Figure 9.2 The mean tongue positions in American English vowels. The points show the locations of the highest point of the tongue with reference to the tips of the frontal incisors and a horizontal plane parallel to the upper molars.

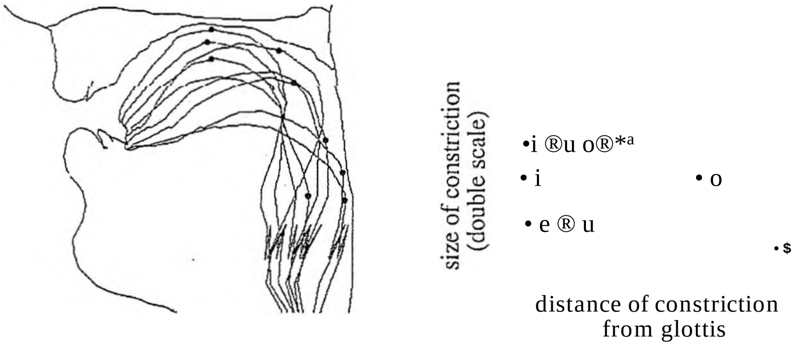

Figure 9.3 The mean tongue positions in American English vowels measured in terms of the size of the constriction, and the distance of the constriction from the glottis, as suggested by Stevens and House (1955) and Fant (1960).

mouth than appears in the figure, which shows only one position of the soft palate. The line along which this distance was measured for the back vowels is shown in figure 9.4.

However, even this representation of the articulation of vowels is not as close to the usual linguistic representation of these vowels as is that provided by the acoustic data. Figure 9.5 compares data on the mean frequencies of the first two formants in these same vowels with the articulatory representation of figure 9.4. In this figure the frequency values are scaled so that equal distances along either axis more nearly correspond to equal perceptual distances (using the Bark scaling techniques proposed by Schroeder, Atal and Hall 1979). The

Figure 9.4 The mean tongue positions in American English vowels measured in terms of the distance of the highest point of the tongue from the roof of the mouth. The lowering of the soft palate that takes place in low vowels has been taken into account in the placement of the points on the right of the figure.

frequency of the first formant, Fl, is plotted against the difference between the frequencies of the second and first formants, F2r-Fl, and the scale on the ordinate is double that on the abscissa, so as to give appropriate prominence to Fl and make the plots more in accord with the auditory judgments of professional phoneticians. The origin of the axes is to the top right of the plot. The acoustic representation corresponds more closely to the auditory phonetic description in terms of height and backness than the articulatory plots in figures 9.2-9.4. Note, for example, the way in which the low vowels ae and a have approximately the same height, and the vowels u and u are slightly forward as they are in American English. There are some notable discrepancies between the acoustic plot and the traditional linguistic classification. In particular the vowels i and u, which are traditionally classed as high, are acoustically closer to the mid- vowels e and o rather than to i and u. But this plot does place the expected vowels at the appropriate comers of the space.

Recognition that the placement of vowels on an auditory chart such as the one in figure 9.1 is supported more readily by acoustic than by articulatory measurements does not mean that articulatory scales can be discarded in the phonetic description of vowels. The first and second formant frequencies do not reflect only the properties that are described as Height and Backness. In fact, many articulatory adjustments contribute to the values of these acoustic parameters, one of the most important being the effect of lip rounding. As will become clear at several points in the remainder of this chapter, formant values often distinguish between pairs of vowels which would be said to have the same Height and Backness. It is important therefore to pay attention to both articulatory and acoustic aspects of vowels.

Figure 9.5 A comparison of an acoustic representation and an articulatory representation of a mean set of American English vowels.

Vowel height

All languages have some variations in vowel quality that indicate contrasts in the vowel height dimension. Even if a language has only two phonologically contrastive vowels, the differences will always be in this dimension rather than the front-back dimension. Thus, in native vocabulary, the Chadic language Margi has i, a and the Australian language Eastern Arremte has a, a. Among the Caucasian languages, Ubykh and Abkhaz have only two phonological vowel heights, with the contrasts usually represented as a and a (Catford 1977b). None of these two-vowel languages make any phonological use of the front-back, or the rounding, dimensions in their vowel systems. The same is true of some of the other Caucasian languages, such as Kabardian, which have three phonologically contrastive vowels (not, as far as Kabardian is concerned, two, one or zero as suggested by Kuipers 1960, Anderson 1978 and Halle 1970 respectively).

In all these cases of languages that have only height differences, there are also very obvious differences in the front-back dimension, so that to the casual observer it might appear as if the language used a wider range of vowel qualities. Figure 9.6 shows the distribution in the F1/F2 space of over 100 tokens of Arremte /a/ spoken by a female speaker. The formants were measured from spectrograms at the vowel mid-point in word-medial CVC syllables with stops. The data points are mostly plotted with symbols that indicate the preceding consonant, as there is some correlation between the preceding consonant and the vowel formants.

However, although figure 9.6 shows that there is much variation in the acoustic quality of the a vowels, this variability is for the most part

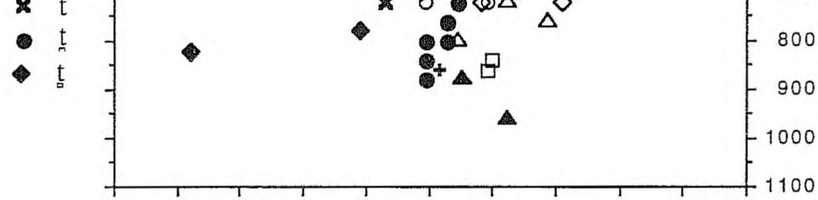

Figure 9.6 Scatter of values of F1 and F2 for /ə/ in Eastern Arrernte.

uncorrelated with particular consonant environments. The tendency for the mid-point of the vowel to be influenced in any consistent way by the place of a preceding consonant is quite weak, as is shown by the plot in figure 9.7. This shows the mean for each of the consonant environments for which ten or more tokens were measured. As is apparent, the means lie very close together in figure 9.7.

As another example, figure 9.8 is a formant plot of the allophones of some Kabardian vowels analyzed by Choi (1991). As is shown by the location of the points on the chart, this language has a wider range of vowel qualities than is indicated by the use of just three symbols that represent only differences in vowel Height, but only certain consonant environments show significant effects on the vowel formants. The main variations within each vowel type occur because the approximants j and w (and labialized consonants) have assimilatory effects on the neighboring vowels, and because uvular and pharyngeal consonants (absent in Arremte) have marked lowering effects. All these different qualities are predictable allophones of the three vowels, i, a, a. It is also clear, as Choi (1991) points out in discussing this analysis, that Catford (ms in preparation) (and many linguists in the former Soviet Union) are correct in recognizing a as a third vowel. In Choi's view a is a long vowel that could be written a:, but it is a separate phoneme, and cannot be considered to be an allophone of a as suggested by Kuipers (1960) and Halle (1970).

Variations in vowel quality often involve all three of the primary dimensions, Height, Backness, and Rounding. This sometimes makes it difficult to

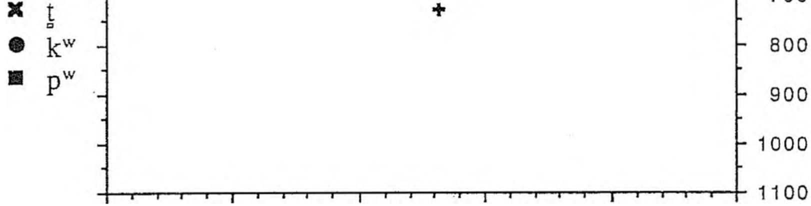

Figure 9.7 Mean position of values of Fl and F2 for /a/ in Eastern Arremte for ten or more tokens sorted according to preceding consonant context.

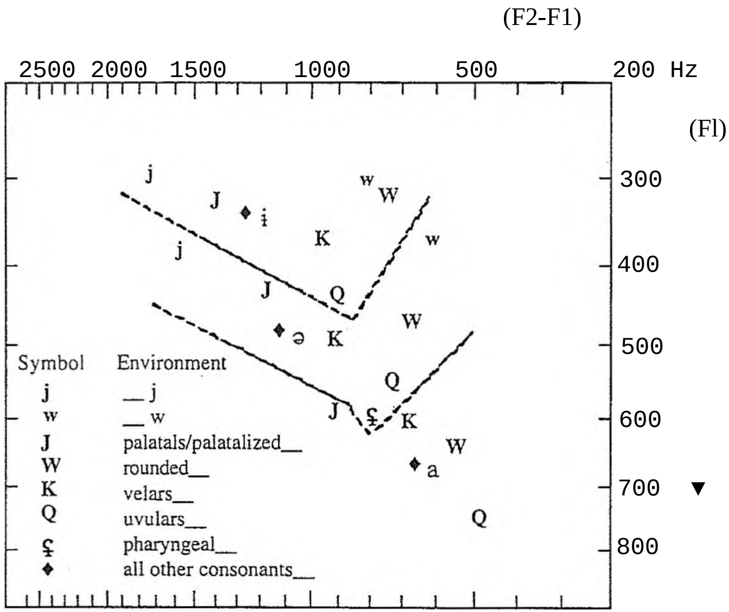

Figure 9.S Mean formant frequencies of the three Kabardian vowels in different contexts as produced in connected speech by three speakers (based on data in Choi 1991). The symbols indicate the formant frequencies of the steady-state portion in the contexts shown.

Figure 9.9 The relative phonetic qualities of the four front unrounded vowels of Danish, based on Uldall (1933).

Table 9.1 Words illustrating four degrees of vowel height in Danish

vila	'wild (pl)'	villa	'rest'	vi:6a	'know'
mens	'remind'	memo	'mean (vb)'	ve:3a	'wheat'
lesa	'load'	le:sa	'read'	ve:3a	'wet (vb)'
masa	'mass'	ma i sa	'mash'	va:3a	'wade'

decide how many distinct levels of Height there may be in a particular language. Bearing this in mind, we will consider how many levels of Height are used in the world's languages. Some linguists (e.g. Chomsky and Halle 1968) have suggested that there are only three (although, of course, these linguists recognize other dimensions which they use for representing what we regard as simply variations in Height). Jones's (1956) Cardinal Vowel scheme makes reference to four particular levels of the Height dimension, but has provision for more possibilities. The full set of vowel symbols recommended by the EPA (1989) implies that there are seven levels. We doubt that any language uses this full range; but there are clearly more than three levels of the auditory property Height.

Evidence for the possibility of more than three contrasting vowel heights comes from Danish, in which there are four front vowels that contrast simply in vowel height. Examples are shown in table 9.1. It is noteworthy that at each of these four vowel heights there is also a contrast between a short and a long vowel, which do not differ appreciably in quality. These vowels are even more interesting because it is quite clear that they are not equidistant. Uldall (1933) represents them as shown in figure 9.9. There is a much larger gap between the vowels represented here by e and a than there is between the vowels i and e. This raises the possibility that there might be a language with five vowel heights.

Traunmiiller (1982) has suggested that the Bavarian dialect spoken in Amstetten, Austria, might be such a language. In his analysis this language has

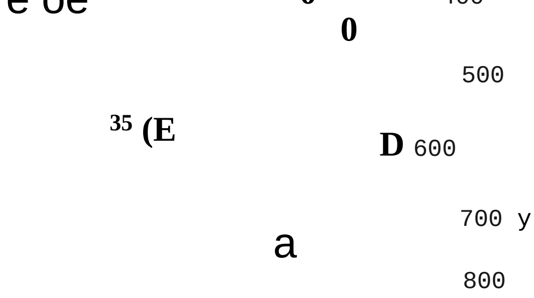

Figure 9.10 The mean formant frequencies of the long vowels of eight speakers of the Amstetten dialect of Bavarian (data from Traunmiiller 1982).

four front unrounded, four front rounded and four back rounded vowels, in addition to the low central vowel a. Traunmiiller conducted a controlled study in which he recorded a number of speakers of this dialect, and measured the acoustic characteristics of the 13 long vowels so as to obtain an indication of the traditional Height and Backness values. The mean formant frequencies of eight of his speakers (as reported by Disner 1983) are shown in figure 9.10. We have not ourselves investigated the vowels of this dialect of Austrian German, and so we cannot say whether there are any other factors involved which might lead to it being possible to describe this language as having fewer than the five vowel heights that are apparent in figure 9.10.

Front-back variations in vowels

The languages of the world make much more limited use of the front-back and rounded-unrounded dimensions, which usually support no more than binary oppositions. There are not many cases of a language with three vowels that contrast just by being front, central and back, with all other features remaining

Table 9.3 Words illustrating contrasting front, central and back vowels in Nweh (from Ladefoged 1971)

	FRONT	CENTRAL	BACK	
ROUNDED	nty 'advise'		mbu 'corners'	
				niGH
	mbi 'cowries'	mbi 'dog'		
	mbe 'knife'	ntsa 'water'	mbx 'ivory'	MID

the same. One possibility is Nimboran, a Papuan language. Anceaux (1965) describes this language as having six vowels which he symbolizes i, e, a, o, u, y. He notes that "all vowels are unrounded and voiced. They contrast in tongue height and tongue placement." The vowel i "is a voiced high close front unrounded vocoid." His y (for which he says "the symbol ... has been chosen quite arbitrarily and for practical reasons only") he describes as "a rather tense voiced high close central unrounded vocoid." We would transcribe this vowel as i. He describes his u as "a voiced high close back unrounded vocoid," which we would transcribe as tu. It would therefore appear as if there were three high unrounded vowels contrasting only in backness in this language. Examples (from his data, but in our transcription) are shown in table 9.2.

There are a number of other cases such as that in Nweh (Ngwe), illustrated in table 9.3, where it is certainly convenient to postulate the existence of a category central, which is neither front nor back. The situation in Nweh is complicated by the fact that Dunstan (1964) has shown that the surface vowel y is underlying i, and the surface vowel a is underlyingly x, so the surface contrast between the mid vowels e, a, and x does not involve a three-way phonological opposition. But even taking this into account there is still a phonological contrast between front i, central i, and back u and x.

Another language which can be said to have a three-way contrast in the front-back dimension is Norwegian, described by Vanvik (1972) as having

ry:ta 'roar'	ru: ta 'window pane'	riita 'draw'

three high rounded vowels as shown in table 9.4. Consideration of a number of very different cases, such as Nweh and Norwegian, leads us to conclude that it is probably appropriate to recognize a front-back dimension containing three major phonetic categories: [front], [central] and [back]. There are also phonological reasons for saying that in languages with systems containing five vowels, and in many of those with systems containing seven vowels, the lowest vowel is neither front nor back, and should be regarded as central. This is often the position taken in descriptions of the vowels of Italian. It is arguable that a similar situation obtains in English with respect to the starting points of the diphthongs in *high* and *how*. For many people these diphthongs have the same, or very similar, starting points. A generalization is lost if the inadequacies of the feature system do not allow one to say that both these diphthongs start with a low central vowel.

A rather unusual acoustic correlate of the front-back parameter occurs in a variety of i in Swedish, which differs from the more usual varieties of i in that it is made with the constriction even further forward. This effect can be achieved by slightly *lowering* the body of the tongue while simultaneously raising the blade of the tongue (Ladefoged and Lindau 1989), and we suggest that this may occur in the usual Stockholm Swedish pronunciation of this vowel. Acoustically this pronunciation is characterized by having a very high F3, and an F2 which is *lower* than that in e. This provides another instance of the need to consider acoustic and articulatory facts together in the analysis of vowels. This Swedish vowel is illustrated in table 9.5.

Lip position

The great majority of the world's languages have a predictable relationship between the phonetic Backness and Rounding dimensions. Front vowels are usually unrounded and back vowels are usually rounded. However, as shown 'to eat' 'we/our'

above for Bavarian. German, front vowels with a rounded lip position also occur. In addition, back vowels without lip rounding can be found, sometimes simply because a language has relaxed the linkage between Backness and Rounding (as for the high back vowel of Japanese), but also on occasion because rounded and unrounded vowels are independently contrastive within the class of back vowels, as in the Turkic languages Chuvash and Yakut. Vietnamese has some notable contrasts between back rounded and unrounded vowels, as shown in table 9.6.

Rounding and Height are also related in that higher vowels are usually more rounded than lower vowels. All of these matters concerning lip position can be illustrated with the data in figure 9.11, which shows the lip position of the ten vowels of laai taken from a videotape of a speaker pronouncing isolated words. Each vowel in this figure is represented by the frame with the maximal gesture of the lips for the vowel. The three high vowels i, y, u illustrate a rounding contrast independent of backness. The four higher mid-vowels e, 0, o, x extend this independence to include a back unrounded vowel. The lip aperture is markedly smaller for the two high rounded vowels (u, y) than for the two higher mid-rounded vowels (0, 0), and the rounded low vowel o has an even greater aperture. The three more open vowels ae, a, o all have relatively open lip positions. Nonetheless, the lips are visibly rounded for o in a way that is not so for ae and a.

There are exceptions to this general relationship between Height and Rounding. Sometimes the deviations are comparatively small, as in the case of RP British English o, which has been described by Jones (1956) as having lips "more closely rounded than for Cardinal o." But in other languages there is a considerable discrepancy between the Height and the degree of rounding. In Assamese there are two low back vowels, one of which sounds like British English a as in 'father', and probably has similar tongue and lip positions to that vowel. The other Assamese low back vowel has a slightly different tongue position - more like that of British English o as in 'caught' - but is accompanied by close lip rounding like that in Cardinal u.