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VOWEL FEATURES

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This paper presents an inventory of the features that are necessary to describe vowel systems in the languages of the world. The relationship between the features and their articulatory and acoustic correlates is explored. Some vowel features, like High and Back, are accounted for in both articulatory and acoustic terms. Others, like Peripheral, are best described with reference to the acoustic domain. When the number of contrasts of each feature is considered, some features turn out to be multivalued.

This paper is an attempt to provide a first approximation to a set of features to specify contrasts and phonological processes involving vowels. The proposed set is exhaustive for these purposes. Most of the features have been proposed elsewhere, in particular by Ladefoged 1971, 1975; the major discussion here centers around the physical correlates of each. The number of phonological values needed for each feature is specified. Features involving interactions between consonants and vowels have usually not been considered, because this would entail a discussion of consonant features which is outside the scope of this paper (concerning these, see Williamson 1977).

The most basic vowel parameter is vowel height: all languages contrast high and low vowels. Another basic contrast is that between front and back vowels. Vowel height and backness form the foundation of a two-dimensional vowel space that is required to describe nearly all the languages of the world. Additional contrasts, like variations in lip position, pharyngal size, nasality etc. can be considered as superimposed on this basic vowel space.

1. HIGH AND BACK. From the time of Bell 1867, the basic two-dimensional vowel space has been described in terms of the highest point of the tongue. Very often vowels are represented on a chart, as in the cardinal-vowel system (Jones 1917). In practice, the points on a vowel chart represent an auditory description in terms of how different the vowels of a particular language sound from certain reference vowels. However, most phoneticians using the cardinal-vowel system for describing vowels also claim that points on the vowel quadrilateral represent the position of the highest point of the tongue (e.g. Jones 1956, Abercrombie 1967, O'Connor 1973). This amounts to suggesting that we hear differences between vowels in a way that is directly related to how the highest point of the tongue moves in producing these vowels; and a specific claim to this effect has been made by Catford 1977. There is, however, very little evidence in support of this view, other than subjective muscular sensations.

Using radiographic data from one speaker of Ngwe, Ladefoged 1964 concluded that the highest point of the tongue was not a good representation of vowel height and backness, particularly for the back vowels. He argued instead that these features were more closely related to their acoustic properties on a formant chart. Following Joos 1948, he equated vowel height with the inverse of the frequency of the first formant. (High vowels have a low first formant, low vowels a high first formant.) Later, Ladefoged suggested (1975) that position on the front–back dimension was best equated with the difference between the frequencies of the first and second formants. The back vowels are in better correspondence with the way in which they are heard when one relates backness to the difference between the first and second formant frequencies, rather than to the second formant frequency alone. On the usual acoustic chart, in which the first formant frequency is plotted against the second formant frequency, the vowels form a triangle where the high back [u] is further back than [ɔ]. A chart with F_2–F_1 plotted against F_1 looks more like the cardinal-vowel chart: the back vowels fall on a slope, with [u] slightly more forward than [ɔ]. Ladefoged (MS) illustrates the close relationship between the auditory and acoustic properties of vowels by comparing Danish vowels as plotted on a cardinal-vowel chart (H. J. Uldall 1933) with the formant frequencies of Danish vowels plotted on an acoustic chart (Fischer-Jørgensen 1972). These two charts are reproduced here as Figure 1. The formant chart is clearly a good description of these Danish vowels.

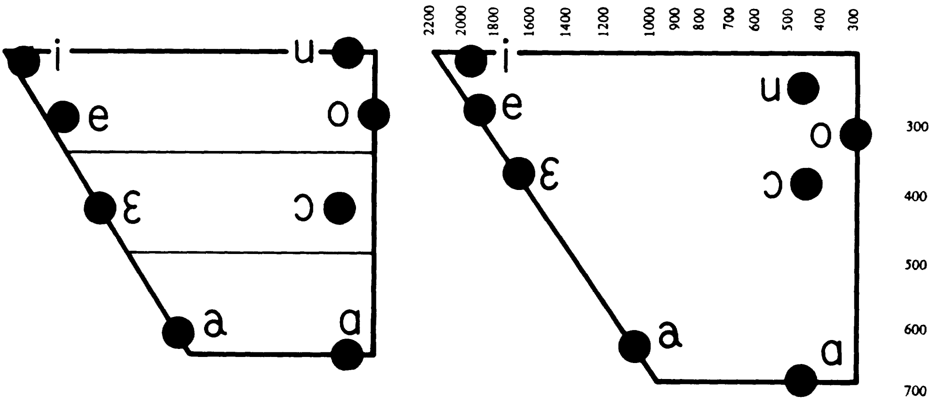

FIGURE 1. An auditory representation of some Danish vowels (after H. J. Uldall 1933) and a plot of the formant frequencies of these vowels (data from Fischer-Jørgensen 1972). The frequency of the first formant is shown on the vertical axis, and the difference between the first and second formant frequencies is shown on the horizontal axis. (After Ladefoged, MS.)

However, when additional radiographic data are analysed, it becomes apparent that Ladefoged has overstated his case: the traditional highest point of the tongue is virtually as good a measure of height and backness as the formant chart is. The data to be considered consist of tracings from cineradiographic recordings of five male speakers of American English from the Midwest. A listening panel of three linguists agreed that the speakers had the same variety of American English. The utterances were ten sentences of the form 'Say h__d again' with the vowels [i ι e ɛ æ ɒ ɔ o ω u] as in *heed*, *hid*, *hayed*, *head*, *had*, *hod*, *hawed*, *hoed*, *hood*, *who'd*. The diphthongs were analysed at a point shortly after the vowel onset (these data have been described in detail by Harshman et al. 1977).

For the purposes of the present study, these tracings were re-analysed, and the highest point of the tongue was marked with reference to the hard palate. For each speaker, the highest point of the tongue for the ten vowels was then measured in a co-ordinate system where the abscissa was a line parallel to the hard palate and the ordinate was a perpendicular to this line, going through a point at the edge of the upper teeth. The measurements of each vowel for the five speakers were averaged and plotted on a single chart.

The formant frequencies of these vowels were available from another study (Ladefoged et al., MS). These formant frequencies were then averaged, and the first formant frequency was plotted against the difference between the first and second formant frequencies.

An auditory chart of American English vowels plotted with reference to the cardinal vowels was found in J. W. Lewis 1972. The tongue height, acoustic, and auditory plots were then normalized so that the points in each of the three charts had the same mean and standard deviation. Figures 2, 3, and 4 show the normalized articulatory, acoustic, and auditory plots. The measurements from the normalized acoustic and articulatory charts were correlated with measurements from the normalized auditory chart, and then compared. If Ladefoged were correct in claiming that vowels are better described in terms of a formant chart than in terms of the highest point of the tongue, then the auditory chart should correlate significantly better with the acoustic chart than with the articulatory one. However, the results do not support Ladefoged's claim.

The correlations (Pearson's r) are shown in the first line of Table 1. The second line shows the value of Student's t, which is another measure of the degree of association between the two variables; and the third line shows the probability, p, of this association's being caused by chance. It may be seen that auditory height has a high correlation with both the vertical dimension of the highest point of the tongue and with the first formant. Auditory backness also correlates very well (in fact, slightly better) with both the articulatory and the acoustic measurements. For

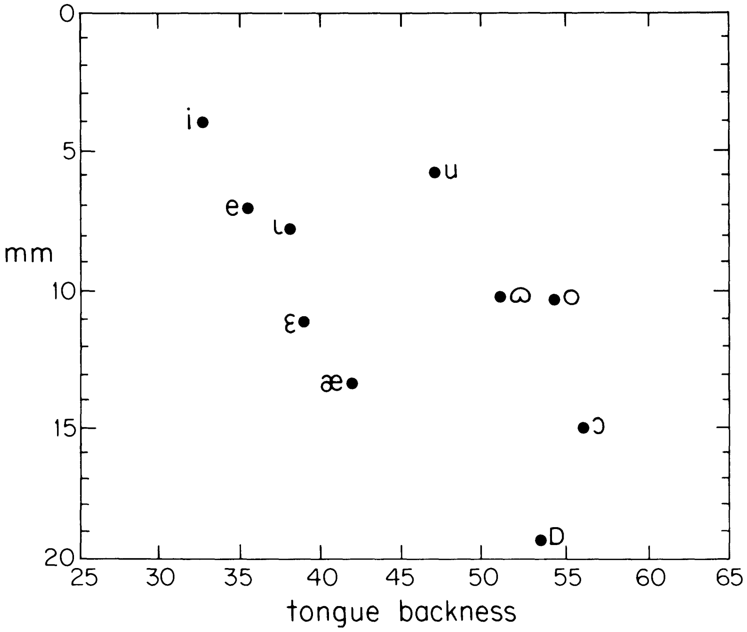

FIGURE 2. Averaged and normalized positions of the highest point of the tongue in American English vowels of five speakers.

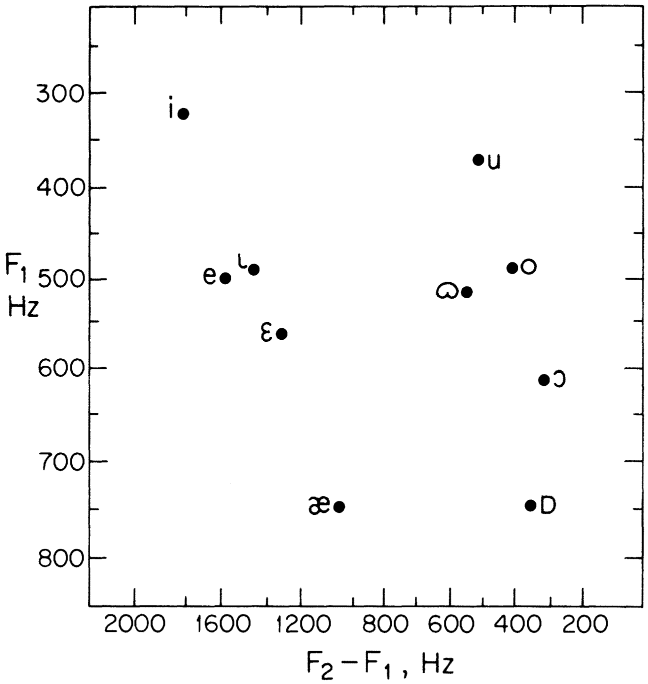

FIGURE 3. Averaged and normalized formant frequencies of American English vowels of five speakers.

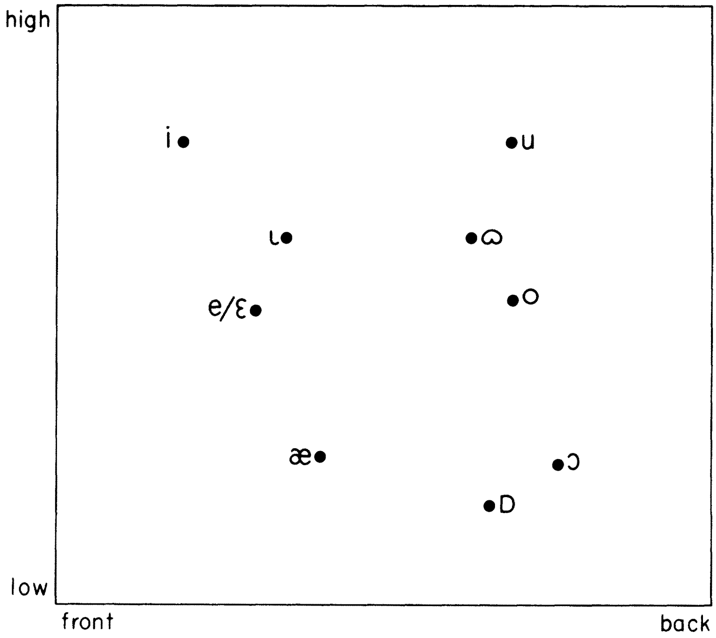

FIGURE 4. Normalized positions of American English vowels on an auditory chart (after J. W. Lewis 1972).

these data, the correlations between the auditory and the acoustic measurements are fractionally higher than those between the auditory and the articulatory measurements. But all the correlations are so high that Ladefoged's claim for the superiority of acoustic data does not seem warranted.

	AUDITORY HEIGHT VERSUS		AUDITORY BACKNESS VERSUS	
	F_1	TONGUE HEIGHT	F_2–F_1	TONGUE BACKNESS
Pearson's r	0.9522	0.9207	0.9817	0.9649
t	8.8163	6.6742	14.5792	10.348
p	< 0.01	< 0.01	< 0.01	< 0.01

TABLE 1. Auditory–acoustic and auditory–articulatory correlations for five speakers of American English.

Thus the features High and Back may be defined in both articulatory and acoustic terms. Neither domain can justifiably be preferred as the better correlate. Phonological processes involving these features are probably sometimes conditioned by the position of the tongue, sometimes by acoustic properties. A weakening process, as when a stop becomes a vowel (e.g. in the development of Modern English *rain* [rein] from Old English *regnian*) seems best explained by a stricture-type assimilation of the highest point of the tongue. But the tendency of non-low nasalized vowels to become lower is conditioned by a rise in the frequency of the first formant, caused by coupling with the nasal tract (House 1957, J. Ohala 1974).

The features High and Back may be regarded as cover features (Vennemann & Ladefoged 1973). High subsumes variations in two phonetic features; one, which we may call F_1, specifies sounds in terms of an acoustic scale; the other, which (following Williamson 1977) we may call Stricture, specifies an articulatory scale. Similarly, Back subsumes variations in F_2–F_1 and in tongue backness.

Both of the features High and Back must be multivalued, because vowel systems may contrast more than two values along each dimension; and there is no justification for regarding any single phonetic parameter as a composite of binary features. In describing phonological processes, the use of binary features to express movements along a single parameter amounts to a wrong claim about relationships between vowels (Ladefoged 1971). For certain phonological processes, a description with multivalued features is the only one that is immediately comprehensible and intuitively satisfying. As a case in point, we can compare rules with multivalued and with binary features in describing the following diphthongizations of Scanian, a Swedish dialect spoken in Malmö (Bruce 1970):

/iː/ → [ei] /yː/ → [øy] /uː/ → [eu]
/eː/ → [ɛe] /uː/ → [øu] /oː/ → [ɛo]
/ɛː/ → [æɛ] /øː/ → [œø] /ɑː/ → [æɑ]

In each case the inserted vowel is one step lower than the underlying vowel. Using multivalued features, where the highest vowels are regarded as [1 High], the rule is as below (rounding is ignored, as it is not pertinent here):

$$\emptyset \rightarrow \begin{bmatrix} \text{V} \\ \text{n}+1\ \text{High} \end{bmatrix} \;/\; \underline{\quad\quad}\ [\text{n High}]$$

The generalization that the inserted vowel is one step lower than the conditioning vowel is immediately captured. This process cannot be described using the binary features High and Low of *SPE* (Chomsky & Halle 1968), because four heights are involved and the combination [+High, +Low] is excluded. Wang 1968 has suggested that the features High and Mid replace High and Low. With these features, the facts can be described by using paired variables:

$$\emptyset \rightarrow \begin{bmatrix} \text{V} \\ \alpha\text{ high} \\ \beta\text{ mid} \end{bmatrix} / \underline{\qquad} \begin{bmatrix} \beta\text{ high} \\ -\alpha\text{ mid} \end{bmatrix}$$

This rule predicts the correct inserted vowel, but it does little else; and it wrongly implies that two separate phonetic mechanisms are involved. The rule must be fully deciphered before one can determine that a vowel-lowering process is described. The lowering nature of the rule is immediately obvious from the rule using the multivalued feature High.

How many contrastive values must be set up for each of the features High and Back? We noted above that all languages have contrasts in vowel heights. Some languages contrast only two values of vowel height, e.g. Kabardian with the following vowel system (Halle 1970):

ə
a

Turkish is an eight-vowel system, best analysed as having only two heights (G. L. Lewis 1967, Zimmer 1969):

i y   ɯ u
e ø   ɑ o

Sedlak 1969 lists some twenty languages with two vowel heights: but the vast majority of languages contrast three values, and the maximum number of values for this vowel feature seems to be four. Ladefoged 1971 reports Danish and English, and Hockett 1955 two Polish dialects, with four heights. Dan, a Mande language of Africa, has a system with at least four central vowels:

i ɨ u
e ᵻ o
ə
(æ) a (ɒ)

The low vowels /æ/ and /ɒ/ are included in the analysis of Dan by Bearth & Żemp 1967, but not by Welmers 1973.

For contrastive purposes, four values of High are needed. These values may be given names such as [high], [mid-high], [mid-low], and [low]. (In this paper, following Ladefoged 1975, NAMES of features are always capitalized, and VALUES of features are cited in square brackets.) When there are fewer contrasts, the values may be named [high], [mid], and [low]. Alternatively, as we have seen in the Scanian dialect described above, numerical values may be more appropriate in phonological rules. In a four-height vowel system, [high] vowels can be regarded as [1 High], and [low] vowels as [4 High]. It may sometimes be convenient to specify approximants like [j w ɥ ʋ] as endpoints of the High continuum; they can then be included at one end of the scale as [0 High]. Diphthongs ending in approximants can then be specified solely in terms of vowel features.

Some languages have no contrasts along the front–back dimension: in these languages, the single value of Back refers to [central] vowels. Such systems occur in some Caucasian languages, e.g. Kabardian. Hockett mentions Adyge, and possibly Abkhaz and Ubykh, with a system like this:

ɨ
ə
a

To my knowledge, there are no languages with only [front] or only [back] vowels. The occurrence of vowel systems with only [central] vowels constitutes a violation of Sedlak's proposed Universal 4: 'All languages have a high or lower high front vowel.' Both Kabardian and Abkhaz have extremely rich inventories of vowel allophones—including [i]—that are derived from assimilations to features of surrounding consonants; but we presume Sedlak refers to vowel systems on the phonological level. These facts further imply the non-existence of any universal to the effect that at least one particular vowel occurs in all languages of the world. Instead, I propose a different universal: 'If a language has no contrast in terms of the feature Back, then all the vowels will be [central].'

Most languages contrast two values of the feature Back. In the vowel systems we have looked at, these two values equal [front] and [back]. We may also propose a second universal pertaining to Back, to complement the first one: 'If a language has horizontal contrasts, then it has [front] and [back] vowels.'

The feature Back in the *SPE* system is binary. This excludes the possibility of specifying central vowels on the systematic phonemic level. Consequently, in languages with three heights, as in the very common seven-vowel system /i e ɛ a ɔ o u/, the vowel /a/ is forced into a [+Back] classification, and is distinguished from /ɔ/ by some other feature such as Round. This implies a curious claim that the third vowel-height somehow 'causes' /a/ to be [+Back]; but in fact, the way in which /a/ functions as [front], [central], or [back] in different languages has no obvious relationship to the number of heights or rounding involved.

There are languages that contrast three values of the feature Back with the same lip position. Norwegian (Vanvik 1972) has four high vowels, /i y ʉ u/, three of which are rounded. The vowels /ʉ/ and /u/ could conceivably be derived just as they are historically, namely from /u/ and /o/ respectively. But a neater system and a reduplication of historical processes are not sufficient justification for describing present-day Norwegian in this way. Current phonological processes do not support this 'solution'; there is no alternation between [ʉ] and [u], nor between [u] and [o]. Furthermore, Norwegian differs from Swedish (see below) in that the vowels /y ʉ u/ have the same lip position, as well as the same value of the feature High. We must conclude that Norwegian contrasts three values of the feature Back.

Since no larger number of contrasts has been found, another universal suggests itself: 'No language contrasts more than three values of the feature Back.'

2. Compressed and Round. Front vowels are naturally unrounded, and back vowels are naturally rounded. The reason for this is that the maximal acoustic distance in the front–back dimension is obtained by maximizing the mouth opening for front vowels, and minimizing it for back vowels (Ladefoged 1971, Liljenkrants & Lindblom 1972). Changing the size of the mouth opening from these 'natural' states is one way of creating more vowels. Decreasing the lip opening for front vowels, or increasing it for back vowels, will add vowels inside the basic acoustic space.

The lip opening can be decreased in two ways: by protruding the lips, or by compressing them—using vertical forces so that the lip opening becomes a narrow slit. These two possibilities have been recognized since Sweet 1877. The most common mechanism is protrusion, or rounding. The degree of rounding is to a large extent related to vowel height; a high [y] usually has a smaller lip opening than a lower-mid [œ]. But some of the variation in the degree of rounding seems to be language-dependent. The Swedish [y] is usually made with a larger lip opening than the German [y]. When looked at in profile, the protruded upper lip in a Swedish [y] looks slightly concave, but more convex in a German [y], which has some vertical compression of the lips. A more concave shape of the upper lip will result in a larger degree of lip opening, at the same vowel height, than a more convex shape. This kind of difference is never contrastive in any language, but it does explain why a Swedish [y] and a German [y] do not sound the same. Although both Swedish and German contain a vowel [y], a Swede learning German must adjust his lip rounding if he wants to sound native.

Decreasing the lip opening by lip compression without simultaneous rounding, in a [β]-like gesture, is comparatively rare. Swedish has three vowels with very similar high front tongue positions, namely the unrounded [i], the rounded [y], and a vowel [ʉ] which has a very small lip opening, produced by vertical lip compression only. Swedish also has a high back [u] with protruded lips, but the degree of opening is smaller than that for [y]. The Swedish [y] is made with a relatively concave upper lip, and [u] with a relatively convex upper lip. The Swedish [ʉ] is historically developed from [u]. Its unusual quality may well have been created by fronting the tongue position, retaining the very small area of the lip opening.

These two mechanisms for varying the size of the lip opening may be described by the features Compressed and Round. The feature Compressed refers to a lip position in which the upper and lower lips approach each other to form a narrow slit. The feature Round is defined as lip protrusion, produced by pulling the corners of the lips forward.

A feature Labial has been recognized, e.g. by Vennemann 1972 and Hyman 1975. Many phonological rules apply to vowels and consonants together, when both kinds of segments involve any kind of lip action. Following Venneman & Ladefoged, Labial is best regarded as a higher-level phonological cover feature, referring to any segments that involve action of the lips. The hierarchical relationships among these three features are illustrated in Figure 5.

Comparisons in phonetic detail, both between languages and within one language, can be made at the lowest level. This accounts for the differences in lip position between a Swedish [y] and a German [y], and for the fact that the lip position of [ʉ] in Swedish is more similar to [u] than to [y]. Phonological contrasts and processes are described by reference to the higher levels. It is a matter of some theoretical interest to note that systematic differences between languages cannot be described without involving more parameters at the phonetic level than are required to describe phonological contrasts within languages.

Although many different degrees of lip opening may occur in a language, no

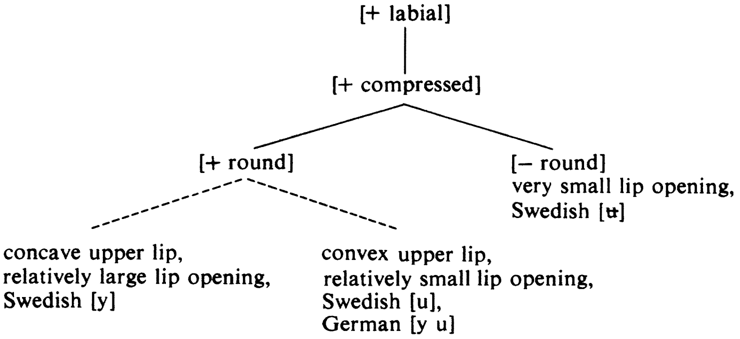

FIGURE 5.

language has contrasts of more than two values for Round or Compressed; so both features are binary at the phonological level. Turning now to how these features are employed in vowel systems, we will first consider the feature Round.

Systems with a single front-rounded vowel are rare: Chacobo, Basque, and Mandarin Chinese are reported by Sedlak. Two front rounded vowels occur in a fairly wide range of languages, e.g. German, Icelandic, Faroese, Norwegian, Swedish, French, Albanian, Turkish, Hungarian, Estonian, Tibetan, and Akha. No language has more than three contrastive front rounded vowels, and systems with this number are rare. They do occur in Danish (Andersen 1954, Spore 1965), although the contrast of /y/, /ø/, and /œ/ is restricted to environments before sonorant consonants (nasals, laterals, and *r*-sounds).

A system with one back unrounded vowel has been reported for Feng Yi, a dialect of South West Mandarin (Yang 1974). This dialect also demonstrates that front rounded and back unrounded vowels may co-occur in a system:

i y ɯ u
e o
ɔ
a

Two back unrounded vowels occur in Turkish:

i y ɯ u
e ø ɑ o

An even more complex system has been reported for Akha (P. Lewis 1968), with two back unrounded vowels:

i y ɯ u
e ø ɤ o
ɛ ɔ
a

The maximum number of back unrounded vowels is the same as for front rounded vowels, namely three, as in Vietnamese:

i ɯ u
e ɤ o
æ ʌ ɔ
a

Central vowels are mostly unrounded, though rounded ones occur in, e.g., Norwegian. No language contrasts rounded and unrounded central vowels at the same height. In languages with a single central unrounded vowel, that vowel is usually /a/. Sedlak lists a number of languages with two central unrounded vowels. Three central unrounded vowels are not very common, but occur, e.g., in Ngwe (Dunstan 1966) and Kashmiri (Kelkar & Trisal 1964):

Ngwe: i ɨ u   Kashmiri: i ɨ u
e ə o   e ə o plus length /ː/
ɛ ɔ   a
a

Four central unrounded vowels occur in Dan.

There is a problem in assessing systems with reported central or back unrounded vowels, since linguists do not consistently use the same symbols for these vowel classes. But as it turns out, this may be a pseudo-problem: two vowel classes never contrast for non-low vowels.

Swedish is one of the rare languages that contrast lip compression with and without rounding for high vowels, as in the following system:

ʉ i y u
e ø o
ɑ

Urhobo approximants supply another example of a Round–Compressed contrast. Urhobo has a round /w/ and an unrounded /ʋ/. Before high back vowels, both are also velar. Before rounded vowels, both /w/ and /ʋ/ are influenced by the rounding —but not in the same way. In the /w/ of /ű̃wùro/ 'bend in the knee' and /owɔ/ 'leg', I have observed that the lips are quite strongly rounded; but in the /ʋ/ in /òdùːʋù/ 'a kind of animal trap' and /ʋurɛ/ 'sever', the lip opening is decreased, though without protrusion (cf. Kelly 1966).

In both Swedish and Urhobo, the vowels and approximants differ by the use of two separate lip gestures, not by different degrees of the same gesture; so they should be characterized by separate features.

3. Expanded. In many Niger-Congo languages of West Africa and Nilo-Saharan languages of East Africa, vowels may be distinguished by a mechanism involving the size of the pharynx, as controlled by variation in the positions of the root of the tongue and the larynx (Ladefoged 1964, Pike 1967, Stewart 1967, Lindau 1975). This mechanism often underlies the phonological process known as vowel harmony. The size of the pharynx divides the vowel system into two sets, which may be labeled Set 1 and Set 2. Set 1 vowels are produced with a relatively large pharynx, Set 2 vowels with a relatively small pharynx. The vowels within a morpheme must harmonize, i.e. be selected from the same set. The ten (phonetic) vowels of the Akyem dialect of Akan are distributed into two sets of five each:

Set 1	Set 2
i u	ɩ ω
e o	ɛ ɔ
a	ʌ

Vowel harmony rules may also apply across morpheme boundaries. Thus, in Akan, the vowel in the prefixed personal pronoun has the same set affiliation as that of the stem morpheme of the verb. The verb 'to leave' is [fí] with a Set 1 vowel, while the verb 'to vomit' is [fɩ́] with a Set 2 vowel. The vowel in the pronoun alternates: [mì fí] 'I leave', [òfí] 'he leaves', but [mɩ̀ fɩ́] 'I vomit' and [ɔ̀fɩ́] 'he vomits'.

Many features have been proposed for this type of vowel harmony in African languages: Tense, Raised Height, Breathy, Covered. But radiographic data have demonstrated that the main phonetic control of the vowel harmony is the movement of the root of the tongue (Ladefoged 1964, Retord 1972, Painter 1973, Lindau 1974). The tongue-root mechanism is usually combined with vertical displacements of the larynx, and sometimes with movements of the back pharyngal wall. It thus seems that what a speaker tries to accomplish is variation of the pharyngal size.

I have investigated radiographic and acoustic data bearing on this from several vowel-harmony languages. In Figure 6 sample tracings have been superimposed from cineradiographic recordings of the eight harmonizing vowels of a speaker of the Akyem dialect of Akan. These vowels were analysed in CV-type words pronounced in a short frame. The Set 1 vowels /i e u o/ are produced with a relatively large pharynx, by advancing the root of the tongue beyond a 'normal' position for that vowel, and by lowering the larynx. The relatively small pharynx of the Set 2 vowels /ɩ ɛ ɷ ɔ/ is produced by retracting the root of the tongue and by raising the larynx. Note, too, that the highest point of the tongue is very similar for /i/ and /ɩ/, and for /u/ and /ɷ/. This demonstrates that the tongue root in this type of language is independent of the mechanism for controlling tongue height.

Figure 7 is a summary statement of the formant space in Akan. Formant frequencies of the Akan vowels were analysed from sound spectrograms of a tape

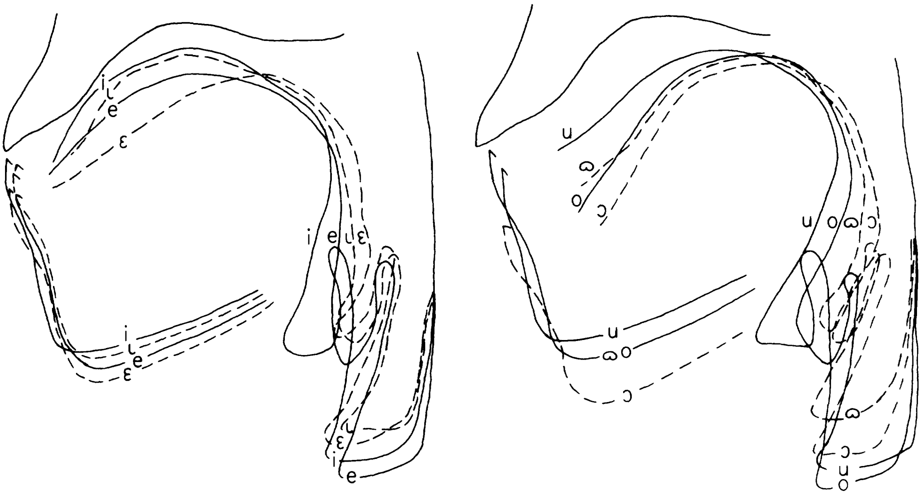

Figure 6. Superimposed tracings of front and back vowels from a speaker of Akan.

recording made simultaneously with the cineradiographic recordings, and then averaged. Four speakers were used, repeating each utterance five times.

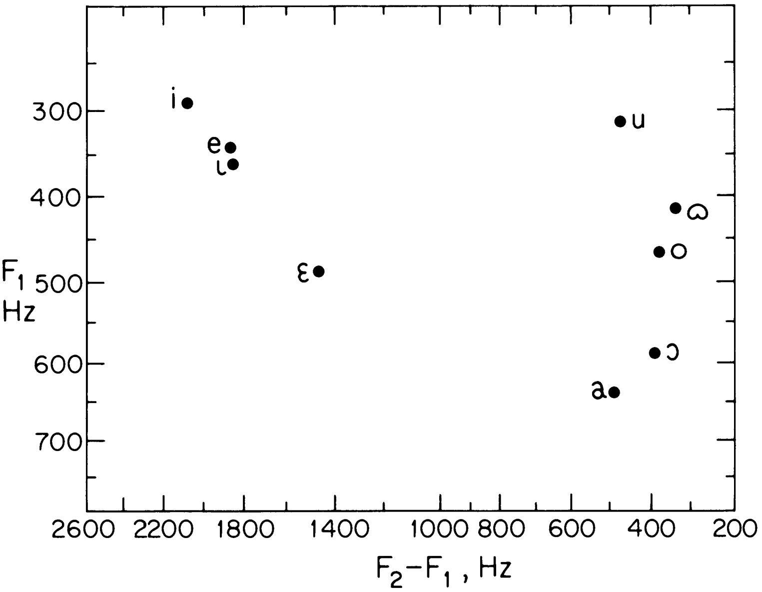

FIGURE 7. Formant chart of Akan vowels.

A comparison of Figs. 6–7 will give some idea of articulatory–acoustic relationships. Varying the size of the pharynx, as in the difference between /i/ and /ɩ/, affects the frequency of the first formant. Varying the highest point of the tongue, as in the difference between /i/ and /e/, also affects the frequency of the first formant. In fact, the two gestures have resulted in acoustic merging for the front /ɩ/ and /e/. These two vowels also have the same third formant. They remain phonetically distinct in that they are produced in characteristic ways. Presumably speakers can maintain this large, consistent articulatory distinction by observing the phonetic correlates of the phonological patterns. The fact that variation in the size of the pharynx and variation of the highest point of the tongue have very similar acoustic effects explains why this type of vowel harmony was described in terms of vowel-height differences by earlier linguists.

The differences between members of harmonizing pairs are always the same. The articulatory correlate of vowel harmony involves the tongue root and the larynx, working together to accomplish variation of pharyngal size. The phonetic feature is therefore best labeled Expanded, referring to pharyngal expansion. This is preferred over Advanced Tongue Root (Halle & Stevens 1969) and Wide (Ladefoged 1971), as these feature labels refer to only part of the articulation involved.

When there is no contrast, the tongue root is not especially advanced or retracted. This state is regarded as a zero value of the feature Expanded. In the African languages, the contrast is achieved by deviating in opposite directions from that zero value. So the feature values may be regarded as [1 Expanded], [0 Expanded], and [−1 Expanded]; or [expanded], [neutral pharynx], and [constricted], respectively.

It is conceivable that the same mechanism is involved in distinguishing the so-called emphatic and non-emphatic consonants in Arabic. It is evident from the cineradiographic data presented by Ali & Daniloff 1972 that vowels in the environment of pharyngalized consonants are all produced with a retracted tongue root, very similar to that in the vowel-harmony languages. This could be described as a contrast between [neutral pharynx] and [constricted].

The maximal vowel harmony system reported is 5+5 vowels, but these ten-vowel systems are relatively rare. They have been reported for some Kwa languages, namely Sele (Allen 1974), Abe (Stewart 1971), Igede (Bergman 1971), and Engenni (Thomas 1969); for some Benue-Congo languages, namely Ọgbia (Williamson 1972), Abuan (Wolff 1969), and Kohumono (Cook 1969); and for some Gur languages, i.e. Kasem, Sisala, and Mianka (Bendor-Samuel 1971). Among Nilo-Saharan languages, ten-vowel systems are found in Kalenjin, Päkot, Acholi, and Lotuko (Hall et al. 1974). Nine-vowel systems, where low vowels merge, are fairly common—e.g., in most Akan dialects, in Delta Ịjọ, and in some Central Delta languages. The vowel /a/ tends to be neutral to vowel harmony, and the 4+4+/a/ system patterns as below:

Set 1	Set 2
i o	ι ɷ
e u	ɛ ɔ
a	

Many languages have reduced the nine-vowel system to a partially harmonizing seven-vowel system. By the time the system has reduced to a five-vowel system, the vowel harmony will be lost (Williamson 1974).

4. Rhotacized. So called 'retroflex' vowels occur in, e.g., American English, Eggon (Maddieson 1972), and Badaga (Emeneau 1939). Badaga even has two degrees of retroflection. Emeneau analyses the Badaga vowel system into the following thirty contrasting vowels, each of which occurs long and short:

i u í ú i̋ ű V́ = slightly retroflex vowel.
e o é ó e̋ ő V̋ = strongly retroflex vowel.
a á a̋

The Badaga contrasts call for a ternary value of the feature for retroflection. This kind of three-way contrast has not been noted elsewhere.

Emeneau describes the retroflex vowels as being produced with the tip of the tongue curled upward and backward to a smaller or greater extent. Ladefoged 1975 points to the vowel in American English *sir*, *cur*, *bird*; and he notes that, although these vowels are strongly *r*-colored, they are nevertheless not always retroflex. Some speakers produce the *r*-coloring with the tip of the tongue down.

The American consonantal /r/ is not always retroflex, either. It is sometimes a 'molar' *r*, produced with the tongue tip down and the body of the tongue raised toward the palate (E. T. Uldall 1958, Delattre & Freeman 1968). The acoustic effect of either gesture is generally described as a lowering of the third and fourth formants (Delattre 1951). Because the invariance of *r*-coloring thus seems to be in the auditory-acoustic domain, rather than in the articulatory domain, Ladefoged 1975 labels the *r*-coloring feature Rhotacized, and defines it in acoustic terms. Stevens & Blumstein 1975 also describe the acoustic effects of retroflex plosives as lowered third and fourth formants during the transition to a following vowel.

There is, however, an invariant articulatory correlate of *r*-coloring—namely, a small retraction of the root of the tongue, 4–6 centimeters above the larynx. This constriction in the pharynx appears on x-ray data of retroflex consonants (Stevens & Blumstein), *r*-sounds (Delattre & Freeman), and *r*-colored vowels (data on five American English speakers described in Harshman et al.) Figure 8 shows the vowel in *heard* from one of these five speakers. The shape of the vocal tract is similar to that of the retracted tongue root in Set 2 vowels in the African vowel-harmony languages described above, but it is not identical.

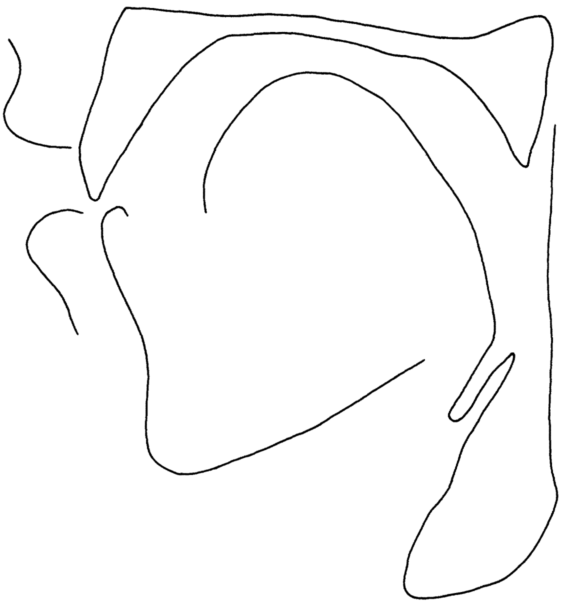

FIGURE 8. X-ray tracing of the American English vowel [əɹ], as in *heard*.

As noted above, the acoustic effect of retracting the tongue root and raising the larynx is a raising of the frequency of the first formant. Retracting a smaller portion of the tongue root above the epiglottis has a similar effect, although to a lesser degree. This has been demonstrated by synthesizing vowels using a line analog speech synthesizer (Rice 1971), which calculates the formant frequencies for a given vocal-tract shape. Vocal tract shapes approximating those in [i e ə o u] were generated on the model; and the root of the tongue above the epiglottis was varied in five steps, from a normal state for each vowel to a retracted position, as illustrated in Figure 9. The resulting acoustic changes are shown on the formant chart in Figure 10.

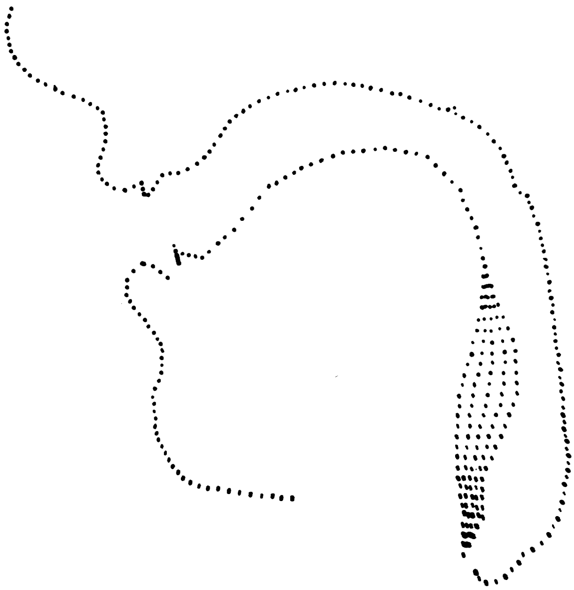

FIGURE 9. A [ə] shape of the vocal tract with the tongue-root position varied in five steps.

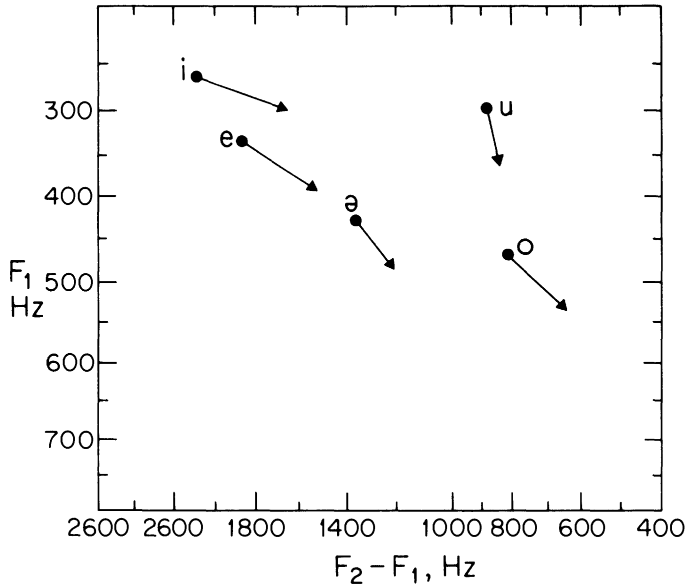

FIGURE 10. Effects on the first two formants of retracting the tongue root, as in *r*-colored vowels.

We may now compare rhotacized vowels with the [constricted] vowels found in vowel-harmony languages. In the [constricted] vowels, the whole pharynx is reduced in size by retracting the tongue root and raising the larynx. In the *r*-colored vowels, retraction appears to involve a smaller portion of the tongue root, and the larynx is not raised. Both actions result in auditory lowering and backing. In rhotacized vowels, the frequency of the third formant is also lowered. In the

African vowel-harmony languages, no difference in the frequency of the third formant was observed.

The retracted tongue root, with a resulting rise in the frequency of the first formant, is an important attribute of *r*-colored sounds. It explains why vowels often lower in the environment of *r* sounds. Lowered vowel allophones conditioned by an adjacent *r*-sound occur, e.g., in Scandinavian languages. Raising the tongue tip results in lowered third and fourth formants, but this does not explain the vowel-lowering rule. A pharyngal constriction above the epiglottis does. It also explains the large variation among speakers in the position of the front part of the tongue during production of *r*-colored sounds, because it may not matter precisely where the tongue tip is, so long as the root of the tongue is retracted.

Ladefoged's feature label Rhotacized is adopted here, but is further defined in articulatory terms as a constriction of the pharynx just above the epiglottis. The feature Rhotacized is ternary: [0 rhotacized] refers to no *r*-coloring, [1 rhotacized] to a small degree of *r*-coloring, and [2 rhotacized] to a large degree of *r*-coloring.

5. VOICE. There are only a few languages in which differences in phonation types among vowels are contrastive. Ladefoged 1971 reports contrasts among Lango vowels, described in terms of the values [voice] and [laryngealized]. Vowels showing a contrast between [voice] and [murmur] occur in Mpi (Peter Ladefoged, p.c.). Allophonic differences of phonation types are common. Voiceless vowels, conditioned by surrounding voiceless consonants, occur in many languages. Vowels in Hindi may have somewhat breathy voice when preceding breathy-voiced consonants. Ladefoged 1975 describes these using the feature Voice, which has values that include [voice], [murmur], and [laryngealized]. The same system is adopted here.

6. LONG. Long and short vowels occur in many languages. Durational differences are, however, not always interpretable as contrastive length. The domain of a length feature may be the syllable structure, e.g. Icelandic, Norwegian, and Swedish. In Swedish, closed long syllables may end in V:C or VCC. In other languages, where long vowels function like diphthongs, long vowels may be derived from VV sequences, as in Finnish (Lehiste 1970). The interpretation of [V:] as /VV/ is also common in tone languages which have tonal glides or double tone over a long vowel, as often happens in the Niger-Congo family.

Differences in vowel length are accompanied by qualitative differences in many languages; problems arise in interpretation, when trying to decide which is significant. The vowel quality differences usually manifest themselves as centralization of short vowels—e.g. in German, Swedish, English, Czech, and Serbo-Croatian, where the two sets of vowel qualities are referred to as 'tense' in long vowels and 'lax' in short vowels. A listening experiment conducted by Hadding & Abramson 1964 showed that, in Swedish, the durational differences became less important when a vowel pair differed substantially in quality. Thus it seems that, when vowels differ in both respects, quality differences are a primary cue, provided these differences are large enough.

There are, however, languages like Luganda, Estonian, and Mixe, where vowels differ solely in segmental quantity; so a feature Long must be included in a universal feature inventory. Probably only two values are contrastive: [short] and

[long]. The question of two or three contrastive lengths in Estonian (Lehiste) has been debated for years. Lehiste demonstrates that Estonian unquestionably has three ranges of durational vowel differences—short, long, overlong—but there are alternative interpretations of the overlong vowel. Hoogshagen 1959 reports that Mixe (in Mexico) has three vowel lengths V, V·, and V:, which he interprets as /V/, /V·/, and /V·h/, respectively. More than two lexically contrastive lengths have not yet been demonstrated unambiguously.

7. NASAL. Properties and processes involving nasalization in vowels have been discussed extensively by Ferguson 1963, Ladefoged 1971, Ruhlen 1973, and others. Nasalized vowels often occur phonetically in the environment of nasal consonants. But many languages show a true contrast between oral and nasalized vowels, e.g. many Kwa languages in West Africa. The feature is Nasal, with an obvious articulatory correlate: the state of the velum. The acoustic effects of lowering the velum are very complex. The feature Nasal is probably binary at the classificatory level, although several degrees of nasality occur phonetically.

8. PERIPHERAL. Vowel quality differences accompany long and short vowels in many European languages, e.g. English, German, Swedish, Czech, Friulian (Francescato 1970, Zannier 1972), and in some languages of India, such as Hindi (M. Ohala, MS). These vowel qualities are often referred to as tense and lax. A feature distinguishing these vowel qualities is needed in many phonological rules, and in order to characterize phonetic differences between languages. It is probably not required for classificatory purposes, because it never seems to occur without concomitant differences in length. The contrast can thus be accounted for by the previously discussed feature Long.

Phonetic correlates of tenseness have been extensively discussed since the time of Bell. Proposed correlates cover a wide range, from 'muscular energy' to perceptual 'color' dimensions. Sometimes, as in English, tenseness is accompanied by diphthongization. Long and tense vowels are more peripheral in the auditory-acoustic vowel space, while short and lax vowels are more central.

Recently, following a suggestion by Halle & Stevens, Perkell 1971 has proposed that tense vowels have an advanced tongue root. Using the radiographic data published in Wängler 1961, I have measured tongue height and advanced tongue root for eight German vowels. Tongue height was measured as the highest point of the tongue along a plane parallel to the hard palate. The degree of tongue-root advancement was measured as the distance from a point on the tongue root just above the epiglottis, where the effect of the genioglossus pull is maximal, to a point on the mandible. The correlation between these two measurements was calculated. A very low correlation would demonstrate that movement of the height of the tongue is not related to movement of the tongue root. In this case, tongue root advancement might constitute an independent mechanism. On the other hand, a high correlation between tongue height and tongue-root advancement would mean that the advancing and retracting of the tongue root is dependent on the height of the tongue, and cannot be an independent mechanism.

Figure 11 is a plot of four German tense–lax pairs. For this speaker, at least, tongue height and tongue-root advancement are highly correlated (Pearson's $r = 0.90$; $p < 0.01$). The tongue-root mechanism is not independent, and the vowel

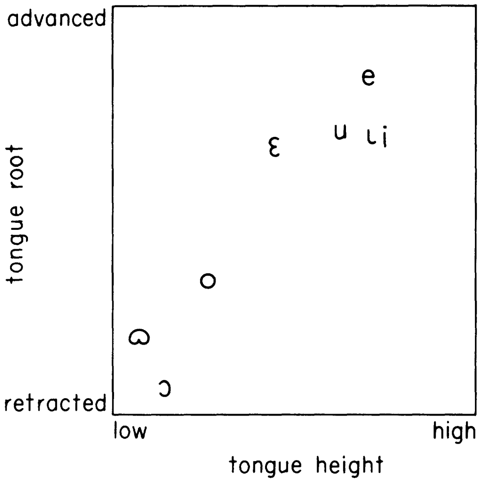

FIGURE 11. Correlation between tongue height and tongue-root position for the German tense–lax pairs [i]–[ɩ], [e]–[ɛ], [o]–[ɔ], and [u]–[ɷ].

quality differences between the tense and the lax vowels are related to differences in the height of the tongue, as Wängler in fact suggests.

The data from the five speakers of American English, described in §1 above, were analysed in the same way. Three of the speakers have a high correlation between tongue height and advanced tongue root (Pearson's $r = 0.90, 0.98, 0.80$; $p. < 0.01$), one speaker has a moderate correlation (Pearson's $r = 0.63$; $p < 0.01$), and only one speaker has a very low correlation (Pearson's $r = 0.21$). So, for four out of five speakers, tongue-root advancement is not independent, but is in fact strongly related to tongue height. Although tenseness may be related to tongue-root advancement, this is most often not the case. Instead, as in German, the tense and lax vowels in American English differ primarily in tongue height, not in terms of an independent tongue-root mechanism.

It is probably fair to conclude that the tongue-root mechanism is not used in any consistent way to distinguish between tense and lax vowels. The variation found among speakers in the American English data indicates that there simply is no unique articulatory correlate for tenseness. The auditory correlates of the difference between tense and lax vowels can be inferred from an acoustic chart. On such a chart, e.g. Fig. 3, the lax vowels tend to be inside the tense vowels. Although the difference is better regarded as acoustic than as articulatory, no single acoustic parameter exactly corresponds to this axis. As Stockwell 1973 has noted, the difference is between peripheral and non-peripheral vowels. It is worth noting here that, from an acoustic point of view, the difference between the so-called tense and lax vowels is not the same as the difference between [expanded] and [constricted] vowels. The tense–lax vowels differ on a peripheral—central axis, while the [expanded] and [constricted] vowels differ on a vertical axis of the first formant.

The difference between tense and lax vowels is best labeled by a feature Peripheral.[1]

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[1] Unlike the other features established here, peripheral is not known to be independently contrastive in any language; however, it is required for complete phonetic description.

It is a binary feature: so-called tense vowels are [+peripheral], and lax vowels are [−peripheral].

9. SUMMARY. The features required for the description of vowels are shown in Table 2. In Table 3, I list the languages mentioned in the text, with their genetic affiliations.

It may be seen that seven of the ten features can assume only binary values at the phonological level. The only features that frequently require specifications in terms of a greater number of values are High and Back. These are also the only two features that are used within nearly every language in the world. It is clear that, as noted at the beginning of this paper, these two features have a special status in the description of vowels.

FEATURE	CORRELATES	VALUES	MAXIMUM NUMBER OF CONTRASTS	LANGUAGE WITH MAXIMUM CONTRASTS
High	highest point of the tongue; the frequency of the first formant	high upper-mid lower-mid low	4	Danish
Back	highest point of the tongue; the difference between the frequencies of the first and second formants	front central back	3	Norwegian
Compressed	vertical lip compression	compressed non-compressed	2	Swedish
Round	lip protrusion	round neutral spread	2	French, Ngwe
Expanded	size of the pharynx	expanded neutral constricted	2	Akan
Rhotacized	retracted tongue root	strongly rhotacized rhotacized weakly *r*-colored plain	3	Badaga
Voice	shape of the glottis	glottal stop creaky voice voice murmur voiceless	2	Lango
Long	duration	overlong long short	2	Finnish
Nasal	state of the velum	nasalized non-nasalized	2	Yoruba
Peripheral	amount of centralization on acoustic chart	peripheral central	2	English

TABLE 2.

Language	Classification	Language	Classification
Abe	Kwa/Niger-Congo	Igede	Kwa/Niger-Congo
Abkhaz	Caucasian	Ịjọ	Kwa/Niger-Congo
Abuan	Benue-Congo/Niger-Congo	Kabardian	Caucasian
Acholi	Eastern Sudanic/Nilo-Saharan	Kalenjin	Eastern Sudanic/Nilo-Saharan
Adyge	Caucasian	Kasem	Gur/Niger-Congo
Akan (Twi)	Kwa/Niger-Congo	Kashmiri	Indo-Iranian/Indo-European
Akha	Burmese-Lolo/Sino-Tibetan	Kohumono	Benue-Congo/Niger-Congo
Albanian	Indo-European	Lango	Eastern Sudanic/Nilo-Saharan
Arabic	Semitic/Afro-Asiatic	Lotuko	Eastern Sudanic/Nilo-Saharan
Badaga	Dravidian	Luganda	Bantu/Niger-Congo
Basque	undetermined	Mianka	Gur/Niger-Congo
Chacobo	Tacana-Pano/Ge-Pano-Carib	Mixe	Zoquean/Macro-Mayan
Chinese	Han-Chinese/Sino-Tibetan	Mpi	Tibeto-Burman/Sino-Tibetan
Czech	Slavic/Indo-European	Ngwe	Benue-Congo/Niger-Congo
Dan	Mande/Niger-Congo	Norwegian	Germanic/Indo-European
Danish	Germanic/Indo-European	Ọgbia	Benue-Congo/Niger-Congo
Eggon	Benue-Congo/Niger-Congo	Päkot	Eastern Sudanic/Nilo-Saharan
Engenni	Kwa/Niger-Congo	Polish	Slavic/Indo-European
English	Germanic/Indo-European	Sele	Kwa/Niger-Congo
Estonian	Uralic/Altaic	Serbo-Croatian	Slavic/Indo-European
Faroese	Germanic/Indo-European	Sisala	Gur/Niger-Congo
Finnish	Uralic/Altaic	Swedish	Germanic/Indo-European
French	Italic/Indo-European	Tibetan	Tibeto-Burman/Sino-Tibetan
Friulian	Italic/Indo-European	Turkish	Turkic/Altaic
German	Germanic/Indo-European	Ubykh	Caucasian
Hindi	Indic/Indo-European	Urhobo	Kwa/Niger-Congo
Hungarian	Uralic/Altaic	Vietnamese	Austro-Asiatic
Icelandic	Germanic/Indo-European	Yoruba	Kwa/Niger-Congo

Table 3.

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