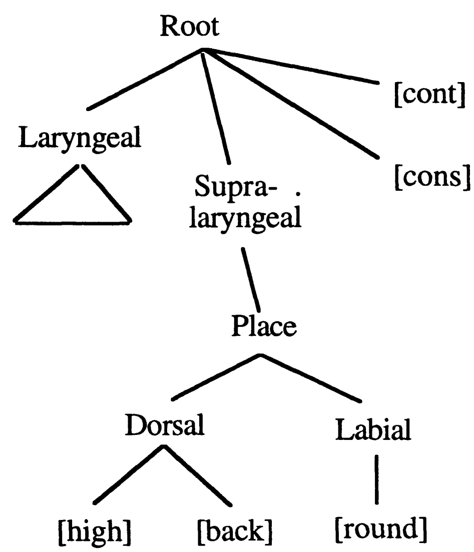
In Stevens *et al.*'s (1986) theory, as well as that presented more generally in a later paper, Halle and Stevens (1990), the phonology presents to the phonetics an abstract structure which includes both underlying and redundantly specified features. Many recent phonological theories (e.g. Clements 1985; Sagey 1986; Halle and Stevens 1990) group features hierarchically based primarily on the types of phonological processes, especially assimilations, apparent in a sampling of the world's languages. Thus a final representation to be interpreted phonetically for the segment [w] would be as shown in (6) or (7). In general, it is not difficult to see how such structures can be mapped onto phonetic goals. Terminal features under one articulator node can be interpreted as giving the location and various attributes of a vocal tract constriction to be implemented. Information about the degree and time course of the execution of the constriction is to be taken from major class specifications found on or around the root node, as well as from information about the position of the features in the prosodic structure of the utterance (as is discussed in de Jong, Beckman and Edwards 1993). Such prosodic information is usually graphically described as residing above the root node in the form of labeled metrical trees (see, e.g. Pierrehumbert and Beckman 1988).

The present case of rounding and backing presents a problem for this general model of the relationship between phonetics and phonology. There are two separate feature complexes – one labial-dependent, one dorsal-dependent – which are said to represent the labial and dorsal movements observed in the speech of the present speakers. The phonological representations given here, however, are missing one crucial piece of information for mapping features onto phonetic goals: that labiality and backing are sub-parts of a single phonetic unit, a contrast.

(6)
Halle and Stevens (1990):



(7)
Sagey (1986):



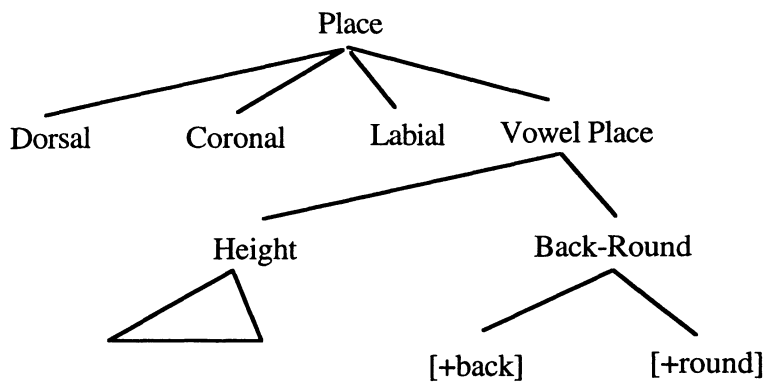
There are two types of approaches to remedy the problem. The first general approach is to reconsider the relationship between phonological features and phonetic goals. Specifically, one could propose that what is phonetically important in phonological representations are not the featural primes used in expressing phonological operations, but rather are meaningful lexical contrasts. Speakers in the process of acquiring and fine tuning their production systems are presented with the problem of producing acceptable lexical contrasts. Their solution to this problem may involve any of a number of articulatory strategies, including in the present case different amounts of rounding and tongue backing. Speakers acquiring a motor system for producing the front-back distinction may come up with rather different techniques for producing the distinction -- using the tongue dorsum, using the lips, or using some combination of the two. Variation in the solution to this problem, then, provides the seeds for diachronic variation, such as that exhibited in American English, as aspects of the particular articulatory strategies become part of the formulation of what is considered an acceptable contrast.

Stating this general approach in terms of a difference in phonetically and phonologically important information entails that phonological representations do not directly dictate phonetic behavior. One might say that phonological descriptions tell about the informational structure that speakers use in organizing their lexicons and their morphological systems, but they do not tell us directly about the physical behavior of a particular speaker. While this approach may allow for a simple approach to the present problem, insulating the phonetics from the phonology complicates both the understanding of the phonetics and of the phonology. It is difficult to imagine how to approach the study of the phonetics of languages with particularly rich morphological structure -- ones in which the structure of the lexicon is not clear from rudimentary phonemic analysis -- without having a clear analysis of the phonological system. Similarly, it is difficult to imagine how to approach the phonological study of (post-lexical) prosodic systems (whose construction is not primarily posited on the basis of lexical contrasts) without assuming a fairly immediate relationship between phonetic behavior and surface phonological structure.

The second general approach is to change the posited phonological structure. For example, one could modify the phonological inventory with an eye toward providing more acoustically isomorphic phonological groupings. In this case, adding the feature [grave] (Jakobson, Fant and Halle 1963) would be one possible solution. This is essentially the structure argued for by Odden (1991), using the same kinds of argumentation from phonological processes used to support the feature hierarchies posited by Sagey (1986), and Halle and Stevens (1990). A part of the featural representation for [w] is shown in (8). The feature node Back-Round combines the features back and round into a single constituent, and it is the articulation of this constituent that (at least) subject MB's labial and dorsal activity is focused. The labial-dorsal yoking under the feature [grave], then would be exactly parallel to the jaw-lip yoking for the feature [labial].

(8)

Odden (1991):



This solution is not entirely without problems, however. For example, the lip-jaw yoking and the labial-dorsal yoking are not entirely parallel with respect to the posited phonological structure. While there are no phonological features representing the jaw and the lip separately under labial, there remain the features [round] and [back]. Are these to be considered separate phonetic goals from that represented by the parent [grave]? Or should the [round] and [back] features simply be eliminated? This would leave the [grave] feature as a terminal node to be interpreted by some unspecified means, labial or dorsal.

Another potential problem with changing the feature inventory to match up with phonetic goals, might also become apparent in examining other cases of redundancy. Keating (1985) suggested several cases which she construed as cases in which several phonetic parameters are yoked together under one feature, such as the case of vowel lengthening before voiced obstruents in English. Vowel lengthening acts as a redundant cue to voicing distinctions. A parallel case to that found above for rounding and backing would be evident in a compensatory relationship between amount of voicing and amount of lengthening in the preceding vowel. Another case would be that of consonant-induced high tone in Chonnom Korean (Jun 1990). Here, initial high tones appear on initial syllables after aspirated and fortis obstruents, while low tones appear after lenis obstruents. A parallel to the case above would be a compensatory relationship between f0 raising and the sharpness of the attack for the fortis consonant. If such cases often show the same kind of mutual compensation as that shown here for backing and rounding, the feature inventory might become prohibitively large.

A second way of changing the phonological structure, without modifying the inventory of features, is to add some sort of linking mechanism, which would effectively unify previously disparate features on a language specific basis (though the linking mechanism might be governed by universal principles). Stevens *et al.* (1986) talk of such linking in terms of transformational redundancy rules. Similar is another suggestion of theirs, that distinctive features may be subsumed under "cover-features." (See the similar treatment of the feature, [flat], by Jakobson *et al.*. 1963.) Whatever the formal shape of the mechanism, it should have the effect of allowing one to express a contrast as a phonological entity comprised of several features.

Of these solutions, modifying the feature hierarchy is most in line with current generative phonological theory. Pursuing this line of explanation, researchers into the structure of featural representations should pay attention to more than just the expression of phonological processes; they should also account for the apparent phonetic goals of the speakers of the languages being analyzed. Thus, though issues in feature geometry might not be decided by *a priori* considerations of vocal tract anatomy or other phonetic facts (as is pointed out by Clements 1985), they should be amenable to explaining the phonetic behavior of particular speakers of a particular language. In line with this goal, the present study shows that the study of feature structure will be especially illuminated by careful phonetic studies of the variation found in the production and perception of similar, redundantly specified contrasts in a broad range of languages.

7. References

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