

What Helmholtz Knew about Neutral Vowels

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0. INTRODUCTION

The essence of vowel harmony is a constraint on the vowels within a larger domain, grammatical or prosodic, requiring that all the vowels agree in a given phonological feature (e.g., backness, rounding, tongue root advancement). For example, in Diola Fogny all vowels in a word must agree in tongue-root position (Sapir, 1965, where this feature is called 'tense'). That very few languages in fact exhibit this ideal harmony type has remained a source of challenge to phonology, both in the descriptive treatment of specific languages and in the revision of formal theory to account for the problems which arise.

Three basic difficulties may be noted. First, there is the problem of ad-hoc domains, i.e., where the domain of harmony does not correspond to any prosodic or grammatical structure of the language. For example, in Turkish, rounding agrees over the domain: any vowel followed by subsequent high vowels (ignoring intervening consonants). Or in Votic, with backness harmony, *o* is opaque and requires subsequent vowels to be back, e.g., *mænk-o-za* 'in the game' (cf. *mæñčiiizæ* 'in playing' < *mæнки-А-зА*, *alčiiiza* 'in the straws' < *alkE-i-za*). Second, there is the problem of ad-hoc features, i.e., where the harmonizing vowel classes are not naturally characterized by established feature parameters. For example, the dominant/recessive harmony alternations of Nez Perce ($\text{æ} > a$, $u > o$, but *i* is either dominant or recessive), viewed by Kiparsky (1968) as 'attraction toward *a*' of the dominant set, allow a rule which reflects that generalization only at the cost of treating dominant *i*'s as underlying abstract ə, i.e., [+back,-high].¹ Finally, there is the problem of neutral vowels, i.e., where not all vowels are subject to the harmony constraints. For example, in the tongue-root-advancement harmony systems of West Africa, the low vowel *a* is frequently neutral (Ladefoged, 1968:36-38). Similarly, among the many tonality harmony systems of Eurasia, it is not uncommon for *i* to be neutral. Although one can readily imagine both articulatory and acoustic reasons why a low vowel might not participate in a tongue-root-advancement opposition system, the neutrality of the front vowel with highest tonality within an otherwise productive front/back harmony remains without an obvious explanation under current theories.

It is this last problem, the neutral vowels within tonality harmony systems, for which I hope to provide a new perspective in this paper. I shall first examine the vowel systems of three Uralic languages with productive tonality harmony – Votic, Finnish and Hungarian. In an attempt to shed light on the phonological role of the neutral vowels in these languages I shall propose a new set of phonological vowel features based upon functional interpretation of vowel spectra. Finally, I shall suggest that the solution to the problem of perceptual vowel normalization lies in the geometry of the energies of the lower harmonics rather than in a calculation based upon the frequencies of the fourth and higher formants.

1. VOTIC (BASED ON ARISTE, 1948)

The harmony status of the Votic vowels is given in (1).

(1) Harmonic: Neutral: i

Front	Back
ū	ɨ u
e ö	ə o
æ	a

Alternating pairs:

- æ ≈ a : joomma 'we drink' – veemmæ 'we take'
 jöimma 'we drank' – veimmæ 'we took'
 e ≈ ə : juvvoza 'in drinking' – vidʹdʹezæ 'in taking'
 naizələə 'to the woman' – mehelee 'to the man'
 ü ≈ u : joonnu 'drunk' – veennü 'taken'

All vowels occur both short (*pälto* 'field') and long (*vääras* 'guest'). Although ɨ is lexically limited to Russian loans, these appear to be well assimilated to Votic phonological and morphological patterns, e.g., *kit-rüiba* 'whale' (cf. Rus. *kit* 'whale', *ryba* 'fish', although Russian has no such compound), *ränkoilla* 'at the market' (< *ränko-i-lla*; cf. Rus. *rynok* 'market'). Neutral *i* occurs freely with both harmony sets: *sika* 'pig': *ikæ* 'each', *talvi* 'winter': *mæči* 'hill', *issuizimma* 'we would sit': *čüsüzimmæ* 'we would ask'. A stem with all *r*'s takes front suffix variants: *pilli ssæ* 'from the musical instrument', *irt-tæ* 'log (part.)'. (Note, however, *mi-lta* 'from me', a suppletive contraction from *minulta*.) *ö* occurs beyond the initial syllable only in limited forms (such as Finnish loans like *tüttö* 'girl'), leaving *o* essentially outside the set of alternating vowels, other than a few cases such as *lähtö* 'departure' (< *lähte-* 'leave') alongside the regular *mænko* 'game' (< *mænki-* 'play'). *o* always

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2. FINNIS

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requires back harmony of subsequent syllables; thus, *leipoita* 'loaves of bread (part.)' < *leipæ-i-tA*; cf. *leipææ* 'bread (part.)' < *leipæ-tA*, *säbräita* 'friends (part.)' < *säbräi-tA*, *pältoiza-pältaiza* 'in the fields' < *pälto-i-tA*. Apart from the neutral vowel *i*, the words with *o* in non-initial syllables and a small list of affixes which are always back (e.g., *-kaa* '2 pl. imperative': *söökaa* 'eat'), the normal domain of harmony is the word.

2. FINNISH

The vowels of Finnish are given in (2).

(2)	Harmonic and alternating:	Neutral: <i>i, e</i>
	Front	Back
	<i>y (=ü)</i>	<i>u</i>
	<i>o</i>	<i>o</i>
	<i>ä (=æ)</i>	<i>a</i>

Vowels occur both short (*tuli* 'fire') and long (*tuuli* 'wind'). Except for the two neutral vowels, words are restricted to vowels agreeing in backness, e.g., *talossansako* 'in his house?' - *kynässänsäkö* 'in his pen?' (*-ssa* 'in', *-nsä* '3 pers. possessive', *-kö* 'interrogative'). The neutrality of *i, e* is illustrated in (3).

- (3)
- a. *sika* 'pig', *laki* 'law', *melu* 'noise', *sade* 'rain'
ikä 'age', *mäki* 'hill', *pesä* 'nest', *säde* 'ray'
itikka 'bug', *sovitellessä* 'in adjusting'
helinä 'tinkling', *käsitellessä* 'in handling'
- b. *itu* 'sprout (noun)' < *itä* 'to sprout'
veto 'pull (noun)' < *vetä-* 'to pull'
 (cf. *lähtö* 'departure' < *lähte-* 'to leave')
selvyys 'clarity' < *selvä* 'clear'
herrsus 'supremacy' < *herra* 'master'
veljeys 'brotherhood' < *veli, velje-* 'brother'
- c. *michuus* 'manliness' } < *miehe-* 'man'
miehyys 'masculinity' }
heinikko 'hayfield' < *heinä* 'hay'
metsikkö < *metsä* 'forest'
mesikka 'arctic bramble' } < *mesi/mete-* 'honey'
mesikkä 'sweet clover' }

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- d. itku 'crying' < itke- 'to cry' (cf. itkenyt 'cried')
 meno 'going' < men- 'to go' (cf. menkö '3 pers. imperative [negative]')
 seistä }
 seisoa } 'to stand' (remaining forms of the paradigm are based on seiso-)
- e.
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|-------------------|--------|---------|
| | 'sea' | 'water' |
| <i>nominative</i> | meri | vesi |
| <i>essive</i> | merenä | vetenä |
| <i>partitive</i> | merta | vettä |

Closer inspection of the morphological formations in (3b-c) gives some notion of the extent to which the neutral vowels complicate the phonology of modern Finnish. The forms of (3b) reveal problems in the rule of stem vowel truncation and its ordering relative to vowel harmony. The apparent inconsistencies among the derivations for the Standard Finnish words in (3c) point up difficulties in determining those rules (and exceptions) which underlie the competence of speakers of modern Finnish. Although the usage of some of these forms is not widespread, native speakers accept all as well formed. The recent formation *miehyys* and the botanical term *mesikkä* might suggest a shift toward the rule for productive inflectional harmony, by which stems containing only neutral vowels take front-vowel endings (cf. 'water' in (3e)).

On the basis of forms of the type given in (3d) (cf. also *miehuus*, *itu*, *veto*) Kiparsky (1973) has proposed a different harmony role for monosyllabic neutral vowel-roots when followed by a vowel-initial affix: for the sequence $C_0(i/e)C_0 + V_i \dots, V_i$ (if harmonizing) will be back, whereas for $C_0(i/e)C_0 + CV_j \dots, V_j$ will be front. The fact that V_i formations are restricted to a small set of nonproductive derivatives led Harms (1966) to posit a difference in boundaries as well as underlying backness for the V_i suffixes. The lack of harmony throughout an inflectional paradigm is exhibited by only two roots, *mer-* 'sea' and *ver-* 'blood', as in (3e), with partitive *-ta* for the expected *-tä*. Here the tonality-lowering effect of the *er* rhyme noted by Wiik (1975) accounts not only for these forms, but also for the absence of $C(i/e)rC\bar{a}$ -stems in general.

The impact of the neutral vowels upon Finnish phonology, as illustrated in (3), is significant. The various synchronic rules required to handle the harmony relationships must necessarily establish formal means to oppose two different vowel classes: (a) neutral vowels as distinct from other front vowels (especially *i, e* vs. *ä*), and (b) harmonizing vowels as distinct from neutral vowels. Five different strategies for Finnish vowel harmony may be seen in McCawley (1964 - abstract central vowels \ddot{a} , \ddot{o} and a rule of absolute neutrali-

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zation), Harms (1966 – an ad hoc feature parameter ‘acute’ is used in addition to the harmonizing graveness feature), Kiparsky (1973 – only underlying back vowels are subject to harmony, with secondary restorative backing in the *veto*, *meno* types), Wiik (1975 – two distinct harmony rules: fronting of all vowels posterior to the first harmony vowel and a backing harmony agreement rule) and Ringen (1980 – left-to-right iterative rule requiring specification of both the neutral and harmony classes of vowels). It is not my intention here to add yet another set of rules for describing the complexities of Finnish vowel harmony. I wish merely to establish the central role the neutral vowels must play in any attempt to achieve an adequate phonology of Finnish.

3. HUNGARIAN

Hungarian presents yet a somewhat different set of harmony relationships as outlined in (4) (with long vowels indicated by acute accents as in Hungarian orthography: \acute{u} = [ü]).

(4)	Harmonic:	Neutral: i, \acute{i}, \acute{e} (= [ē])
	Front	Back
	$\acute{u}, \acute{ü}$	u, \acute{u}
	$\acute{o}, \acute{ö}$	o, \acute{o}
	e (= [ε, æ]) ²	a, \acute{a}

Alternating sets:

- $u \approx \acute{u}$ hat-ul ‘behind’ – fel-ül ‘above’
- $\acute{u} \approx \acute{ü}$ X-haj-ú ‘X-haired’ – X-szem ü ‘X-eyed’
- $\acute{o} \approx \acute{ö}$ ház-ból ‘from a house’ – fej-ből ‘from a head’
- $o \approx \acute{o} \approx e$ var-tok ‘you wait’ – jöt-tök ‘you come’ – men-tek ‘you go’
- $a, \acute{a} \approx e, \acute{e}$ ház-a ‘his house’ – fej-e ‘his head’
- ház-á-ban ‘in his house’ – fej-é-ben ‘in his head’
- ház-á-nál ‘his house (adessive)’ – fej-é-nél ‘his head (adess.)’

Neutral vowels occur with both back and front harmonizing vowels (e.g., *bika* ‘bull’, *példa* ‘example’). Unlike Finnish, roots with only neutral vowels must to some extent be keyed lexically with regard to harmony type, cf. *víz-nél* ‘water (adess.)’ – *híd-nál* ‘bridge (adess.)’, *kéz-nél* ‘hand (adess.)’ – *cél-nél* ‘goal (adess.)’, *vidék-e* ‘her region’ – *férfi-ja* ‘her husband’. A count of lexical association of the various neutral vowels with back harmony gives the order $\acute{i} - i - \acute{e}$, with only four items, all nouns, having \acute{e} . In *leány* ‘girl’ and a few words of foreign origin even short e appears marginally neutral, e.g., *Agnes-nak* \approx *Agnesnek* ‘to Agnes’. Suffixes with i, \acute{i}, \acute{e} are strictly neutral in the sense

that they do not influence the harmony class of word structures, e.g., *pizsk-lt-ni-uk* 'for them to make dirty' (cf. *pizok* 'dirt'; contrast also *Tibi*, diminutive form of *Tibor*, *Tibinek* 'to Tibi') – *kér-ni-ük* 'for them to ask' (cf. *kér-ek* 'I ask'). For four different formal treatments of Hungarian vowel harmony, see the recent series of views expressed by Jensen, Phelps, Ringen and Vago in *Linguistic Inquiry*, 9 (1978).

4. THE HIGH TONALITY AS NEUTRAL TONALITY PARADOX

In summary, tonality harmony continues to play a productive role in the phonologies of the various Finno-Ugric languages surveyed here, although it is significantly complicated by the presence of neutral vowels. On the one hand, the tendency toward a regular association of the neutral vowels with front vowel harmony seems perfectly natural in view of their phonetic frontness. On the other hand, strange as it may seem, the neutral vowels are just those with the highest tonality (i.e., F_2/F_3 frequency values): the non-low unrounded front vowels. Indeed, it is possible to recognize an implicational hierarchy *i - e - ε*, ranked by decreasing tonality values, by which the lowest occurring neutral vowel entails the neutrality of all higher vowels in the series (Figure 1).³

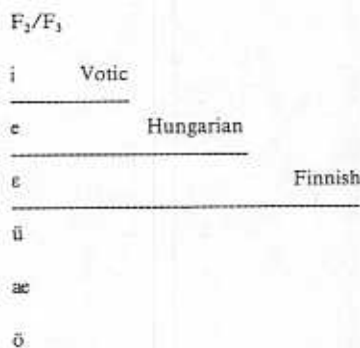


Fig. 1. Tonality scale for front vowels based on F_2/F_3 values.

In my opinion this apparent contradiction of the front/back harmony principle by the fact that the neutral vowels are the most front presents a rather serious obstacle to attempts to provide a plausible nonlinear (autosegmental or metrical) accounting for such systems.

Attempts to explain the problems associated with the neutral vowels as historical accident, the consequence of contact with European languages, or with vague notions of markedness do not completely succeed. Early Hungarian is generally assumed to have had consistent front/back harmony, with

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neutral vowels arising through loss of a central *ɨ or monophthongization of back vowel diphthongs, but not all back-harmonizing neutral vowels are the result of secondary fronting, e.g., the German loan *cél* 'goal' (cf. *cél-nak* 'to the purpose'). Clearly the neutral vowel category has taken on a purely synchronic role. In the case of the more closely related Baltic-Finnic Finnish and Votic, the currently prevailing opinion is that the neutrality of *i* and *e* reflects the original Proto-Baltic-Finnic system, if not that of Finno-Ugric, with unrounded central vowels (as in Votic and Estonian) as secondary developments (Hakulinen, 1961:21). Although I accept instead the opposing view that Proto-Baltic-Finnic had complete tonality harmony, with central unrounded vowels (cf., e.g., Kettunen, 1929:30), I do not consider the presence of the neutral vowels in Finnish in itself to be an argument for an earlier merger of central and front vowels (as suggested by Aoki, 1968:144-45). And appeals to markedness (Aoki, 1968:145) do not allow us to account for the merger of *i:*ɨ in Votic and Estonian alongside the retention of the supposedly even more highly marked *e:*ə opposition – and this in an area with evidence of contact influence (e.g., consonant palatalization, voicing of obstruents) from Russian, which maintains a primary [ɨ] vowel target type.

The unquestionable continuing vitality of vowel harmony among the widely dispersed western Finno-Ugric languages in the face of the neutrality of the front unrounded vowels must be accounted for on purely synchronic grounds. I shall argue below that a fresh approach to the feature parameters for vowels – one based on psychoacoustic and functional considerations – leads to a view of the neutrality of non-low front unrounded vowels as perfectly neutral.

5. VOWEL FEATURES

The set of vowel features I shall introduce here represents a highly speculative revision on substantive, psychoacoustic and functional grounds. In large part it was inspired by the mandate of Liljencrants and Lindblom (1972:859):

to derive linguistic form as a consequence of various substantive-based principles pertaining to the use of spoken language and its biological, sociological, and communicative aspects. We would then proceed by asking the following questions:

- (a) What are the mechanisms available for human speech communication?
- (b) How can the use of these mechanisms be constrained and optimized with respect to various psychological conditions and communicative efficiency?

The possible implications of these features for phonology, including their application to the problems of vowel harmony, were considered later in testing the system against feature related aspects of phonological systems, e.g., natural class specifications, the typology of vowel systems, etc.

My preliminary analysis was based on the spectra for Swedish vowels presented by Fant (1973:40).⁴ Thus a wide range of vowel types, 19 in all, within a rich system of phonemic contrasts and the most advanced experimental data were assured. Fant's spectra for *u*, *ü*, *i*, *a* and *æ* are given in Figure 2.

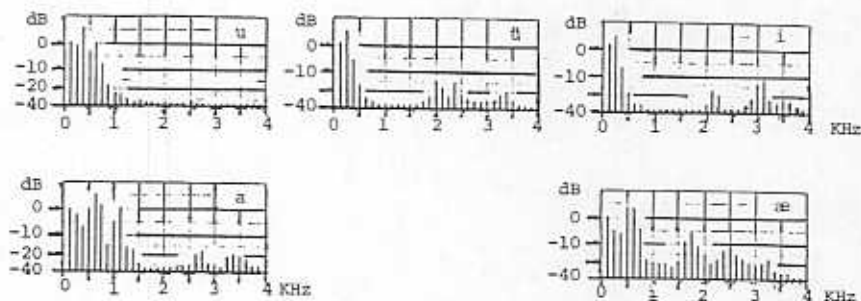


Fig. 2. Selected Swedish vowels as presented in Fant (1973). (0 dB = 1 dyne/cm²).

Closer examination of the full set of spectra reveals a significant drop in harmonic energies above 1300 Hz and an even more drastic reduction after roughly 3200 Hz. By plotting the highest decibel value for any given harmonic over the entire 19 spectra, the composite of harmonic maxima, shown in Figure 3, was produced.⁵ The envelope of the harmonic maxima, rounded off slightly, is given in Figure 4. To some extent this curve may be seen as an approximation of the maximum energy available for vowel differentiation at any given frequency (at the amplitude level represented, presumably a normal speech level). The sharp drop in harmonic energies between roughly 1200 and 1500 Hz effectively divides the spectral envelope into two energy zones, one significantly stronger than the other. I have labeled these PEZ (primary

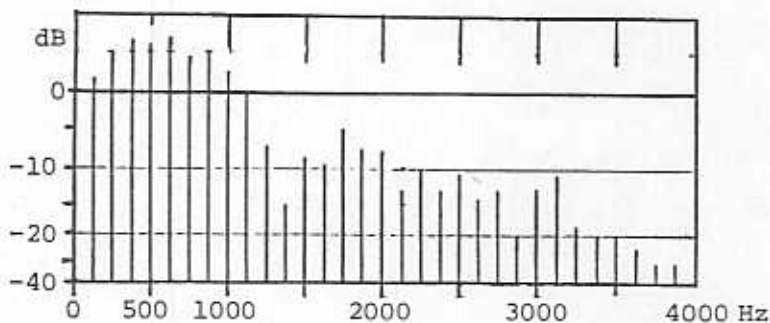


Fig. 3. Composite of harmonic maxima.

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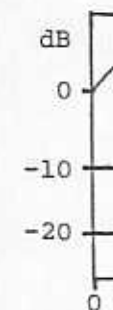


Fig. 4. M
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energy zone) and SEZ (secondary energy zone) in Figure 4. The break between these two zones is labeled CEZ (central energy zone). This three-way division of the maximal spectral envelope is not peculiar to Fant's informant (cf., e.g., the spectra for Estonian below in Figure 8). I shall assume that the basic pattern (not specific Hz values) is universal, stemming from the action of the vocal tract resonator upon the glottal spectrum, which otherwise ought to show a more gradual fade from lower to higher harmonics.

From a functional point of view, the division of vowel spectra into stronger and weaker energies makes a hypothesis such as (5) appear attractive.⁶

- (5) The burden of phonological distinctiveness is greater over those harmonics with the greatest energy.

If we take into account only the spectral envelope within the PEZ - i.e., the pattern of those harmonics stronger than -10dB up to 1200 Hz - it is possible to provide easily distinguishable patterns for most smaller vowel systems, excluding those with high central vowels. This is illustrated in Figure 5 for the Swedish vowels *u*, *ɔ*, *a*, *i*, *ɛ*, *æ*. The following four envelope features seem plausible: (1) full use of the PEZ (*a* vs. the others), (2) double-peaked (back rounded and low central vs. front), (3) antiresonance over the initial (lowest) harmonics (low vs. non-low), (4) strong initial harmonics (high vs. non-high). I am not, however, proposing that all possible distinctions be made within the PEZ; note especially the relatively small difference between *u* and *ɛ* in Figure 5 (apart from the slight one-harmonic 'gap' between the two formants of *u*), hardly an optimal distinction.

Obviously all height distinctions occur in the PEZ, but I wish to suggest that the basis for the contrast does not lie in perceiving and computing an F_1 frequency value, somehow to be interpreted ('normalized') by using the fourth and higher formant values as a reference point. Note in Figure 2 the

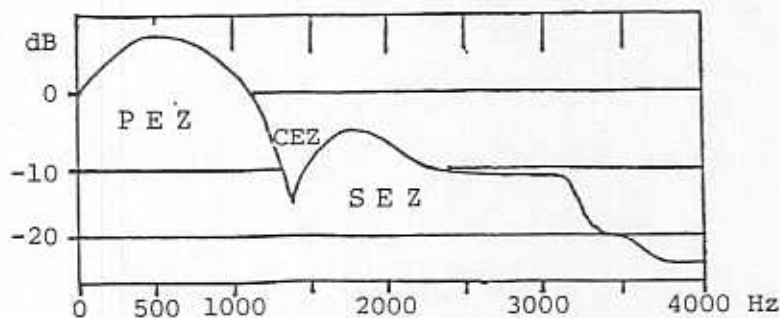
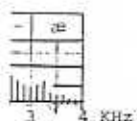
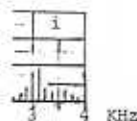


Fig. 4. Maximal spectral envelope. (PEZ = primary energy zone, SEZ = secondary energy zone, CEZ = central energy zone).

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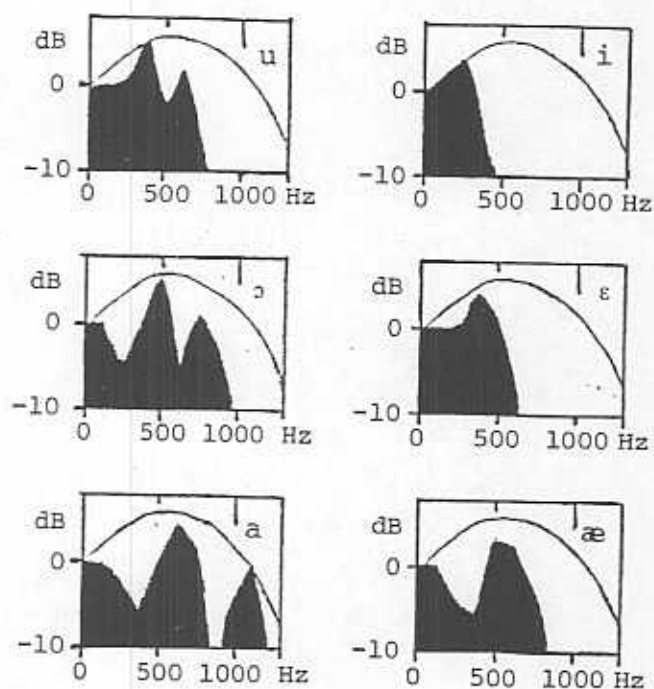


Fig. 5. PEZ spectral envelopes for six Swedish vowels.

extremely low energy levels that would have to serve as the basis for the normalization algorithm. The key to the perception (normalization) of vowel height is, in accord with (5), more likely to be tied to the cavity-filtering effect on the initial harmonics of the PEZ. Since the PEZ maximal curve appears to be a function of universal properties of speech production, only a few reference sounds would be needed to establish the specific values of an individual speaker's PEZ curve.

Psychoacoustic evidence for the correctness of (5) may be adduced from the fact that the perceptual distance between tones does not correspond to a linear frequency scale (in Hz), but varies according to frequency. In general, a given frequency difference in lower frequencies will be perceived as a much greater pitch difference than the same difference in higher frequencies. This is reflected in the experimentally established mel scale, which expresses the perceptual distance between given frequencies (Fant, 1973:47-48). Figure 6a presents the corresponding Hz and mel values over the maximal energy curve of Figure 4, with the linear Hz scale along the bottom of the graph and the mel values along the top. In figure 6b the energy curve is restated using the same linear scale for mels. Most striking is the extreme foreshortening of the frequency ranges above the PEZ relative to the perceptual distance scale

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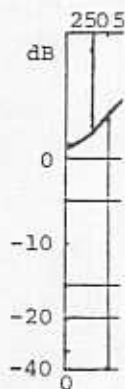


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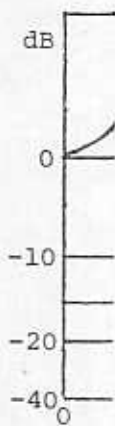


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within the PEZ. Conversely, the linear mel scale in Figure 6c, with essentially the same graphic length as Figure 6a, shows a significant expansion of perceptual distance within the PEZ, a slight reduction within the SEZ, and a substantial reduction above the SEZ.⁷

Thirteen Swedish vowel spectra, replotted according to the mel-based energy curve of Figure 6c, are given in Figure 7. The envelope-initial harmonics, the suggested basis for phonological height distinctions, have obviously benefited the most from this conversion. Perhaps the second most noteworthy effect is the reduced separation between the peaks for the second and third formants. This is consistent with the recognition of the joint function of these formants. For example, Fant (1973:52) maps the vowel space in terms

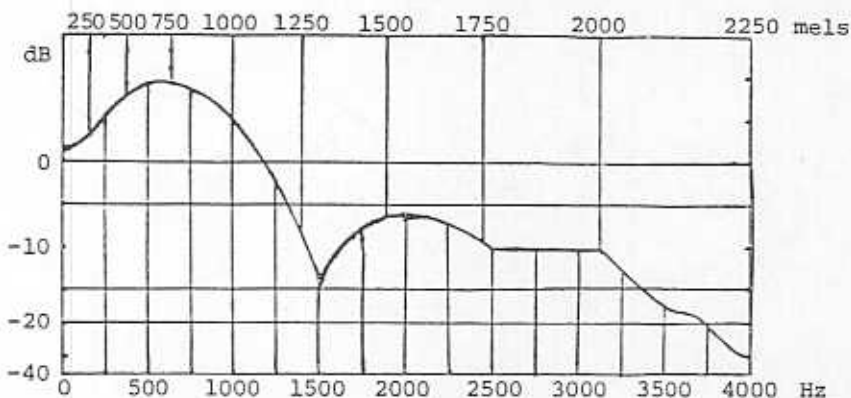


Fig. 6a. Hz to mels conversion scale over the maximal spectral envelope.

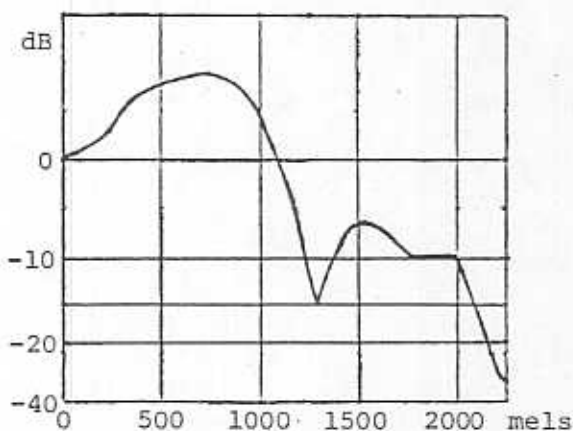


Fig. 6b. Maximal spectral envelope in mels (with 0-1000 mels on the same scale as 0-1000 Hz in Fig. 6a.).

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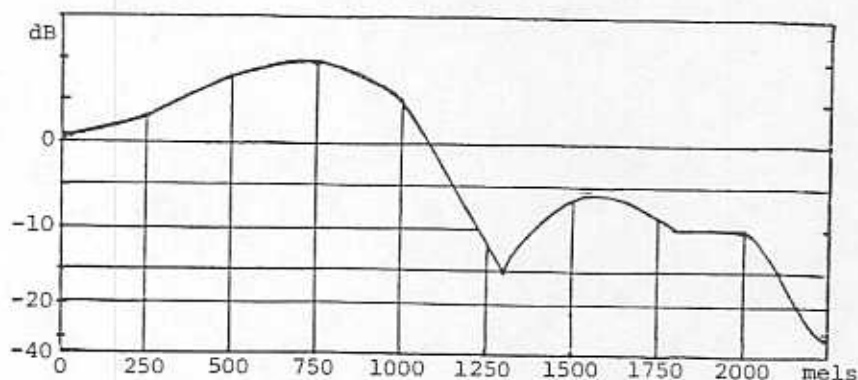


Fig. 6c. Maximal spectral envelope in mels.

of 'an upper effective second formant frequency, labeled F'_2 , chosen so as to take into account a gradual increase in the importance of the third formant as F'_2 is raised in frequency.' Finally, we note that the perceptual distance between the first two formants of the back vowels is essentially of the same magnitude as that for the second and third formants of the front vowels.

Spectral envelopes for selected Estonian vowels are shown in Figure 8, based upon the measurements of Liiv (1962). Estonian, like Swedish, has a basic nine-vowel system, including one central vowel (*a*, unrounded), with quantitative oppositions (short as opposed to long and overlong) associated with vowel quality. The measurements were taken from a variety of speakers (indexed by Roman numerals), and although the acoustic filtering was different from Fant's, the resulting envelope patterns are consistent with those observed for Swedish. The logarithmic frequency scale of the original was not changed, since over the PEZ it corresponds quite closely to the mel scale. The manner of presentation differs from that of the original (illustrated in Figure 9) in the following ways: (a) for each token the fundamental and individual harmonics were identified and plotted up to 1000 Hz and (b) the envelopes formed by the harmonics were redrawn for the first 1000 Hz, producing a totally different set of patterns from those of the original. Above 1000 Hz, since the logarithmic scale pushes the harmonics more closely together, no difference in envelope geometry results.

Not surprisingly, the Estonian patterns are essentially the same as those for Swedish. What is interesting here is the strong similarity across speakers, especially the PEZ patterns for the two tokens of *i*, one with a fundamental of 150 Hz, the other with 255 Hz (obviously a woman speaker). The logarithmic scale has the effect of normalizing the distance between the harmonics of the PEZ, with F_0 in effect a baseline for the subsequent envelope geometry. This would also be true for the mel scale. I interpret this as clear additional support for (5) as well as for the view that normalization is a function of information within the PEZ.



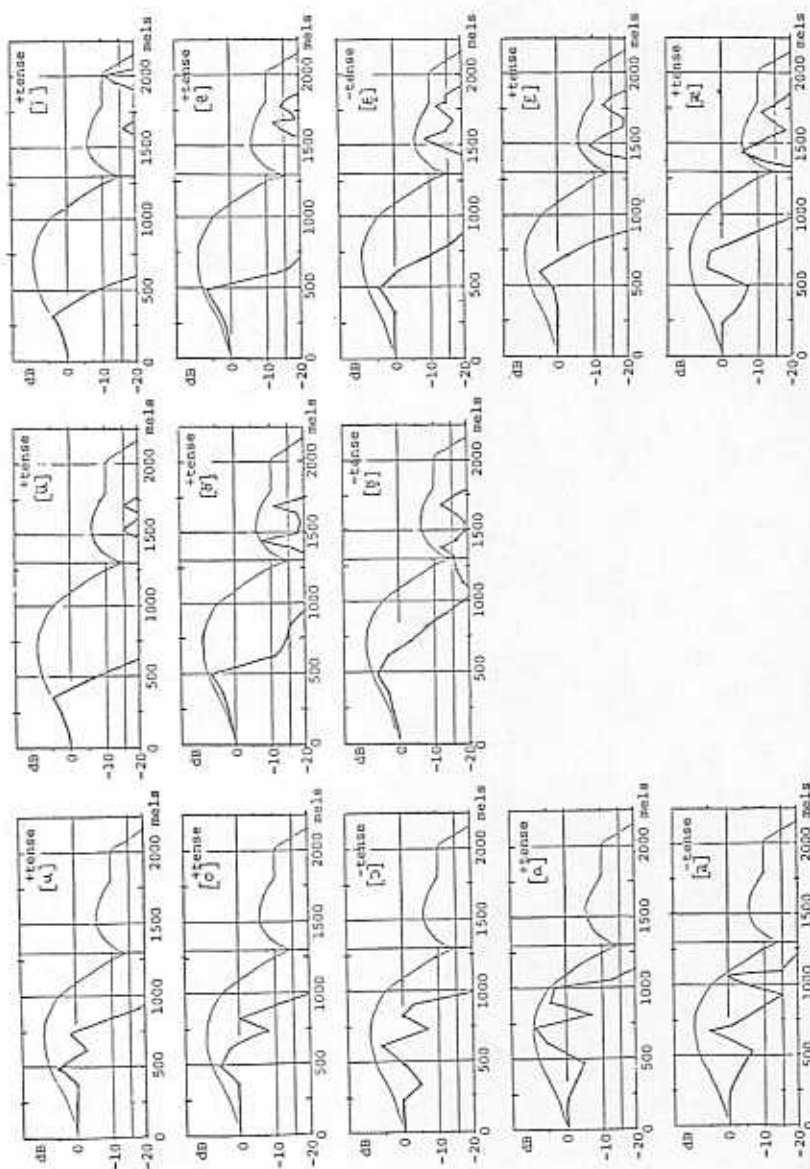
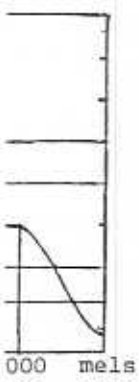


Fig. 7. Selected Swedish vowel spectra, mel conversion.



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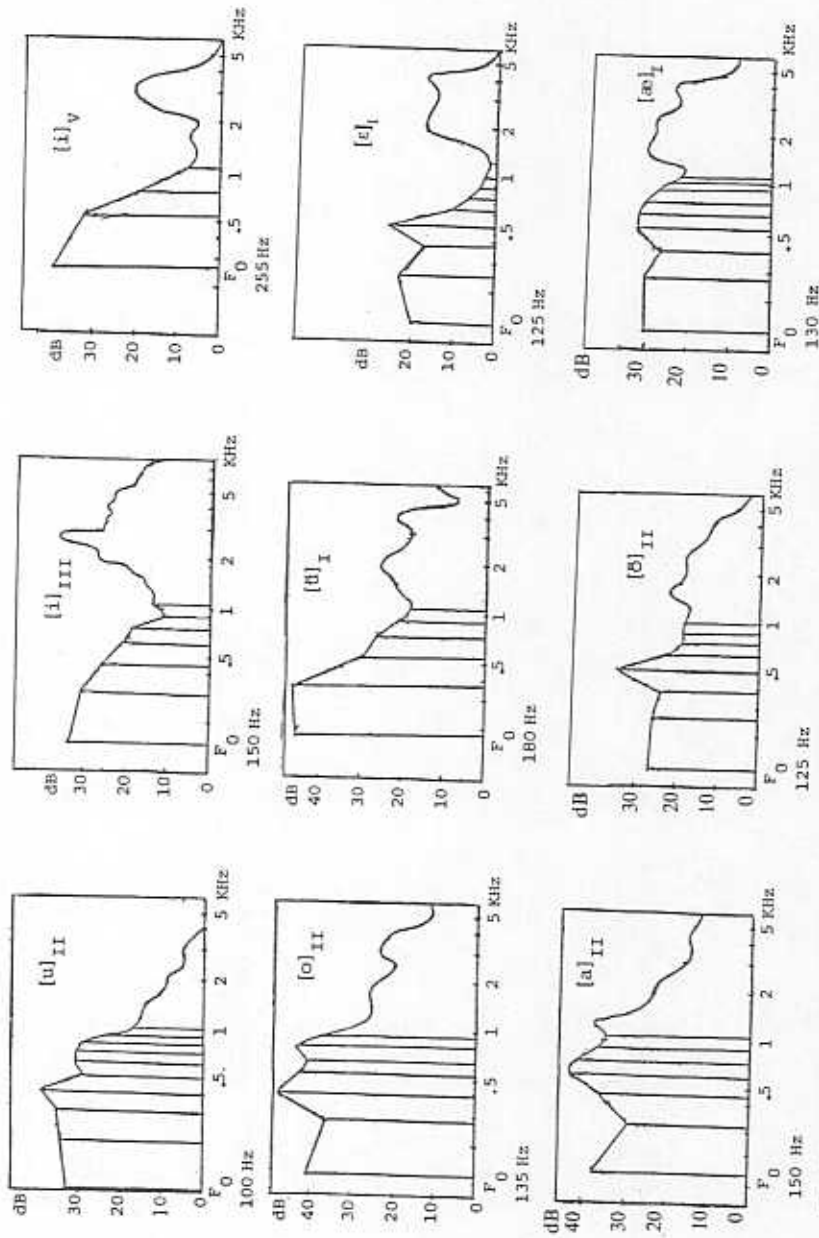


Fig. 8. Selected Estonian vowel spectra, various speakers. (Logarithmic frequency scale).

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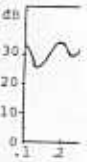


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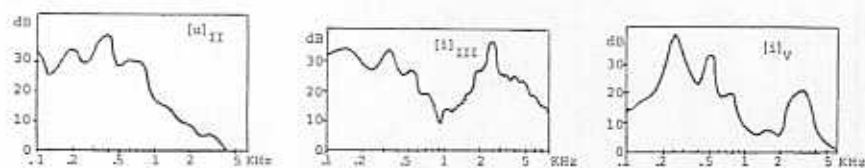


Fig. 9. Spectral envelopes for Estonian short vowels as presented in Liiv (1962).

6. FEATURE PROPOSALS

Accordingly I propose the spectral envelope features for vowels in (6), listed in a projected hierarchical order correlated with an assumed perceptual ranking.

- (6)
- a. DROP: envelope-initial antiresonance (= LOW)
 - b. DUAL: dual resonance peaks – one in the PEZ and one outside the PEZ (front and non-low central vs. back rounded and low central)
 - c. RISE: envelope-initial enhancement (= HIGH)
 - d. ROUNDED: an articulatory parameter, has contrastive value only for '+dual' vowels
 - e.
 - i. CENTRAL: formant peak in the CEZ, or alternatively
 - ii. HI-TONALITY: formant peak in the SEZ (front vs. back and central)

The feature 'dual' is hardly new. Indeed, it reflects the one-formant (=back) vs. two-formant (=front) spectral opposition discovered in the nineteenth century by Hermann Helmholtz (see Helmholtz, 1954, based on the German edition of 1877). And it remained as the primary acoustic basis for the back/front opposition until the middle of this century, when advances in acoustics made it possible to recognize a two-formant basis for the back vowels as well. Helmholtz's experiments, relying upon the human ear as the primary measure of psychoacoustic significance, have perhaps brought us closer to phonological validity than the acoustic technology of the past decades.

But 'dual' is not to be identified with any of the more standard Jakobsonian or articulatory features. It yields the natural classes of back-rounded plus low-central vowels vs. front vowels (*plus* non-low central vowels). It is thus not quite the same as the more familiar grave/acute parameter. As we shall see below, 'dual' plays an important role in my interpretation of the Finnish neutral vowels.

The features 'drop' and 'rise' are tied to the geometry of the envelope-initial harmonics. The initial antiresonance of the low vowels seems quite

Fig. 8. Selected Estonian vowel spectra, various speakers. (Logarithmic frequency scale).



apparent. The enhancement posited for the initial harmonics of high vowels seems to be more difficult to identify. Back vowels and front vowels show somewhat different patterns, and Fant's data for the Swedish back vowels do not reveal a significant difference in this respect between *u* and *o* (cf. Fig. 7). The Estonian data, on the other hand, do seem to support a height-correlated difference over the initial harmonics of the back vowels (cf. Fig. 8).

'Rounded' is viewed primarily as an articulatory feature, perhaps not trivially associated with the fact that it is one of the few features with clear visual characteristics. An auditory basis for distinctive rounding is required only for the nonback vowels. Since I have rejected the traditional plotting of F_1 vs. F_2 (or F'_2) – essentially because the normalization algorithm this approach assumes does not appear to be forthcoming – a different auditory basis for differentiating the rounding of front and central vowels is needed. One approach which works well for the limited data I have examined thus far is to plot the harmonics (a) in the PEZ (up to the last harmonic above the minimum intensity level – here taken as 10dB for the Swedish vowel data), and (b) the number of harmonics between the last harmonic in the PEZ and a projected F_2/F_3 center. The ratios for the Swedish front vowels are given in Table 1.

Table 1. Ratio of (a) the number of harmonics in the PEZ to (b) the number of harmonics between the PEZ and a projected F_2/F_3 center. (Swedish vowels.)

i	1:9.5	(2:19)	-	ū	1:7	(2:14)
ɛ	1:5.3	(3:16)	-	ü	1:4.3	(3:13)
e	1:5	(3:15)	-	ö	1:3.7	(3:11)
ɛ	1:2.7	(4:11)	-	ø	1:1.4	(5: 7)
ɛ	1:2.2	(5:11)	-	œ	1:0.8	(5: 4)

The remaining features, 'central' and 'hi-tonality', are regarded as mutually exclusive parameter options. The lack of a positive feature characterizing the primary central-vowel phonemes of many Eurasian languages, e.g., Komi Nivshera (with primary *u:u:* oppositions, both long and short), must be regarded as an ethnocentric bias which has become rooted in phonological theory (not to be disturbed even by the rounded central-vowel phonemes of such cultured tongues as Swedish or Central Texas English). 'Hi-tonality' also appears to represent a central Eurasian type, and may be considered the basis for those systems with complete consistent tonality harmony, such as Turkish (with *i:ı̄, ü:u, e:a, ö:o*).

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7. CONCLUSION

The Finnish vowel features can now be stated as in (7).

(7)		u	o	a	ü	ö	æ	i	e
	DUAL	-	-	-	+	+	+	+	+
	DROP	-	-	+	-	-	+	-	-
	ROUNDED	+	+	-	+	+	-	-	-
	RISE	+	-	-	+	-	-	+	-

Once the feature 'dual' is recognized as the basis for Finnish vowel harmony, the neutrality of *i* and *e* is no longer anomalous on phonetic grounds. In fact, it is a consequence of the proposed feature system, since central *i* and *ə* also have dual resonance peaks, and an $i \approx \dot{i}$, $e \approx \dot{e}$ alternation would fall outside the harmony basis. Further, with 'dual' as the harmonizing parameter, the asymmetry in the direction of agreement – by which back vowels assimilate to neutral vowels – receives a plausible explanation. The back harmonic vowels can assimilate to '+dual', but a phonological shift of *i*, *e* to '-dual' would necessarily require a concomitant change in 'rounded' as well (since '-dual, -low, -rounded' vowels are excluded by universal constraints, just as '+high, +low' within current theory).

Finally, the apparent conflict of neutral '+dual' vowels and back harmony '-dual' vowels within stems requiring back-vowel affixes seems much less unnatural if the relative sonority of the vowels is taken into account. Within the PEZ the ranking given in (8), from low to high sonority, can readily be discerned.

- (8)
- a. *i, ü*
 - b. *e, ö*
 - c. *ɛ, œ*
 - d. *æ, u*
 - e. *o*
 - f. *ə*
 - g. *a*

In other words, within stems neutrality may be seen as the result of a dominance principle based on the low sonority inherent in the neutral vowel set. The back vowels thus tend to be dominant. Further, the sonority scale in (8), together with recognition of the feature 'dual', also accounts for the neutrality hierarchy illustrated in Figure 1, and the relationship with tonality must be regarded as fortuitous. In Hungarian, *e* (= [ɛ, æ]) is the '+dual' counterpart of *a*; and *é* in affixes, of *á*. Votic harmony, on the other hand, is not based on 'dual', as the $e \approx \dot{e}$ alternations demonstrate, but rather on

'hi-tonality'. I interpret the neutrality of Votic *i*, and not *e*, as the result of the interaction of the sonority scale and the historical merger of *i* and *ɨ*. Thus Votic, unlike Finnish and Hungarian, does not have consistent harmony, and the neutrality of Votic *i* reflects some degree of anomaly, unlike the seemingly similar neutral *i* in Finnish.

FOOTNOTES

1. Kiparsky's formal rule accounts for the alternations without having to resort to absolute neutralization, but that rule no longer reflects an agreement relationship:

$$\begin{bmatrix} \text{+back} \\ \text{+high} \end{bmatrix} \longrightarrow \begin{bmatrix} \text{+back} \\ \text{-high} \end{bmatrix} \quad / \text{*}\#X \begin{bmatrix} \text{+back} \\ \text{-high} \end{bmatrix} \quad Y _$$

2. The quality of *e* varies by dialect (cf. Lotz, 1952) and by context, with low [æ] tending to occur only in initial syllables.
3. In Harms (1966) this scale was exploited in interpreting the acute/grave parameter as two independent features (parallel to compact/diffuse or high/low), with the high tonality "acute" vowels as neutral and nonacute vowels harmonizing in graveness.
4. The spectra represent sustained vowels as spoken by a single speaker, identified as a professor of phonetics at Uppsala University.
5. All spectra were given with a fundamental of 125 Hz, thus making it possible to identify the *n*th harmonic for each vowel.
6. Cf. Lindblom (1980:11): "We shall hypothesize that vowel systems tend to evolve so as to make the process of speech understanding efficient ..." In other words, if God had wanted man to make greater use of the higher frequencies, he would have (a) put more energy there or (b) made our basilar membrane significantly more sensitive to those frequencies.
7. It should be noted here that perceptual loudness also varies by frequency, the so-called phon scale. However, at the intensity level of the SEZ with a reference sound pressure of 1 dyne/cm² (Fant, 1973:36) there is no significant increase in perceptual loudness that might be viewed as compensation for the weaker energies in the higher frequencies.

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