THE OSCILLOGRAMS AND THE PHYSIOLOGY OF AUDITION

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Introduction

As the functioning of the cochlea is understood at present, the basilar membrane on the impact of sound waves registers distinctly recognisable movements. The latters' final mechanical effect however is the shearing action of the hairs of cort against the superjascent tectorial membrane (Davis, 1958; Zalin, 1961). Subsequent to this, cytochemical (Vinnikov and Titova, 1963 and 1964) and electrical (Wever, 1966) changes take over. The mechanical reactions of the basilar membrane thus form a crucial step in audition. It is also recognised that among the various cochlear structures it is this membrane that possesses the necessary extent, physical property and histology (Engstrora, 1955) to effectively intervene within the cochlear fluids the passage of sound viz. the micropressure changes caused by it in the medium and be responsible for handing it over further to the hair cells (Wever and Lawrence, 1954). However, the observable mechanical as well as electrical responses of the membrane to the stimulus is known since long (Lawrence, 1966) to be considerably broad while the actual auditory response is quite sharp. For instance, a great discrepancy is noticeable in the resolution of pitch. Our descrimination of pitches is fixer than what is indicated by the known responses of the membrane. For example, a trained ear can discern a change of even 2-3 frequency range in an incoming sound while the membrane's known responses are never so fine.

Though this is believed to be overcome by a stepwise contrast increasing mechanism along the entire acoustic pathway (Bekesy, 1960) beyond the membrane it is pertinent to enquire if mechanical responses more minute than Bekesy's travelling waves, which are known to be gross enough occur at the basilar membrane itself and if so, how to assess them. Such minute responses are recognised sometimes to occur and mathematical description of how the basilar membrane moves have been computerised to study the membrane's complicated action (see also Allaire, *et al.*, 197!). Nevertheless, a recognised handicap here is that there does not exist any direct method to observe these minute reactions of the membrane *in vivo* to the micropressure changes of a sound especially as they might be following specific sound examples—speech ensemble, for instance. Under this circumstance, it has been suggested (Krishnamurthy, 1971) that a detailed study of the micropressure changes with the help of

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oscillogram records of specific speech ensembles may be profitable. Appraisal of this pressure pattern is important in the physiology of cochlear action, for, ultimately the forces following them in the cochlear fluids are the sole factors for all cochlear mechanics.

Phonetically, any speech output with its phonemes, pauses, accents etc., is always a much patterned structure. Many kinematic correspondences for these details have been demonstrated. Analysing chin and breath movements in terms of operational phonemes (Krishnaraurthy, 1967) is a recent attempt while deeper levels of correspondences are also pointed out electrophysiologically (Fromkin, 1965; Leanderson, *et ai,* 1966). We are however more concerned here with the receptor end of the basilar membrane responses as may be due to the very small changes of the pressure that constitute a sound like that of speech; hence the selection of oscillograms of short speech ensembles. Strictly, such oscillograms represent the micropressure changes in the transmission medium of air outside the ear for the ensemble concerned and as they fall on the tympanum (Fig. 3). But, the acoustic distortion in the middle ear is believed to be negligible on other accounts (Wever and Lawrence, 1954) and is also considered is general to be remarkably linear (Sweetman and Dallos, 1969). These oscillograms themselves can therefore be regarded, atleast tentatively, as a picture of the pressure changes at the level of the oval window itself or in fact, the vicinity of the basilar membrane across the cochlear fluids (Fig. 3). This is a measure of expediency at present no doubt. Its experimental verification with the help of a cochlear model designed by the author is under separate study. Assessing physical characteristics of speech with the help of oscillograms is well cultivated following Fletcher (1961) What is attempted as new here is to seek explanation for every feature of oscillogram track clearly in terms of the micropressure changes responsible for it with an implied objective that it may aid understanding of the mechanical action at the basilar membrane.

The Problem

Comparative study of the structure of the oscillogram tracks of several speech ensembles is a first step here. This was carried out earlier (Krishnamurthy, 1971) and only a general note on one oscillogram viz. that of /val/ is reproduced here. The problem was to select out and describe as many distinctive features as possible in the figure of the tract and try to refer them to the aspect of the micropressure changes that might have been responsible for them.

Method

Fig. **1**

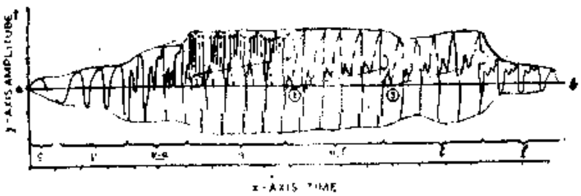

Fig. 2

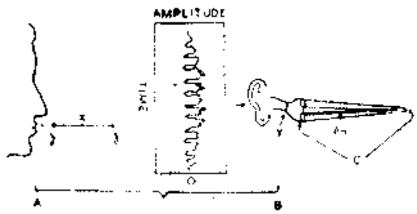

Fig. 3

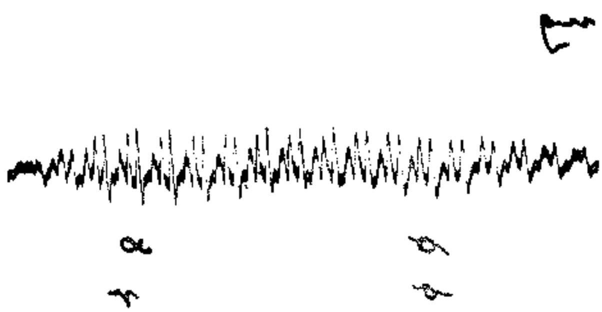

Fig. 4

Fig. 1 is **the oscillogram** of the ensemble /val/—a Tamil Word. Fig. 2 is its idealised diagram. **Fig.** 4 is a portion of a highly expanded (10 mm of the track = 0.001 second of duration) oscillogram of /Vorberetung/—a German Word. If we discount for the present any mecl anical distortion introduced by the tape recorder feeding the oscilloscope or in the oscilloscope itself, the oscillograph record can be held to be a true picture of how a particle of air vibrated to and fro at the time of the utterance of the ensemble concerned. In the diagram of the net process of speech (Fig. 3), AB is the extent of the medium of vibration between the speaker and hearer, *x*, any particle of the medium vibrating to and fro on its axis till the duration of the ensemble to two positions *y* and z, T, tympanum and *bm*, the basilar membrane within C, the cochlea. The movement between *y* and *z* is of changing distance throughout the utterance i.e. the length of *yz* continues to vary and what constitutes the patternment of pressure changes is the details of this variation in length chiefly. The motion of the particle *x* is presumed to be reflected by all the particles of the medium AB faithfully because of which reason the impulse of vibration travels from A to T and then from T to *bm*. This to and fro movement is extended on a time base to yield the oscillogram figure O. This is the principle of interpreting the oscillogram record for pressure pattern. To obtain the measurements of Table 1, a 10 mm portion of the original oscillogram of /Vorbereitung/ and a centimeter scale were projected together on a miiimeter graph sheet in such a way that one division of the scale (i.e. 1 mm) corresponded with one centimeter on the graph sheet. The lengths of the tracings can be easily and reliably read of on the graph sheet in terms of centimeters. We can thus avoid the difficulty and errors in direct measurements of the oscillogram tracings.

Results

General discription. The oscillogram track consists of a linear succession of several sharply repetitive units (Fig. 1 and 4). Each unit roughly bounds a vertically drawn out triangular space with its vertex on the upper and base on the lower side of a base line *ab* of Fig. 2. Its actual structure is constituted by the details of the tracing which makes up its two sides and the apex. This varies over the horizontal extent of the track. Since the oscillogram display is a faithful representation of the micropressure changes of the sound we can relate the several complexities of the tracing to the details of the micropressure changes as follows : .

A succession of large number of units occur for each track which means that the concerned micropressure itself develops as repetitive discrete units as is well known for any sound. The details of tracing within a unit, in other words, its particular tracing pattern in turn, reflects the details of the micropressure changes which have lasted for the duration of the unit concerned. It is this aspect which shows pronounced and characteristic variation over the horizontal extent of the track. It is customary to equate a speech oscillogram to its constituent phonemes on a general assumption that any major change in the tracing pattern of the units can be taken to indicate a major change in the phonetics of the oscillogram itself, namely the generation of a new phoneme. On these grounds the track consists of as many phonemes as there are types of units in their ensembles. Thus there are three types of units in /val/ and two types only in Fig. 4.

For the duration of any single phoneme, the units are generally more than one in each type and not single, the actual number being variable so that we can speak of *large* phoneme stretches or regions in the track (viz. 'v', 'a' and '1' regions of "val" Figs. 1 and 2) and not just points. Though there are several such units for a phoneme it is to be noted that the final auditory perception of the phoneme is single. It is interesting to enquire how this gets accomplished and more so, if there is any minimal number of units for a phoneme perception.

The general form and the detailed structure of the individual unit varies in the several phonemes of the ensemble. It is broad and *simple* in 'v' (Fig. 1) but the greater number of the units show a complex tracing. In 'a' of /val/, the simple form of V is almost completely replaced by a close row of vertical spikes giving a similarity in the appearance of oscillograms to what is common in the EEG records. The uniis of Fig. 4 can be best described as *peaked.* The track as a whole is widest in the midregion and becomes gradually smaller on either side. Such gradualness is also seen within many of the individual phoneme stretches so that the characteristic pattern of its units tends to occur well pronounced in the mid-region of the concerned stretch. In most areas of the phoneme stretches, the tracing for a unit starts at a point below the base line and reaches back to more or less the same level after sometime, this time representing the duration of the micropressure change for the unit. Consequently this duration is indicated by the basal breadth of the unit. It can be seen (Fig. 1 and 4) that this breadth is mostly the same for the whole track of the ensemble. As noted above, what varies in these units is the tracing pattern of their sides and apices. Since the oscillogram tracing is entirely due to deflections caused by the micropressure force of the sound (and the concommitant potential generation of the sound) the variations in the sides and apices can be taken to indicate the development of additional micropressure changes (and potential sounds) over and above the one responsible for sketching the unit itself. In other words, the unit's pattern indicates its total micropressure make up.

In view of the visible complexity of this pattern for many phonemes we should expect in the interest of acoustic faithfulness that atleast the major portion of this pattern should have an abiding and related effect on the basilar membrane as additional micropressure changes over and above the one responsible for the unit itself. In places where the form of the unit shows just an *indentation* and the tracing itself remains resolute and not discontinuous or hazy, it can be presumed that the generation of the sound itself has been gradual and steady. In 'a' of 'val' (Fig. 1) the EEG like appearance results because the generation of the pressure changes has been quick and they have been many as well so that this range of changes is not resolvable into just two peaks or a mere indentation. The tracing is consequently broken into the sudden shootings of the straight spikes. In this way we can recognise four types of units viz. simple (smooth), indented (not shown here), peaked and spiked at the level of the resolution the oscillogram affords. It is to be noted that a particular type of unit is repeated unaltered in its pattern over the shorter or greater region of its concerned phoneme.

The form of the unit changes from one stretch to the next stretch gradually but very systematically (see 'v-a' and 'a-1' regions of 'val'). At each step the complicated configuration gets shifted gradually, indentation for indentation or spike for spike, until the configuration resulting from the changes of the next phoneme replaces it. Because of this, in addition to the basic phoneme types of the units, one has to recognise certain transition units also in the track as between 'v' and 'a' or 'a' and '1' of 'val' (Fig. 1 and 2). The slowly developing nature of the sound in terms of the micropressure for a phoneme as well as the real difficulty in pinpointing the place where the phoneme actually gives over to the next one arc both clearly seen in this gradualness in the change in form of the several units. A line drawn as an envelope over all the basal as well as apical endpoints of the tracing of the units will indicate the way amplitude has registered its change in the ensemble (Fig. 2).

Quantitative data: Based on the above principles we can derive many quantitative data as well. It is here that the expanded oscillograms and the greater resolution they afford as in Fig. 4 are indispensable. The actual number of the units in a track can first be ascertained. Commencing from left of the base line of the track we can fix their serial numbers as well. The total number of the units in the track for 'val' is 76. Their distribution corresponding to the three component phonemes and the two transitionals can be roughly indicated as follows (leaving out one initial as well as a few terminal units, where the typical form is not traced resolutely): 7 for V, 8 for 'v-a'transitionals, 17 for'a', 30 for'a 1'transitionals and 14 for T. We can also undertake a detailed description of the pattern of each of the units. Since 'a' has the most complex tracing it can be subjected to further study. As can be seen from the Fig. 2, the following can be noticed in each unit of 'a': a tall middle spike, four short spikes of similar heights distributed on either side of the middle spike and a minor spiked peak in the beginning of the unit i.e. on the left of the base line. A succession of dark dots are visible throughout most of the tracing (Fig. 1). This height of the spikes and the level of the dots can be held to indicate, as elsewhere, the course and range of the amplitude while the horizontal placement of the spikes, peaks or any other mark shows the particular time of their development on the base line and thus their temporal relation to the unit itself. If we deduce the height of the whole 'a' stretch by the level of the tall spikes it becomes clear that the net amplitude of the region as a whole is the same, as the tall spikes of all the units go up to the 'same' level. It is to be noted that this is so, in spite of amplitudinal changes internal to a unit as revealed by the composition of the spikes unlike as in the V stretch where the units show a distinct rightward increase throughout. Many other details of such nature concerning the development of sound can be deduced by a close study of the oscillo grams.

In addition to such details of the individual units, some significant conclusions regarding the general development of the whole of the oscillogram track can also be drawn by a study of its overall form. This is illustrated here by what can be recognised as ' melody traces ' in a way (Fig. 1 & 2). If, in the definition of melody, namely, that it is an agreeable succession of single musical sounds (as distinguished from harmony which requires two different sources of sounds), we emphasise the feature of succession (i.e. occurrence in some graded manner) of single sounds, in other words, *a sustained graded pattern of occurrence* rather than their agreeable nature (mostly a psychological factor), we shall be able to understand some interesting and Characteristic internal patterns visible over large stretches of the tracks. In ' val ' (Figs. 1 & 2), within the region of 'a' and towards the vertices of the units, there occurs a dense packing of many minor spikes in all the units successively. It appeals as if these units themselves form together a single laterally sustained tracing gradually diminishing upward, towards the left side of the base line which means that at this particular level of amplitude, a large number of individual sounds were produced in a graded manner to form a 'melody'. Such dense graded collection of the tracing can thus be called a 'melody trace'. Three such tracings are seen in 'val' (Kg. 1 & *2)* : 1, in the initial region of 'a'; 2, in the region of transition between 'a' and'1' and 3, in the middle and end region of 'I'. The first tracing shows an upward shift towards the 'a-1' transition region to die away eventually and soon after this there is the second sustained dense tracing of the several individual sounds wft'h its course steady in 'a-1' region for sometime but steeply fading upwards where *'I'* starts. This is allowed by the third similar tracing, starting soon after the second is over and gradually ascending upward to die out at the apices of the '1'—units. The closeness of the spikes here is not so much as in the first two traces.

More precise data are obtainable from Fig. 4, whose net duration is 0.001 second. The total number of the units are 17, distributed as 7 for 'o' region, 2 for 'o.r' transition and 8 for 'r' region. For each peak, the length of right and left arms Was measured separately starting from the base line. The peaks themselves are three (designated as a, b and c) for one unit of 'o' region and four (designated as a, b, c and d) for one unit of 'r' region. In each region, the readings were taken for four units. Since the values between the two regions differ very minutely but characteristically they were analysed to ascertain if they bear any statistical significance atleast. ''No such significance was noticeable. It becomes necessary therefore to explain as to how discrimination between 'o' and 'r' sounds become possible despite the very minujte bust maintained differences of their micro pressure. It is undeniable that this difference itself will have to be considered critical for the membrane's response.

Discussion

for the purpose of auditory perception of a word all the details of the sound data that an oscillogram reveals as noted above may not be necessary. Redundancy of speech at the physical level is well known (Fry, 1960). Neither can we hold entirely, even in spite of the known acoustic faithfulness of the middle ear, that all the details displayed by the oscillogram track are perforce reproduced at the basilar membrane without any alteration whatsoever. Nonetheless, the importance of studying details of sound development as pressure changes of eventual understanding of the mechanism at the basilar membrane cannot be minimised as these two represent the two actual end points of the chain of mechanical events during audition. Importance of this study is likely to be more striking if a comparative study of the structure of oscillogarms of carefully selected contrastive ensembles is carried out on some lines as above. For this purpose however oscillograms of sufficiently expanded nature as in Fig 4 are necessary. For instance, the difference in the values between the two regions of 'o' and 'r' as yielded by the Table 1 should be considered critical (eventhough not even statistical significance is traceable) for representing their micropressure pattern on the basilar membrane. Any theory of speech audition should take into account the role that such minute differences in amplitude at very close intervals of time play apart and as distinct from changes in pitch.

TABLE —I. *(Amplitude Measurements in Milimeters)*

Unit Number	'O' REGION						'R' REGION							
	'a' peak		'b' peak		'c' peak		'a' peak		\ V peak		' peak		'd' peak	
	K	L	R	L	1 R	L	R	L	I K	L		L	R	L
I	3.5	2.5	2.5	2.5	0.8	2.3	5,.0	4.2	3.6	3.4	2.3	2.3	1.0	2.0
II	3.8	2.8	2.8	2.8	1.4	2.4	5,.5	4.8	3.8	3.4	3.4	2.2	1.0	2 2
III	4.2	3.2	3.5	3.5	2.0	3.0	5..4	4.3	4.0	3.8	2.4	2.2	1.0	2.3
IV	4.5	3.5	3.5	3,3	2.4	2.8	5..5	4.5	3.8	3.5	2.4	2.2	1.0	2.2
Average	4.00'	3.00	3.07	3.02	1.65	2.62	5.35	4.45	3.8	3.52	2..63	2.2	1.0	2.17

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