II A TENTATIVE SURVEY OF THE DISTINCTIVE FEATURES

2.1 PREFATORY ACOUSTICAL REMARKS

In the sound spectrograms* the frequency-intensity pattern of speech is portrayed as a function of time. In this "running frequency analysis" the statistical properties of the speech wave are sampled within time intervals that are short compared to the duration of a phoneme. The spectrograms and the supplementary "cross sections" of intensity vs. frequency provide a source of information that may be rather confusing unless an optimal set of parameters is used in the analysis. These parameters can best be discovered by an analysis of language into distinctive features.

The speech wave may be considered as the output of a linear network; i.e., the vocal tract coupled to one or more sources. The speech wave has no other properties than those of the sources and the network. This relation may be written

$$W = T \cdot S$$

where W represents the speech wave, T the transfer function of the network, and S the source. Two simultaneous sources may be handled by superposition:

$$W = T_1S_1 + T_2S_2$$

Speech analysis shows that only a very limited number of characteristics of the source and of the transfer functions are utilized in the various languages of the world for semantic discriminations. These characteristics are described in the following paragraphs.

2.11 Properties of the Source Function Utilized in Language

2.111 Type of Source. There are basically two kinds of sources, periodic and noise sources. A periodic source is manifested by a characteristic harmonic structure in the spectrogram. A noise source, on the other hand, causes an irregular distribution of energy in the time dimension. These two sources can be simultaneously active in the production of a single phoneme.

2.112 Number of Sources. Some sounds such as [v] or [z] have two sources. One of these is located at a point of maximum stricture in the vocal tract, while the other, i.e. the so-called voice, is located at the larynx and is more or less periodic. A source which lies above the larynx in the vocal tract produces anti-resonances in the transfer function (cf. 2.122).

* The sound spectrograms to which reference is made in this report either are of the type produced by the Kay Electric Company Sonagraph or are from the book Visible Speech by Potter, Kopp, and Green (1).

2.113 Transient Effects. The manner in which the source is turned on and off is linguistically significant. We distinguish abrupt onsets and declines from smooth ones. For example, in the phoneme /ʃ̂/ as in chip we have an abrupt onset, while in /ʃ/ as in ship the onset is smooth.

2.12 Transfer Functions Utilized in Language

2.121 General Properties. In the mathematical treatment of the transmission properties of the vocal tract it has been found convenient to utilize the techniques and concepts developed for network analysis (2). One of the standard cases treated in network analysis is a lossless transmission line with no branches in parallel, where the input (source) is located at one end of the line and the output measured at the other. The intensity vs. frequency spectrum of the output of such a transmission line can be completely specified by stating the frequencies at which the output will be infinite (resonance). In network analysis it is usual to call these resonance frequencies poles.

When in a lossless line, some of these conditions are not fulfilled, e.g. the source is not located at the end of the line, then the output will deviate from that in the case discussed above: in certain frequency regions there will be no output. It is possible to view the deviation as due to an anti-resonance or zero which suppresses the energy in a given frequency region; i.e. acts like a resonance in reverse. Thus, in order to specify the intensity vs. frequency spectrum of the output of any lossless system, it is sufficient to state the frequencies of the poles and the zeros (if any).

When a system contains small losses, the responses at resonance and antiresonance are finite. In the complex frequency notation the poles and the zeros then have two parts, one giving the frequency location of the resonance or antiresonance, and the other specifying the amount of damping (damping constant).

The poles depend primarily on the electrical properties of the series transmission line. In the case of speech this means that the poles depend upon the configuration of the vocal tract. The zeros, on the other hand, depend primarily upon the interaction of parallel branches. In speech that would mean that they depend upon the interaction of the two resonating systems in parallel which are created either by a) the opening of a supplementary passage or by b) the non-terminal location of the source.

When the location of a zero is close to that of a pole, the zero tends to cancel the effect of the pole. As the separation between them increases, the suppression decreases.

2.122 Location of Source. In general the zeros occur at frequencies at which the impedance arising from the source in the direction opposite to the air flow is infinite. A source located at the larynx will cause no anti-resonances of importance in the transfer function. It is for this reason that we can specify vowels completely by the poles which give the frequency positions and bandwidths (damping constants) of the formants. A source located above the larynx in the vocal tract between cavities that have finite coupling to each other introduces zeros into the transfer function.

2.123 Shape of the Vocal Tract. The poles of the transfer function are primarily related to the geometrical configuration of the vocal tract and are independent of the source and its location. Calculations on the basis of x-ray data lead to substantial agreement between the poles and zeros of the predicted and measured spectra (3).

2.13 Neutral Position of the Vocal Tract

In the following, reference will be made to the neutral position of the vocal tract. This is the position of the vocal organs for producing a very open [æ] With respect to its acoustic results this articulatory position can best be approximated by a single tube closed at one end. As is well known, a tube of length L closed at one end resonates at frequencies where L is an odd multiple of one quarter wavelength. Since the average length of the vocal tract of males is about 17.5 cm, the resonances appear at approximately 500, 1500, 2500 cps. etc. The neutral position is of importance for predicting the effects on formant positions of variations in the over-all length of the vocal cavity of different individuals (3). It also serves as a reference point for the tenseness feature (cf. below 2.431).

2.14 Phoneme Boundaries

For practical purposes each phoneme can be represented by a quasi-stationary spectrum in which the transfer function is invariable with respect to time, except in the manner stated for transient effects (cf. 2.113). These transient effects, which are produced by rapid variations in the source function, may serve to delimit the individual phonemes in the chain. Rapid variations in the transfer function caused by swift changes in the position of the articulating organs also indicate the beginning or end (boundary) of a phoneme. Here, however, the minimum rate of change must be determined experimentally for each case. Rapid fluctuations in the over-all intensity of the speech wave provide an additional means for determining the location of a phoneme boundary.

2.2 FUNDAMENTAL SOURCE FEATURES

This class consists of two binary oppositions: vocalic vs. non-vocalic and consonantal vs. non-consonantal.

2.21 Vocalic vs. Non-Vocalic

Phonemes possessing the vocalic feature have a single periodic ("voice") source whose onset is not abrupt.

Usually, the first three vocalic formants for male voices are found below 3200 cps. The vocalic formants have small damping which expresses itself in the relatively narrow bandwidth of the formants. Because of the negative slope of the "voice" spectrum, the lower formants have greater intensity. But because of the ear's higher sensitivity to loudness in the region about 1-2 kc. it appears likely that in perception the effect of the declining spectrum tends to be equalized.

2.22 Consonantal vs. Non-Consonantal

Phonemes possessing the consonantal feature are acoustically characterized by the presence of zeros that affect the entire spectrum (cf. 2.441).

2.221 Vowels and Consonants. Vowels are phonemes possessing the vocalic feature and having no consonantal feature. A limited number of combinations of positions of the first three formants are significant for the identification of vowels. Information on the intensity level (other things being equal, vowels louder than other speech sounds), duration, rise and decay time of the sound furnish supplementary identifying criteria for vowels.

Consonants are phonemes possessing the consonantal feature and having no vocalic feature. Certain features of consonants are perceived most readily by the influence they exert over the formants of adjacent vowels, but even in the absence of any adjacent vowel, all the features of a consonant are perfectly recognizable; cf. the last phoneme in the English words whisk - whist - whisp or in the Russian words /l̦'ift/ "elevator" - /f̦in̦'ifț/ "enamel", /b'ukf/ "of letters" - /xar'ukf̦/ "standard" (see Fig. 10).

2.222 Liquids. The so-called liquids, i.e. the laterals (l-sounds) and the various intermittent r-sounds, have the vocalic as well as the consonantal feature: like vowels, the liquids have only a harmonic source; like consonants, they show significant zeros in their spectrum envelope. The formant structure of the liquids is basically similar to that of vowels. The configuration of their first three formants, however, usually differs from that of any vowel. In the beginning of a liquid we observe a very sudden downward shift of most formants which is due to the increased length of the resonator system in comparison with that of adjacent vowels. The over-all intensity of the liquids is considerably lower than that of the vowels.

2.223 Glides. The so-called glides (30), like the English h and the "glottal catch", are distinguished from the vowels in that they have either a non-harmonic source as in the case of [h] or a transient onset of the source as in [?]. They are distinct from the consonants in that they have no significant zeros in their spectra.

2.224 Production. Vowels have no obstructive barrier along the median line of the mouth cavity, whereas consonants have a barrier sufficient to produce either complete occlusion or a turbulent noise source. Liquids are complex structures: they have a greater axial length-dimension in the direction of the air flow and they combine closure and aperture, either intermittently or by barring the median way and opening a lateral by-pass. Glides are produced by a stream of air passing through the glottis when it is narrowed or just after an abrupt opening following complete closure.

2.225 Perception. The vowels have far higher power than the consonants. As determined by Sacia and Beck, the average power for different English vowels is from 9 to 47 microwatts, while for consonants it ranges between 0.08 and 2.11 microwatts(4).

2.226 Occurrence. The distinction between vowels and consonants is universal. In America and Africa there are a few native languages without liquids. Many languages, e.g. Italian and Russian, have no glide phonemes.

The vowels figure predominantly as syllabics and, vice versa, the role of syllabics is assumed primarily by vowels. Most of the vocalic phonemes occur only as syllabics. A few others, being preponderantly syllabic, lose their syllabicity in some positions. For instance, English unstressed /i/ and /u/ become non-syllabic when adjacent to any other vowel (including the stressed /i/ and /u/); e.g. boy, day, geese, yes, yield (phonetically [j'i:ld] and phonemically /i'iild/), out, soul, shoe, well, wood (phonetically [w'ud] and phonemically /u'ud/) woo (phonetically [w'u:] and phonemically /u'uu/).

It is rare for non-syllabic vowels to be autonomous phonemes that may occur in the same positions as the corresponding syllabic phonemes; e.g. Russian /'ul̦ii̯/ "hive" - /'ul̦ii/ "hives".

Phonemes other than vowels occur for the most part only as non-syllabics. A few others (mostly liquids or nasal consonants), being preponderantly non-syllabic, acquire syllabicity in some positions. For instance, the Czech r and l become syllabic when preceded by a non-syllabic and not followed by a syllabic. Compare such dissyllables as škrtl [ʃkr̥tl̥] "scrapped", trval [tr̥val] "lasted" and monosyllables as rval [rval] "tore" and zlo [zlo] "evil". Syllabic liquids occasionally appear as autonomous phonemes capable of occurring in the same position as the corresponding non-syllabic phonemes; e.g. in Old Czech: dissyllabic brdu /br̥du/ "to the summit" - monosyllabic brdu /brdu/ "I stroll".

A set of rules, some of them universal, determine the pattern of the syllable. For instance, there is no known language where a syllable cannot begin with a consonant or terminate in a vowel, whereas there is a number of languages in which a syllable cannot begin with a vowel or terminate in a consonant. Thus, for a sequence of phonemes, the contrast of vocality and non-vocality is of primary importance, while the occurence of these opposites in one and the same position is much more restricted: cf. English wet /u'et/, yet /i'et/ with vet, set, net, etc., or he /h'ii/ with his /h'iz/, hit /h'it/ etc.).

2.3 SECONDARY CONSONANTAL SOURCE FEATURES

This class includes:

1) two types of features due to the primary source: a) envelope features, and b) the stridency feature,
2) the voicing feature due to a supplementary source.

2.31 Envelope Features

By the temporal envelope of sound intensity we mean the speech power averaged over about 0.02 seconds as a function of time. There are two basic types of envelope: smooth and rough. Phonemes with smooth envelopes have gradual onsets and decays and no abrupt changes in their temporal course. Phonemes with rough envelopes have abrupt variations of power in their temporal course. The latter can be subdivided into two groups depending upon whether or not there is sound after the abrupt variation in power.

Phonemes with smooth onsets are called continuants. They are opposed to interrupted (more exactly, discontinuous) phonemes, which have an abrupt onset. According to their decays, phonemes are divided into checked (with abrupt decays) and unchecked (with gradual decays.)

2.311 Interrupted vs. Continuant

2.3111 Stimulus. The abrupt onset distinguishes the interrupted consonants (stops) from the continuant consonants (constrictives). The onset of constrictives is gradual. The main characteristic of stops, on the contrary, is a sharp wave front preceded by a period of complete silence, for which, under certain conditions, a mere vibration of the vocal bands may be substituted. The spectrograms show here a sharp vertical line preceded either by a period of silence or a "voice bar" (1).

In English the abrupt onset of /p/ as in pill or of /b/ in bill is opposed to the smooth onset of /f/ as in fill or /v/ in vill. Similarly, /t/ as in till is opposed to /θ/ in thill and to /s/ in sill.

In the liquids it is not primarily the onset and decline that serve a distinctive purpose, but rather the interruption of the sound course. The continuant l-sound is opposed to the interrupted r-sound. There are two varieties of the latter: the flap with a single interruption and the trill with recurrent interruptions, which is much more common. Measurements of Czech trills show normally from two to three taps in the sound; in final position this may be reduced to a single tap, while the initial trill in emphasis has 4 to 5 taps. The rate of the taps is approximately 25 per second. There are languages, e.g. Mongolian, which have a considerably more rolled /r/ with a higher number of interruptions. Examples of the interruption feature in Czech liquids: /kora:l/ "coral" - /kola:r/ "Roman collar".

As for the so-called "continuant r", it is actually a non-syllabic vowel. For example, the English "Received Pronunciation," possesses a vowel phoneme, which is opposed as diffuse to /a/, as grave to /i/ and as unrounded (plain) to the rounded (flat) /u/. This phoneme is split on the prosodic level into an unstressed /ə/ and a stressed /'ə/. The former loses its syllabicity in the neighborhood of another vowel phoneme (<u>bear</u> /b'eə/) and becomes still "closer" when followed by a vowel (<u>red</u> /ə'ed/). The stressed phoneme /'ə/ is represented by a more advanced and close variant before an unstressed /ə/ (<u>bird</u> /b'əəd/) and by a more retracted and open variant [ʌ] in other positions (<u>bud</u> / b'əd/).

2.3112 Production. The stops have complete closure followed by opening. The constrictives have incomplete closure; but the narrowing considerably reduces the contribution of the cavities behind the point of articulation (3). The continuant liquids, i.e. laterals like /l/, combine a median closure with a side opening, whereas in the interrupted liquids like /r/, complete or partial cut-off of the air stream is effected by one or more taps of the apex of the tongue, or of the uvula.

2.3113 Perception. Experiments conducted by L. G. Jones at Northeastern University have demonstrated that when the onset of a constrictive like [s] or [f] is erased from a recording, the sound perceived is a stop: [ŝ] or [t] for the [s]; [f̂] or [p] for the [f]. (On the distribution of these two alternative perceptions see Sec. 2.323).

2.3114 Occurrence. The opposition of interrupted (stops) and continuant consonants (constrictives) is found in most languages. As a rule, the number of constrictives in a language is lower than that of the stops and occasionally the class of constrictives contains but a single phoneme, usually /s/. In languages in which the opposition of constrictives and stops is not autonomous, it is either a concomitant of the opposition strident vs. mellow (see below 2.324), or, all the consonants are stops in contradistinction to the vowels. The latter is the case in some languages of Oceania and Africa.

In a great number of languages, for example in nearly all languages of the Far East, liquids are not divided into interrupted and continuant phonemes. The liquid phoneme in these languages may be represented either by [l] as in Chinese, or by [r] as in Japanese, or by a complementary distribution of two contextual variants - [r] and [l] pertaining to one single liquid phoneme as in Korean. In Korean the liquid phoneme in prevocalic position is [r]; elsewhere it is [l]. For this reason the Korean alphabet has only one letter for the two sounds, in [maru] "floor" and [pal] "foot", for instance. By a Korean the Czech words /karar/, /volal/, /oral/ and /dolar/ are all perceived and reproduced as terminating in [-ral].

2.3115 Double Stops. The peculiar consonants with a double closure, which are widespread in languages of South Africa, are but special forms of consonant clusters. They are extreme cases of co-articulation, which is widely used in language for building up phonemic sequences (5). In the production of such consonants, the two closures attain their release in immediate succession. Nevertheless, they are perceived as clusters since the two releases are not simultaneous despite the considerable contraction of the sequence, and since other types of clusters do not occur in these languages (or at least not in the same positions). In the South African clicks that are produced by a sucking in of air, the more frontal closure, e.g. dental or palatal, is released first and then the velar, as can be seen in the spectrograms (Fig. 2). The opposite order is shown in the African labio-velar stops spelled kp, gb. Since they are produced by expiration, the velar closure is released before the labial (6).

2.312 Checked vs. Unchecked

2.3121 Stimulus. An abrupt decay is the opposite of a smooth one. In spectrograms, checked phonemes are marked by a sharper termination, but this is ordinarily less prominent than an abrupt onset.

2.3122 Production. The air stream is checked by the compression or closure of the glottis.

2.3123 Occurrence. Certain varieties of checked stops, called glottalized, are found in many native languages of America, Africa, the Far East and the Caucasus; e.g. the spectrograms of the Navaho and Circassian glotallized stops (for the latter see Fig. 1) disclose a striking similarity of structure.

Examples: checked vs. unchecked stops: Circassian /t'a/ "dig!" - /ta/ "we"; /c'a/ "name" - /ca/ "tooth"; /p'a/ "place" - /pa/ "be out of breath!". Less clear and most uncommon is the glottalization of constrictives (7) observed in Tlingit (Northwestern America) and Kabardian (N. Caucasus).

In languages that have an opposition of checked and unchecked stops, the checked glide (called "glottal catch") is related to the unchecked (even or gradual) glide as a glottalized consonant is to the corresponding non-glottalized.

2.32 Strident vs. Mellow

2.321 Stimulus. Sounds that have irregular waveforms are called strident. In the spectrogram such sounds are represented by a random distribution of black areas. They are opposed to sounds with more regular waveforms. The latter are called mellow and have spectrograms in which the black areas may form horizontal or vertical striations. The proper measure for this property is an auto-correlation function. Mellow sounds have a wider auto-correlation than the corresponding strident, *ceteris paribus*, i.e. if the sounds in question have been properly normalized.

In the case of constrictives, mellowness is a consequence of a limitation upon the randomness in the energy vs. frequency distribution. While there are no clear formant regions observable in the spectrum of the strident /s/, we can easily discern them in the mellow /θ/ (see Fig. 3). The oscillograms show a distinctly higher periodicity and uniformity in mellow constrictives such as /θ/ in comparison with /s/ and other strident constrictives.

In the case of stops, mellowness is achieved by a limitation upon the randomness of the phase. Cf. the pertinent remark of Licklider:

> "..... the various frequency components of the white noise are assigned their phase angles at random; the frequency components of the single pulse all reach their maximum amplitudes at the time t = O, and they cancel one another at all other times. As a result, we hear the white noise as sshhhh and the single pulse as pt." (8)

Examples. Strident vs. mellow constrictives: English sin - thin /θ'in/, breeze /br'iiz/ - breathe /br'iið/; Ewe (West Africa) /fu/ "feather" - /ɸu/ "bone", /vu/ "tear" - /βu/ "boat"; Low Sorbian /ʃiç/ "to sew" - /çiʃ/ "calm", Circassian /χy/ "sea" - /xy/ "net". Strident and mellow stops: German Zahl, /ŝa:l/ "number" - Tal, /ta:l/ "valley" - Pfanne, /f̂anə/ "pan" - Panne, /panə/ "breakdown", Czech čelo /ʃ̂elo/ "brow" - tělo, /celo/ "body"; Chuckchee (in Northeastern Siberia) /χ̂ale/ "cap" - /kale/ "drawing".

The strident stop is called affricate. The sequence of stop plus constrictive is distinguished from an affricate by an intervening intensity minimum, which can be observed on a display of the speech wave as a function of time. Cf. Polish czy /ʃ̂i/ "or" - trzy /tʃi/ "three", czech /ʃ̂ex/ "Czech" - trzech /tʃex/ "of three" (31).

2.322 Production. Strident phonemes are primarily characterized by a noise which is due to turbulence at the point of articulation. This strong turbulence, in its turn, is a consequence of a more complex impediment which distinguishes the strident from the corresponding mellow consonants: the labiodentals from the bilabials, the hissing and hushing sibilants from the non-sibilant dentals and palatals respectively, and the uvulars from the velars proper. A supplementary barrier that offers greater resistance to the air stream is necessary in the case of the stridents. Thus beside the lips, which constitute the sole impediment employed in the production of the bi-labials, the labiodentals involve also the teeth. In addition to the obstacles utilized in the corresponding mellow consonants, the sibilants employ the lower teeth (see Fig. 3) and the uvulars, the uvula. The rush of air against such a supplementary barrier following the release of the strident stops yields the characteristic fricative effect that distinguishes these from other stops.

2.323 Perception. Experiments of L. G. Jones in which the onset of recorded constrictives (like [s]) was erased showed that as long as the sound interval remained over 25 to 30 millisec., the consonant was identified by listeners as an affricate (like [ŝ]) while a shorter sound interval was identified as a mellow stop (like [t]).

2.324 Occurrence. The maximum, hence optimal, distinction of consonants from vowels may be achieved either by the greatest muffling of sound or by the closest approximation to noise. High degree of muffling is found in the mellow stops, while noise is best approximated by the strident constrictives. Thus the optimal constrictive is strident, while the optimal stop is mellow, and in numerous languages the opposition constrictive vs. stop merges with the opposition strident vs. mellow. For instance, in French all constrictives are strident /f v s z ʃ ʒ/ and all stops mellow /p b t d k g/.

In some of these languages the opposition strident vs. mellow alone is relevant and constant; the difference of constrictives and stops becomes a redundant feature which, under certain conditions, can fail to materialize. This happens in Portuguese, where the intervocalic [d b g] become mellow constrictives [ð β ɣ] so that they are opposed to /z v ʒ/ not by the stop feature but only by their mellowness. In other languages with a fusion of both oppositions, the stridency feature may become redundant, if some of the stop phonemes, at least under certain conditions, are represented by affricates.

In addition to strident constrictives and mellow stops, many languages possess such classes of phonemes as strident stops (affricates) and/or mellow constrictives. For example, German and Czech have beside /s/ and /t/ the corresponding affricate /ŝ/, cf. German *reissen* "to tear", *reiten* "to ride", *reizen* "to tease". Moreover, beside /f/ and /p/ German includes /f̂/; and Czech has /ʃ̂/ beside the strident constrictive /ʃ/ and the mellow stop /c/. On the other hand, beside /s z/ and /t d/ English possesses the mellow constrictives /θ ð/, both spelled *th*.

When, beside strident constrictives and mellow stops, a language possesses either corresponding strident stops as German or mellow constrictives as Arabic, this state may be interpreted in terms of one single opposition: optimal constrictive vs. optimal stop. Should we symbolize the former by a "plus" and the latter, correspondingly, by a "minus", such a complex unit as a strident stop or mellow constrictive would be "±". The same device is applicable also in the case when, as in English, one pair of optimal constrictive and optimal stop (e.g. /s/ - /t/) is supplemented by a mellow constrictive (/θ/) and another pair (/ʃ/ - /k/) by a strident stop (/ʃ̂/): both of these complex units could be designated by the same symbol ±. In the relatively few languages with all four members in one series, e.g. those North Caucasian languages which have the strident constrictive /χ/, the mellow stop /k/, the mellow constrictive /x/ and the strident stop /χ̂/, we must operate with two autonomous oppositions - constrictive vs. stop and strident vs. mellow. Furthermore, insofar as it is preferable to deal with simple two-choice situations and to exclude complexes, the two oppositions might be treated separately in the case of ternary series as well, e.g. in English.

In addition to consonants proper, liquids may participate in the opposition strident vs. mellow. A few languages, e.g. Czech, have a strident counterpart of the phoneme /r/. This sibilant variety of trill is spelled *ř* : cf. *řada* "row", rada "council". Some American Indian, African and Caucasian languages contain strident counterparts of the /l/ phoneme - lateral affricates and/or constrictives (9). Despite the high damping of their formants all these phonemes retain manifest acoustic traces of their relation to liquids. They are liquids with superposed stridency (cf. below 2.441).

2.33 Supplementary Source: Voiced vs. Voiceless

2.331 Stimulus. The voiced or "buzz" phonemes as /d b z v/ vs. the voiceless or "hiss" phonemes are characterized by the superposition of a harmonic sound source upon the noise source of the latter (10). For the voiced consonants this means a joint presence of two sound sources. The spectrum of voiced consonants includes formants which are due to the harmonic source. The most striking manifestation of "voicing" is the appearance of a strong low component which is represented by the voice bar along the base line of the spectrogram (11).

2.332 Production. Voiced phonemes are emitted with concomitant periodic vibrations of the vocal bands and voiceless phonemes without such vibrations.

2.333 Occurrence. The use of the distinctive consonantal opposition voiced vs. voiceless is widespread in the world; e.g., in Europe it is found in all Slavic languages as well as in Hungarian: cf. Russian /don/ "Don" - /ton/ "tone". The extension of this feature to liquids is extremely rare; e.g. in Gaelic voiced /r l/ and the corresponding voiceless /r̬ l̬/ may occur in the same positions. (On the nasal consonants see 2.443).

Vowels are normally voiced. It is still questionable whether there are languages in which parallel to the consonantal opposition voiced vs. voiceless, there actually is a similar distinctive opposition of voiced and murmured vowels, as reported about a few American Indian languages, e.g., Comanche. Either the vocal murmur is not a distinctive feature and functions merely as a border mark, or it may be a concomitant of the tense-lax opposition (Fig. 12).

In languages lacking an autonomous opposition of voiced and voiceless consonants, the latter is either used as a mere concomitant of the opposition of lax and tense consonants, as in English (cf. 2.434), or oral consonants are normally voiceless, as in Finnish dialects. Here the difference between "hiss" and "buzz" acts as a concomitant factor of the consonant-vowel opposition. In some of these languages an automatic voicing of consonants takes place in certain phonemic contexts.

2.4 RESONANCE FEATURES

This class includes:

1) three types of features generated in the basic resonator: a) the compactness feature, b) three tonality features, c) the tenseness feature,
2) the nasalization feature due to a supplementary resonator.

2.41 Compact vs. Diffuse

2.411 Stimulus. Compact phonemes are characterized by the relative predominance of one centrally located formant region (or formant). They are opposed to diffuse phonemes in which one or more non-central formants or formant regions predominate.

Compact vs. diffuse vowels: English (RP) pet /pˈet/ - pit /pˈit/; pat /pˈat/ - putt /pˈət/; pot /pˈot/ - put /pˈut/. Compact vs. diffuse consonants: kill - pill or till; shill - fill or sill; ding /dˈiŋ/ - dim or din. The Czech symmetric pattern of compact and diffuse oral consonants presents good examples of the one-to-one correspondence: ti /ci/ "they" - ty /ti/ "them"; šál /ʃa:l/ " shawl" - sál /sa:l/ "hall; kluk /kluk/"boy" - pluk /pluk/ "regiment"; roh /rox/ "horn" - rov /rof/ "grave".

In the case of the vowels this feature manifests itself primarily by the position of the first formant (11): when the latter is higher (i.e. closer to the third and higher formants), the phoneme is more compact. The closer the first formant is to the upper formants, the higher will be the intensity level of the region above the first formant, especially the level between peaks. (See Fig. 4.).

In the consonants, compactness is displayed by a predominant formant region, centrally located, as opposed to phonemes in which a non-central region predominates; (cf. Fant's analysis of Swedish stops (3)). The compact nasals have a dominant formant region between the characteristic nasal formants (200 cps and 2500 cps). Delattre's observations on the positions of the first formant in stops and nasal consonants (12) corroborate the parallelism between the compactness feature in vowels and consonants.

It has been suggested that the proper measure for the feature of compactness would be somewhat akin to the measures of dispersion accepted in statistics. The usual measure for this is the second moment about the mean. Preliminary calculations suggest this as a possible measure of compactness. Certain questions regarding the proper weighting of the frequency vs. intensity spectrum remain open: especially whether a weighting like the equal loudness contour should be applied to the spectra before the moments are computed.

2.412 Production. The essential articulatory difference between the compact and diffuse phonemes lies in the relation between the volume of the resonating cavities in front of the narrowest stricture and those behind this stricture. The ratio of the former to the latter is higher for the compact than for the corresponding diffuse phonemes. Hence the consonants articulated against the hard or soft palate (velars and palatals) are more compact than the consonants articulated in the front part of the mouth. In the case of vowels the compactness increases with an increase in the cross-sectional area of any constricted passage. Thus open vowels are the most compact, while close vowels are the most diffuse.

A higher ratio of the volume of the front to that of the back cavity can be also achieved by shortening the pharynx. This is the case in the production of compact consonants. In the corresponding diffuse consonants the pharyngeal cavity is lengthened by raising the velum and lowering the hyoid bone. X-ray photographs of the articulation of Finnish vowels and their measurements made by Sovijärvi are particularly revealing in this respect (13). The volume of the pharyngeal cavity for a diffuse phoneme is always bigger than for the corresponding (ceteris paribus) compact phoneme. (See Fig. 5).

2.413 Perception. Because of the higher over-all level usually associated with a longer duration, the compact phonemes display a higher "phonetic power" than the diffuse phonemes, ceteris paribus. Fletcher's calculations give the following "average values" ((14): table VIII, last column) for consonants of American English (and similar results for vowels):

Compact		Diffuse			
/k/	3.0	/t/	2.7	/p/	1.0
/g/	3.3	/d/	1.7	/b/	1.1
/ʃ/	11.0	/s/	0.9	/f/	1.0
/ŋ/	12.0	/n/	4.1	/m/	2.9

On the perceptual level a distinct association links the consonantal and vocalic opposition of compactness and diffuseness. As a recent experiment in Haskins laboratories (15) discloses, the same artificial "schematic stop was judged by a large majority of the subjects to be [p] when paired with [i] and [u], but to be [k] when paired with [a]". The contact with [a], the most compact, and with [i] and [u], the most diffuse of the vowels, prompts the association of this stop with [k], the most compact, and with [p], the most diffuse of the stops, respectively. Similarly the scale of magnitude, i.e. the small-vs.-large symbolism, latently connected for the average listeners with the opposition of compact and diffuse, works alike for vowels and for consonants (16).

The opposition compact vs. diffuse in the vowel pattern is the sole feature capable of presenting a middle term in addition to the two polar terms. On the perceptual level, experiments that obtained such middle terms through the mixture of a compact with the corresponding diffuse vowel (17) seem to confirm the peculiar structure of this vocalic feature, which sets it apart from all other inherent features.

2.414 Occurrence. The distinction of compact and diffuse vowels is apparently universal. A few geographically scattered languages such as Tahitian and Kasimov-Tatar lack compact consonants (both velars and palatals). Often compact consonants occur only among stops, as in Danish.

But while consonants obey a strict dichotomy and may be either compact or diffuse, a parallel state in the vocalic pattern is frequent but not universal. E.g. in Roumanian (and similar relations exist in many other languages) the open /a/ and the close /ɨ/, as in rad "I shave" - rîd "I laugh", are opposed to one another as compact vs. diffuse. The corresponding mid vowel /ə/ is diffuse with respect to /a/ (cf. răi "bad" - rai "paradise") but at the same time compact in relation to /ɨ/ (cf. văr "cousin" - vîr "I introduce"). Thus compactness and diffuseness may be envisaged as two opposites, one symbolized by "plus" and the other by "minus": then /ə/ would be denoted by ±. This opposition of two contraries could, however, be resolved into two binary oppositions of contradictories: compact vs. non-compact and diffuse vs. non-diffuse. In this case, /ə/ would be doubly negative -- both non-compact and non-diffuse.

2.42 Tonality Features

This sub-class of the resonance features comprises three distinct dichotomous features capable of interacting variously with one another: a) the gravity feature, b) the flattening feature, and c) the sharpening feature.

2.421 Grave vs. Acute

2.4211 Stimulus. Acoustically this feature means the predominance of one side of the significant part of the spectrum over the other. When the lower side of the spectrum predominates, the phoneme is labeled grave; when the upper side predominates, we term the phoneme acute. Two measures suggest themselves as proper for this feature: a) the center of area, and b) the third moment about the center of area. As stated above (cf. 2.411), it is necessary before applying these criteria to normalize the spectra in some way. At present the proper normalizing function is still undetermined.

The great advantage of the third moment lies in the fact that here the predominance of the lower end of the spectrum would give negative values, while the predominance of the upper end would give positive values. Thus we could determine the gravity or acuteness of a sound without reference to any other standards. However, the fact that we must cube one of our variables (the frequency difference) seems to make the third moment an extremely sensitive measure which can only be used with extreme caution.

When using the center of area we avoid these difficulties, but at the same time we lose the advantages outlined above. The absolute values of the center of area cannot indicate whether a phoneme is grave or acute, for the center of area of an acute phoneme might well be lower than that of a grave; cf. the centers of area of the acute /e/ and the grave /f/ in the English word deaf. Thus it is impossible to decide whether a given phoneme is grave or acute without knowing at least some of the other features which the phoneme in question possesses.

Grave vs. acute vowels: Turkish /kɨs/ "malevolent" - /kis/ "tumor", /kus/ "vomit!" - /kys/ "reduce!"; /an/ "moment - /en/ "width", /on/ "ten" - /ɸn/ "front"

The position of the second formant in relation to that of the other formants in the spectrum is the most characteristic index of this feature: when it is closer to the first formant the phoneme is grave; when it is closer to the third and higher formants it is acute.

Grave vs. acute consonants: fill - sill, pill - till, bill - dill, mill - nil. In identifying the gravity feature of a consonant it is often profitable to observe the second formant in the adjacent vowel, if any: it is lowered in the case of grave consonants, and raised if the consonant is acute. This is the method advocated by Visible Speech (1). In some cases the position of the third and even higher formants may also be affected.

2.4212 Production. The gravity of a consonant or vowel is generated by a larger and less comparted mouth cavity, while acuteness originates in a smaller and more divided cavity. Hence gravity characterizes labial consonants as against dentals, as well as velars vs. palatals (see Fig. 5,) and, similarly, back vowels articulated with a retraction of the tongue vs. front vowels with advanced tongue (19).

Usually, however, a notable auxiliary factor in the formation of grave phonemes (back vowels and labial consonants as well as velars if opposed to palatals) is a contraction of the back orifice of the mouth resonator, through a narrowing of the pharynx, whereas the corresponding acute phonemes (dental and palatal consonants and front vowels) are produced with a widened pharynx. For instance, the widths of the cross-section of the pharyngeal cavity for the two classes of Czech consonants deviate from its width in silence (13.3 mm) as follows (measurements in mm):

Grave		Acute	
/u/	- 3.8	/i/	+ 15.2
/o/	- 5.5	/e/	+ 4.0
/f/	- 4.7	/s/	+ 6.3
/x/	- 3.8	/ʃ/	+ 1.7
/p/	- 2.5	/t/	+ 0.5
/k/	- 2.6	/c/	+ 12.7
/m/	- 2.5	/n/	+ 8.9 (See Fig. 5)

2.422 Flat vs. Plain

2.4221 Stimulus. Flattening manifests itself by a downward shift of a set of formants or even of all the formants in the spectrum.

Flat vs. plain vowels: Turkish /kus/ - /kɨs/, /kys/ - /kis/; /on/ - /an/; /ɸn/ - /en/ (See Fig. 4). We employ a conventional musical term for labeling this feature, and in phonemic transcription we may correspondingly use a subscript or superscript musical flat "♭" to denote the flat consonants. Examples from Rutulian, a North Caucasian language: /iak♭/ "light" - /iak/ "flesh" /χ♭ar/ "more" - /χar/ "hail". (See Fig. 6).

2.4222 Production. Flattening is chiefly generated by a reduction of the lip orifice (rounding) with a concomitant increase in the length of the lip constriction. Hence the opposition flat vs. plain has been genetically termed "orifice variation", and the opposition grave vs. acute "cavity variation" (18).

Instead of the front orifice of the mouth cavity, the pharyngeal tract, in its turn, may be contracted with a similar effect of flattening (20). This independent pharyngeal contraction, called pharyngealization, affects the acute consonants and attenuates their acuteness (See Fig. 7). The fact that peoples who have no pharyngealized consonants in their mother tongue, as, for instance, the Bantus and the Uzbeks, substitute labialized articulations for the corresponding pharyngealized consonants of Arabic words, illustrates the perceptual similarity of pharyngealization and lip-rounding. These two processes do not occur within one language. Hence they are to be treated as two variants of a single opposition-flat vs. plain. The two phonetic signs [t̫] and [ƫ] used for rounded and pharyngealized consonants respectively could be replaced by a single symbol in the phonemic transcription. The subscript or superscript musical flat which we have employed for the Caucasian rounded consonants can also be used for the Arabic pharyngealized consonants: /d♭irs/ "molar" - /dirs/ "camel's tail", /s♭alb/ "crucifixion" - /salb/ "despoiling."

On the autonomous use of the "back orifice variation" for the grave consonants and for the vowels see 2.4236.

2.423 Sharp vs. Plain

2.4231 Stimulus. This feature manifests itself in a slight rise of the second formant and, to some degree, also of the higher formants.

Examples: Russian /m̦'aț/ "to rumple" - /m̦'at/ "rumpled" - /m'aț/ "mother" - /m'at/ "checkmate", /kr'of̦/ "blood" - /kr'of/ "shelter" (see Fig. 9).

2.4232 Production. To effect this feature, the oral cavity is reduced by raising a part of the tongue against the palate. This adjustment, called palatalization, is made simultaneously with the main articulation of a given consonant and is linked with a greater dilatation of the pharyngeal pass in comparison with the corresponding plain consonant. The pharyngeal dilatation of the plain acute consonants is further augmented for the sharpened ones. The pharyngeal contraction of the plain grave consonants is supplanted by a dilation for the sharpened ones (see Fig. 9). Hence the behavior of the pharynx is particularly important in the sharpening of the grave consonants and may, under certain circumstances, become its main factor (see 2.4236).

2.4233 Perception of Tonality Features. The intelligibility of acute phonemes is seriously impaired by the elimination of their high frequencies, while the grave phonemes are hardly recognizable when losing the low frequencies (21 and 14). A schematic stop is perceived as [t] when endowed with distinctly higher frequencies and as [p] when endowed with distinctly low frequencies (cf. 2.413).

Two phonemes contrasted as grave and acute (e.g., /u/ vs. /y/ or /ɨ/ vs. /i/ or /f/ vs. /s/) are easily identified as dark and light respectively by responsive subjects synesthetically oriented, while the contrast of flat and plain, /u/ vs. /ɨ/ or /y/ vs. /i/, produces rather a sensation of depth, breadth, weight and bluntness vs. thinness, height, lightness and shrillness. A closer study of these two dimensions of auditory sensation in their relation to the distinct acoustic stimuli and to the reactions of the same listeners upon the compactness feature could contribute to the elucidation and delimitation of the different sound attributes.

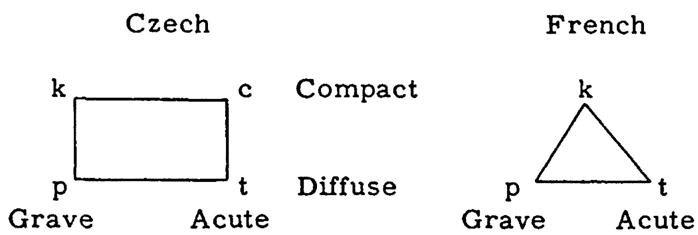
The increased "corpulence" and "hardness" ascribed by the Arabic grammatical tradition to the pharyngealized consonants in terms of auditory experience is similarly applied by Caucasian observers to the rounded consonants.

The sharpened acute consonants as /ş/, /ţ/ are sensed by responsive subjects as slightly brighter than /s/, /t/ and the sharpened grave /f̦/, /p̦/ as somewhat less dark than /f/, /p/.

Subjects endowed with colored hearing refer to vowels as chromatic and to consonants as achromatic, grayish. The contrast between acute and grave phonemes is correlated with the white-black, yellow-blue and green-red responses, whereas compact phonemes are prevalently matched with the colors at the greatest distance from the white-black axis (22). Experiments in vowel mixing show that grave and acute vowels when sounded simultaneously are not perceived as a single vowel (17). This test may be compared to a similar experience with colors - the non-existence of bluish yellow or reddish green (23).

2.4234 Occurrence of Tonality Features. Each language presents at least one tonality feature. We term it primary. Moreover, a language may contain one or two secondary tonality features.

2.4235 The Primary Tonality Feature. Consonants almost universally possess a tonality feature. As a rule, the diffuse consonants exhibit the opposition grave vs. acute, which often is found also in the compact consonants. In other words, the consonant patterns usually include both labial and dental phonemes and frequently also mutually opposed velars and palatals. Such is, for instance, the case in several Central European languages - Czech, Slovak, Serbocroatian and Hungarian. Their consonant phonemes form a square pattern, while in languages such as English and French, which do not split their compact consonants into grave and, _ceteris paribus_, acute phonemes, this pattern is triangular:

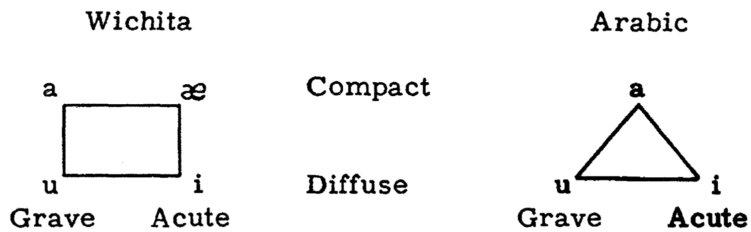


In the few American and African languages that have no labials, their absence, for the most part, can be traced to the traditional use of labrets. Moreover, most of these rare consonant patterns, devoid of the opposition grave vs. acute, have another tonality feature: flat vs. plain; e.g. Tlingit (Alaska), Iroquoian, and Wichita (Oklahoma); cf. such Tlingit word-pairs as [ja:k̹] "canoe" - [ja:k] "shell".

In vowel patterns with only one tonality feature, the following three cases are found: a) the opposition grave vs. acute alone; b) rarely, the opposition flat vs. plain alone; c) quite frequently, a fusion of the two oppositions. Examples for the first kind are Wichita (24) and Slovak, with such pairs as Slovak _mat'_ /mac/ "mother" - _mät'_ /mæc/ "mint", or Japanese, where the grave phoneme opposed to /i/ is produced without lip-rounding. In Russian, which exemplifies the second type, close phonemes /u/ and /i/ are opposed to each other only as flat (rounded) to plain (unrounded), because in certain positions both of these phonemes are represented by front variants and in certain others by back variants: [ʃ̂yd̹'it̹] "to play pranks" - [ʃ̂id̹'it̹] "to smoke", [rv'u] "I tear" - [rv'ɨ] "moats". In these cases only one of the two processes is phonemically relevant, while the other is a redundant feature appearing only in certain definite phonemic contexts. The third type, an indissoluble fusion of both processes, takes place in Spanish and Italian: e.g. Spanish /puso/ "he put" - /piso/ "tread", /poso/ "sediment" - /peso/ "weight". Here in the opposition grave vs. acute a wide undivided mouth cavity is _always_ accompanied by rounding, while a smaller and more comparted cavity is _never_ accompanied by rounding. Thus in these patterns only the optimal grave and the optimal acute are opposed to each other.

If there is only one tonality feature in the vowels of a given language, then it may be lumped with the primary (or only) tonality feature of the consonants, regardless of which of the three above patterns actually occurs. For example, Russian uses one opposition (flat vs. plain) as the only tonality feature in the vowels, and another (grave vs. acute) as the primary tonality feature in the consonants. The difference between these features is, however, redundant since it accompanies the opposition of vowels vs. consonants, and consequently the only relevant factor here is the common denominator of the two tonality features.

The sole or primary tonality feature is often confined to diffuse vowels. Hence vowels, like consonants, form either a square or a triangular pattern:



2.4236 The Secondary Tonality Features. In a number of languages the consonants use the opposition flat vs. plain as a secondary feature, in addition to the primary feature, i.e. the opposition grave vs. acute. Flattening produced by lip-rounding is wide-spread in the Caucasus and also occurs in some native languages of Asia, Africa and America. It mainly affects velars, but is sometimes extended to other consonants as well. Another variety of flattened phonemes, the pharyngealized (so-called <u>emphatic</u>) consonants appear in some Semitic and adjacent languages. This process affects the diffuse acute (dental) consonants and attenuates their acuteness, while in the compact consonants it fuses with the primary opposition grave vs. acute and intensifies the distinction between palatals and velars by imposing upon the latter a very strong pharyngeal contraction.

The distinction of retroflex and dental consonants, characteristic in particular of various languages in India, is another manifestation of the same opposition (see Fig. 8): both the contraction of the pharynx and the elongation of the resonating cavity take place in producing emphatic as well as retroflex consonants, but for the former the first process, and for the latter the second one seems to be of greater pertinence.

Liquids and glides, also, undergo either rounding or pharyngealization and may partake in the opposition flat vs. plain. Thus Circassian distinguishes a rounded and unrounded glottal catch: /ʔ̫a/ "say!" - /ʔa/ "hand". Arabic has an aspiration with and without contraction of the pharynx: /ḥadam/ "it was hot" - /hadam/ "he pulled down", /jaḥdim/ "it is hot" - /jahdim/ "he pulls down".

The opposition of sharpened and plain consonants plays an important part, e.g., in Gaelic, Roumanian, Polish, Russian and several languages adjacent to the latter. It primarily affects the diffuse acute consonants (dentals), but is sometimes extended also to other classes (labials and velars).

In a few languages rounded (flat) and palatalized (sharp) consonants may coexist, e.g. the Abkhazian language in the Caucasus opposes a plain phoneme as /g/ to the corresponding flat /g̊/, on the one hand, and to the sharpened /g̡/, on the other. In single languages such as Dungan Chinese and Kashmiri, the two co-existing oppositions realize all four possible combinations: 1) rounded unpalatalized, 2) unrounded unpalatalized, 3) rounded palatalized, 4) unrounded palatalized. (Cf. the vowel series /u/ - /ɨ/ - /y/ - /i/). E.g. Kashmiri distinguishes in this manner four different grammatical forms of the verb "to do": /kar̊/ - /kar/ - /kar̡/ - /kar̡̊/. In the rounded palatalized phonemes the second formant moves closer to the third while at the same time all formants are moved down in frequency.

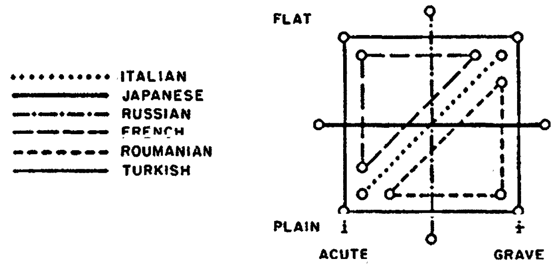
Finally the combination of flats and sharps within one language can acquire another form. Beside languages such as Arabic, which confine the autonomous role of the pharynx to its contraction for the flattening of the acute consonants, there are a few languages in the NE Caucasus which employ the widening of the pharynx to sharpen the grave consonants. This is the essence of the so-called "emphatic softening" (25). Both these processes - the flattening of the acuteness and the sharpening of the gravity - may be reduced to a common denominator: the attenuation of the primary feature through a pharyngeal modification. Consequently we may transcribe the dentals with narrowed pharynx in one and the same way. Examples from Lakkian (NE Caucasus): /d̈a: / "middle" - /da:/ "come ", and /m̈a/ "bolt" - /ma/ "have it.".

In a great number of languages each of the two oppositions - grave vs. acute and flat vs. plain - acts separately in the vowel pattern. If in such a language two vowel phonemes are opposed to each other by contrary positions of their second formant, then at least one of these two phonemes is at the same time opposed to a third phoneme by a shift in the first three formants and in some of the higher formants. Thus French (and similarly Scandinavian languages, standard German, and Hungarian) distinguishes two classes of acute vowels and one - an optimal class - of grave vowels: plain acute - flat acute - flat grave: nid /ni/ "nest" - nu /ny/ "naked" - nous /nu/ "we".

Other languages, e.g. Roumanian and Ukranian, have two classes of grave vowels - flat as /u/, plain as /ɨ/ - and only a single, optimal class of acute vowels - plain as /i/. A comparable distribution appears in the variety of English described by D. Jones (RP). Diffuse vowels: acute in pit /p'it/ - plain grave in putt /p'ət/ - flat grave in put /p'ut/; compact vowels: acute in pet /p'et/ - plain grave in pat /p'at/ - flat grave in pot /p'ot/. It is true that in pat the contextual variant representing the phoneme /a/ is the front [æ], but the tongue in producing this English vowel is more retracted than in producing acute vowels, and moreover a pharyngeal contraction "appears to be an inherent characteristic of the sound", as noted by D. Jones and other observers. This connects it with the back variant of the same phoneme and with the other grave vowels.

Finally in Turkish both the grave and the acute vowels are split into two opposite sub-classes - flat and plain: /kus/ - /kɨs/ - /kys/ - /kis/; /on/ - /an/ -

/øn/ - /en/. Cf. the diagram:



When a language possesses only three classes of vowels: an optimal grave, an optimal acute and an attenuated class, i.e. either flat acute or plain grave, then, as far as the structure of the vowel pattern does not prevent it, it is possible to interpret all three classes in terms of one opposition. With this assumption, /u/ is "+", /i/ is "-" and /y/ or /ɨ/ is "+" vs. /i/, but "-" vs. /u/ and hence may be symbolized by "±". The opposition flat vs. plain as a secondary tonality feature of vowels supplements the optimal grave vs. acute opposition by an attenuated grave and/or acute; for instance /u/ and /i/ by /ɨ/ and/or /y/. In a few Caucasian, Nilotic and Hindu languages, a similar attenuation is performed by a dilation of the pharynx (sharpening) for the grave vowels and its contraction (flattening) for the acute vowels. This pharyngeal behavior generates two series of centralized vowels opposed to the back and front vowels respectively, e.g., in Dinka (Anglo-Egyptian Sudan) /ü/ - /u/, /ö/ - /o/; /ï/ - /i/, /ë/ - /e/: /dit/ "bird" - /dit/ "big".

2.43 Tense vs. Lax

2.431 Stimulus. In contradistinction to the lax phonemes the corresponding tense phonemes display a longer sound interval and a larger energy (defined as the area under the envelope of the sound intensity curve; cf. 2.31).

In a tense vowel the sum of the deviation of its formants from the neutral position is greater than that of the corresponding lax vowel (cf. 2.13). A similar deviation may be presumed for the spectrum of the tense consonants (called strong or fortes) in comparison with their lax counterparts (called weak or lenes).

In consonants, tenseness is manifested primarily by the length of their sounding period, and in stops, in addition, by the greater strength of the explosion.

The opposition of tense and lax vowels has often been confused with the distinction between more diffuse and more compact vowels and with the corresponding articulatory difference between higher and lower tongue position. But the more diffuse vowels are, ceteris paribus, shorter than the more compact, whereas the tense vowels have a longer duration than the corresponding lax.

Examples. Tense vs. lax consonants: English pill - bill, till - dill, kill - gill /gil/, chill - gill /ǯil/, fill - vill, sip - zip. Tense vs. lax vowels: French saute /sot/ "jump" - sotte /sot/ "fool" (fem.), pâte /pạt/ "paste" - patte /pat/ "paw", las /lạ/ "tired" - là /la/ "there", jeûne /ʒø̣n/ "fast" - jeune /ʒøn/ "young", tête /tẹt/ "head" - tette /tet/ "suckle", thé /tẹ/ "tea" - taie /te/ "pillow case" (the difference in duration which is crucial for the distinction between /ẹ/ and /e/ before consonants is notably reduced at the end of the word).

French Tense and Lax Vowels

	F_1	F_2	F_3	$\Sigma\Delta f$
Neutral Position (Mlle. D.)	570	1710	2850	
saute /sọt/	480	1000	2850	
Δf	90	710	0	800
sotte /sot/	520	1400	3000	
Δf	50	310	150	510
pâte /pạt/	600	1200	2800	
Δf	30	510	50	590
patte /pat/	650	1600	2650	
Δf	80	110	200	390
tête /tẹt/	600	2100	3200	
Δf	30	390	350	770
tette /tet/	600	1900	2500	
Δf	30	190	350	570
thé /tẹ/	450	2300	3200	
Δf	120	590	350	1070
taie /te/	600	2100	2650	
Δf	30	390	200	620

The sum of the deviations of the formants of a tense vowel is always greater than that of the corresponding lax vowel. Tense vowels are usually considerably longer than the corresponding lax vowels (32).

2.432 Production. Tense phonemes are articulated with greater distinctness and pressure than the corresponding lax phonemes. The muscular strain affects the tongue, the walls of the vocal tract and the glottis. The higher tension is associated with a greater deformation of the entire vocal tract from its neutral position. This is in agreement with the fact that tense phonemes have a longer duration than their lax counterparts. The acoustic effects due to the greater and less rigidity of the walls remain open to question.

2.433 Perception. Rousselot's (26) and Fletcher's (14) tests have shown that ceteris paribus, tense phonemes possess a higher audibility than the corresponding lax phonemes. For English consonants, Fletcher (Table IX) gives the following data on the number of decibels by which single sounds must be attenuated in order to render them inaudible.

Tense:	k 83.8	t 84.1	p 80.6	s 82.4	f 83.6
Lax:	g 82.9	d 78.9	b 78.8	z 81.6	v 81.4

The importance of the difference in the duration for the distinction of tense and lax consonants is illustrated by the experiments of L. G. Jones: when the beginnings of [p], [t], [k] (originally produced by cutting the corresponding constrictives, cf. 2.3113) had been erased on tape recordings, they were apprehended by native English listeners as [b], [d], [g]. Slavic listeners, however, still heard [p], [t], [k], since not the tenseness but the voicing feature is relevant for them (see 2.434).

2.434 Occurrence. In many languages, e.g. Cantonese, the consonant phonemes display neither of the two oppositions, voiced vs. voiceless and lax vs. tense.

In a number of languages only one of these two oppositions is relevant. If the opposition of tense and lax consonants is the only distinctive one, then either none of them are voiced, as, for instance, in Danish, or voicing and voicelessness become concomitant factors of laxness and tenseness respectively, as in English or French. In such languages the tenseness feature is more constant than the redundant voicing feature. This hierarchy is illustrated, for instance, by the French pattern, where [ʒ], the voiced lax (lenis) consonant of such forms as tu la jettes, becomes a voiceless lax [ʒ̥] before the voiceless [t] in vous la jetez but is still distinguished from [ʃ], the voiceless tense (fortis), in vous l'achetez. In some of these languages the tense stops are aspirated either generally, or, as in English, the aspiration is confined to certain positions.

The inverse relation is observable, e.g. in Slavic languages, where the voicing feature is the relevant one, while the tenseness feature is only concomitant and optional to a certain degree.

Finally, there is a relatively limited number of languages where both of these oppositions are present in the phonemic pattern. In this case the autonomous opposition voiced vs. voiceless is ordinarily confined to the stops; the aspiration is used to implement the opposition of tense and lax stops, and, for the most part, only the unvoiced stops are split into aspirated and non-aspirated; e.g. Suto (South Africa): /dula/ "sit" - /tula/ "crack" - /thula/ "to butt" (27). Seldom, especially in a few Indic languages, the voiced class, too, presents pairs of tense and lax stops (aspirated and unaspirated respectively). Conversely, in some languages of the Caucasus, which distinguish voiced, checked, lax and tense stops (e.g. in Lezgian and Ossete), the redundant feature of aspiration marks the lax stops in contradistinction to the tense.

The prevocalic or postvocalic aspiration /h/ is opposed to the even, unaspirated onset or decay of a vowel. The former is a tense glide (spiritus asper), and the latter, a lax glide (spiritus lenis), which properly speaking is a zero phoneme. This opposition (/h/ - /#/) occurs in English in initial prevocalic position:

hill:ill≃pill:bill; hue /hi'uu/: you / i'uu/≃tune / ti'uun/: dune / di'uun/. The lax counterpart of /h/ presents an optional variant: in cases of emphasis a glottal catch may be substituted for the even onset: an aim can appear in the form [ənʔ'eim] in order to be clearly distinguished from a name [ən'eim]. Ordinarily languages which possess an opposition of tense and lax consonants have an /h/ phoneme too.

An example of the opposition tense vs. lax in liquids is presented by the strongly rolled and flapped /r/ in Spanish: tense in perro "dog" - lax in pero "but".

The opposition of tense and lax vowels occurs in various regions of the world: sometimes it encompasses the entire vocalic pattern, but most often it affects only some of the vowel phonemes, as in Italian with its two pairs of tense and lax vowels, e.g. /tọrta/ "tart" -/torta/ "crooked" (fem.), /pesca/ "fishing" - /pesca/ "peach".

2.44 Supplementary Resonator: Nasal vs. Oral

2.441 Stimulus. The nasalization feature may pertain both to consonants and to vowels: English din - did, dim - dib, ding /diŋ/ - dig; French banc [bạ̃] "bench" - bas [bạ] "low".

The spectrum of the nasal phonemes shows a higher formant density than that of the corresponding oral phonemes (see Fig. 11). According to M. Joos (28) between the first and the second vowel formants there appears in the nasal vowels an additional formant with concomitant weakening in the intensity of the former two. In vowels like /a/ with a high first formant the additional nasal formant appears below, rather than above, the lowest formant of the corresponding oral vowel.

The nasal consonants add to the corresponding oral stops (/m/ to /b/, /n/ to /d/, /ŋ/ to /g/, and /ɲ/ to /ɟ/) a nasal murmur throughout their closure period. In addition to several variable formants, this murmur possesses two constant and clear formants, one at about 200 cps. and the other at about 2500 cps.

The formants in the murmur part are relatively stable: in the spectrogram they appear as straight horizontal lines, and the transitions to and from the adjacent phoneme are usually quite abrupt.

The additional poles and zeros, due to nasalization, are a local distortion in the spectrum without any influence on the other resonance features. These fundamental features are determined solely by the original set of non-nasal poles which affect the entire spectrum.*

2.442 Production. The oral (or more exactly, the non-nasalized) phonemes are formed by the air stream which escapes from the larynx through the mouth cavity only. The nasal (or more exactly, nasalized) phonemes are, on the contrary, produced with a lowering of the soft palate, so that the air stream is bifurcated and the mouth resonator is supplemented by the nasal cavity.

2.443 Occurrence. The opposition oral vs. nasal is nearly universal in consonant patterns, with isolated exceptions such as Wichita (24). But a great number of languages have no distinction of nasal vs. oral vowels. The number of nasal phonemes in the vowel and consonant pattern is never higher, and usually lower, than the number of oral phonemes. Nasality can be combined with other resonance features, and with rare exceptions at least two nasal consonants are distinguished - the diffuse acute /n/ and the diffuse grave /m/. Frequently there is, in addition, one compact nasal; rarely, two: one acute /ɲ/ and the other grave /ŋ/. In respect to the voicing feature the nasal consonants behave like liquids; normally they are voiced and seldom partake of the opposition voiced vs. voiceless: cf. Kuanyama (SW Africa): /na/ "with" - /n̬a/ "quite" (27). Other consonantal source features are also very rare in nasals.

2.5 CONCLUSION

The inherent distinctive features which we detect in the languages of the world and which underlie their entire lexical and morphological stock amount to twelve binary oppositions: 1) vocalic/non-vocalic, 2) consonantal/non-consonantal, 3) interrupted/continuant, 4) checked/unchecked, 5) strident/mellow, 6) voiced/unvoiced, 7) compact/diffuse, 8) grave/acute, 9) flat/plain, 10) sharp/plain, 11) tense/lax, 12) nasal/oral.

No language contains all of these features. Their joint occurrence or incompatibility both within the same language and within the same phoneme is to a

* John Lotz has made the following suggestion: "There are vowels which are not nasal and there are vowels which are nasal and consequently show a consonantal disruption of the vocalic pattern. But the nasal quality is clearly superposed, since it can only function in addition to another quality. In general terms, if a feature is implied - and in the hierarchy secondary - we subtract it from the total wave and thus obtain the basic phenomenon."

considerable extent determined by laws of implication which are universally valid or at least have a high statistical probability: X implies the presence of Y and/or the absence of Z. These laws exhibit the stratification of the phonemic patterns and reduce their apparent variety to a limited set of structural types.

Despite their multiform interdependence within the phoneme and within the entire phonemic pattern, the different distinctive features remain autonomous. Not only may any feature perform its distinctive function (/gip/≠ /gib/≠/gid/), but the identification of a single feature regardless of the different phonemes in which it occurs is seen to play a significant part in language.

The autonomy of various distinctive features clearly comes to light in the grammatical process known in certain languages under the name of vowel harmony. In such languages a word-unit is limited in the choice of its vocalic features. Thus in some languages of the Far East the vowels of a word unit must be either all compact or all diffuse, e.g. in Gold (on the Amur) it may contain either only /o a e/ or only /u ə i/: /gepalego/ "liberate" - /gisurəgu/"retell".

In Finnish those acute vowels which ceteris paribus are paired with grave vowels cannot belong to the same simple word-unit as the grave vowels. The Finnish vowel pattern includes:

Flat		Plain	
Grave	Acute	Grave	Acute
		a	æ
o	ø		e
u	y		i

Hence a word unit may contain either / a o u/ or / æ ø y/, while the plain acute vowels / e i/, which have no plain grave correspondents, are combinable with any Finnish vowel.

In most of the Turkic languages, grave and acute vowels are incompatible within a word unit; and to a greater or lesser extent the same device is applied to the flat and plain vowels. E.g., in Turkish:

Root-vowels	Suffix "our"
flat grave	/-muz/
plain "	/-mɨz/
flat acute	/-myz/
plain "	/-miz/

Ibo (S. Nigeria) has eight vowel phonemes displaying three oppositions: compact vs. diffuse, grave vs. acute, and tense vs. lax. A root contains either only tense /ọ ẹ ụ ị/ or only lax vowels /o e u i/.

A "consonant harmony" has been developed by the language of the NW Karaites (in Lithuania): the consonants of a word unit are either all sharp or all plain; e.g. /k̦un̦l̦ar̦d̦an̦/ "from days" - /kunlardan/ "from servants".

An extraction of the consonantal compactness and gravity features achieved by an extinction of all other consonantal features is documented by the conventional consonant mutilations in the diction of the Pima songs (SW America) recorded and analyzed by George Herzog.

Voicing is the only consonantal feature relevant for the Slavic assonances (22). For example, Polish oral and written poetry, when using assonances, takes as equivalent all voiced (doba - droga - woda - koza - sowa) and similarly all unvoiced consonants (kopa - sroka - rota - rosa - sofa), while the pairing of voiced and unvoiced consonants is inadmissible. The fact that the words /rota/ "company" and /rosa/ "dew" are semantically distinguished by one feature (interrupted vs. continuant) and at the same time equated in assonance by another feature of the same phoneme (voicelessness) is striking testimony for the operational autonomy of the distinctive features.

Analytic Transcription

The phonemes may be broken down into the inherent distinctive features which are the ultimate discrete signals. Were this operation reduced to yes-or-no situations, the phoneme pattern of English (Received Pronunciation) could be presented as follows:

	o	a	e	u	ə	i	l	ŋ	ʃ	ʃ̂	k	ʒ	ʒ̂	g	m	f	p	v	b	n	s	θ	t	z	ð	d	h	#
1. Vocalic/Non-vocalic	+	+	+	+	+	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
2. Consonantal/Non-consonantal	−	−	−	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
3. Compact/Diffuse	+	+	+	−	−	−		+	+	+	+	+	+	+	−	−	−	−	−	−	−	−	−	−	−	−		
4. Grave/Acute	+	+	−	+	+	−									+	+	+	+	+	−	−	−	−	−	−	−		
5. Flat/Plain	+	−		+	−																							
6. Nasal/Oral								+	−	−	−	−	−	−	+	−	−	−	−	+	−	−	−	−	−	−		
7. Tense/Lax									+	+	+	−	−	−		+	+	−	−		+	+	+	−	−	−	+	−
8. Continuant/Interrupted									+	−	−	+	−	−		+	−	+	−		+	+	−	+	+	−		
9. Strident/Mellow										+	−		+	−							+	−		+	−			

Key to phonemic transcription: /o/ - pot, /a/ - pat; /e/ - pet, /u/ - put, /ə/ - putt, /i/ - pit, /l/ - lull, /ŋ/ - lung, /ʃ/ - ship, /ʃ̂/ - chip, /k/ - kip, /ʒ/ - azure, /ʒ̂/ - juice, /g/ - goose, /m/ - mill, /f/ - fill, /p/ - pill, /v/ - vim, /b/ - bill, /n/ - nil, /s/ - sill, /θ/ - thill, /t/, - till, /z/ - zip, /ð/ - this, /d/ - dill, /h/ - hill, /#/ - ill. The prosodic opposition stressed vs. unstressed, splits each of the vowel phonemes into two.

The superposition of the distinctive features in the given language - in this instance English - determines their order in our analytic transcription.

I) The identification of the fundamental source features (1,2) divides the components of the message into vowels, consonants, glides and a liquid, whereby the latter does not demand further analysis.

II) The superposition of resonance features in vowels and consonants presents the following order: A) the compactness feature (3) encompasses all vowels and consonants; B) the gravity feature (4) concerns all vowels and compact consonants whereby the analysis of the acute vowels is exhausted; C) the flattening feature (5) is confined to grave vowels and terminates their analysis, while D) the nasality feature (6) affects uniquely the consonants and concludes the identification of the nasals; finally the tenseness feature (7) concerns all phonemes without a vocalic and nasal feature, i.e. the oral consonants and the glides.