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A CRITIQUE OF EXPERIMENTAL TECHNIQUES, METHODS AND ANALYSES IN THE STUDY OF STRUCTURE IN SPEECH

BY

C. R. SANKARAN AND LEON HENRI STRONG

POONA

1965

INDIAN INSTITUTE OF
ADVANCED STUDY
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DECCAN COLLEGE

BUILDING CENTENARY AND JUBILEE

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POST GRADUATE AND RESEARCH INSTITUTE

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A CRITIQUE OF EXPERIMENTAL TECHNIQUES, METHODS AND ANALYSES IN THE STUDY OF STRUCTURE IN SPEECH

BY

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and

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Poona

1965

Dedicated

to

Prof. Dr.—Ing. FRITZ WINCKEL
Technische Universität,
Berlin.

FOREWORD

On the 15th of October 1964 the Deccan College celebrates the centenary of its main Building, and curiously enough this period coincides with the Silver Jubilee of the Postgraduate and Research Institute which, as successor to the Deccan College, started functioning from 17th August 1939 when members of the teaching faculty reported on duty. When I suggested to members of our faculty the novel idea that the centenary should be celebrated by the publication of a hundred monographs representing the research carried on under the auspices of the Deccan College in its several departments they readily accepted the suggestion. These contributions are from present and past faculty members and research scholars of the Deccan College, giving a cross-section of the manifold research that it has sponsored during the past twentyfive years. From small beginnings in 1939 the Deccan College has now grown into a well developed and developing Research Institute and become a national centre in so far as Linguistics, Archæology and Ancient Indian History, and Anthropology and Sociology are concerned. Its international status is attested by the location of the Indian Institute of German Studies (jointly sponsored by Deccan College and the Goethe Institute of Munich), the American Institute of Indian Studies and a branch of the Ecole Francaise d'Extreme-Orient in the campus of the Deccan College. The century of monographs not only symbolises the centenary of the original building and the silver jubilee of the Research Institute, but also the new spirit of critical enquiry and the promise of more to come.

7th March 1964. S. M. KATRE.

CONTENTS

The present monograph has a distinct goal. It lays stress on the problem of structure in speech. Towards this goal the various types of techniques, methods and analyses in vogue in the field of phonetics are first studied in the introductory chapter.

The author of the second chapter "The Anatomy of Speech Apparatus" is Professor LEON HENRI STRONG now of the Department of Anatomy and Cardiovascular Research at the Chicago Medical School, and formerly faculty member of University of Michigan Medical School. He was the first to lift anatomy out of general medical anatomy and to specialize it in voice science and biolinguistics. Dr. STRONG has contributed studies on the functions of the larynx and has worked on the finer structures and functions of the tongue — a study of far-reaching importance to prosthetists, linguists and speech therapists[1]. After becoming emeritus professor some years ago, now in his 77th year he is under contract with the U.S. Government in connection with a work in embryonic blood vessel development, as his studies have been in the field of patterns of development of embryonic internal blood-vessels of the central nervous system since his leaving the University of Michigan in 1947. With the handicap of a bad health in his advanced age as he is suffering from lymphocetic leukemia and with his fresh commitment too to the National Institute of Health for a period of two years after 1965, he still hopes to get back to further investigations into the vocal apparatus.

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1 Publisher's note to LEON H. STRONG's foreword in Handbook of Biolinguistics, Part I, Section A, The Structures and Processes of Expression with General Introduction to Biolinguistics by Clarence. L. MEADER and John H. MUYSKENS, published by Herbert C. Weller. Toledo Speech Clinic, Toledo 2, Ohio 1950. p. ix.

I am deeply indebted to him for his generous consent to have his name associated with me as joint-author of this monograph. A free exchange with me of his fruitful ideas in his highly specialized field has led me on to seek the connecting link between his significant investigations into the anatomy of the vocal apparatus and my own investigations into the problem of structure in speech.

His contributions in the second chapter of this monograph will, it is hoped, lead to various interesting suggestions towards establishing such a link. This is all the more so as even his comparatively recent and a very noteworthy contribution on "Muscle Fibers of the Tongue Functional in Consonant Production"[2] has not been paid the attention it so richly deserves, from speech-scientists for the last one decade.

As early as in 1935[3], Professor STRONG had presented an analysis based upon the only earlier histologic study in the literature of the microfibers of the vocalis muscle, namely, that of JACOBSON of St. Petersberg in 1887. Professor STRONG used JACOBSON's framework of fibers on a theoretical basis, in combination with his own physiological gross anatomical study, as he has described it in his very recent letter of April 15, 1965 to me. Professor STRONG's contributions to the theory of Voice Physiology are (1) that in a system in which the vibrating structure is a membrane, whose elastic limit exceeds its ultimate strength, no amount of linear tension would change its pitch. For, pitch change accompanies progressive molecular strain. Since such a strain does not occur in the vocal ligament when stretched, no resulting pitch change occurs, and (2) that the forces operating in pitch change on the vocal ligament were

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[2] *Anatomical Record,* Vol. 126, No. 1, September 1956. pp. 61-79.

[3] LEON H. STRONG, The Mechanism of Laryngeal Pitch. *Anatomical* Record, Vol. 63, No. 1, August, 1935. pp. 13-28.

of micro-order in modulation, and that they act lateral and perpendicular to the axis of the vocal ligament. They would thereby lessen the medial pressure at any point or region so that the air would meet less impedance than elsewhere along the vocal ligament. Thus, it would force a valve through the vocal folds of definite length which would vibrate at a definite number of cycles.

In 1938, Professor STRONG fixed less than 18 hours after death a larynx taken from a throat cut. The sections were cut parallel to the ventricular surface of the vocal ligament. Observations of this new material led Professor STRONG to examine a series of sections cut frontally (at a right angle to the former sections). Thus Professor STRONG had the vocal lip in three dimensions. The upshot was that his original theoretical (1935) schema proved to be more involved than need be to explain the mechanism. In 1940, Professor STRONG again, therefore, presented a paper covering his newer observation at the Meeting of the American Association of Anatomists. This paper was printed as an abstract in the Anatomical Record, Vol. 76, No. 2, pp. 53-54. This abstract is now being published for the first time in our present monograph (in section 8.0) as originally Professor STRONG had written it. We are also publishing in section 9.0 the joint contribution of Professor STRONG and Dr. Ernest M. GOLD[4]. The summation of Professor STRONG's views since 1950 to date should be of interest to phoneticians.

The two photographs (diagrams 1 and 2 in section 6.0 of our present Monograph facing pages 28 and 29 respectively) show us the sections through the larynx.

Professor STRONG's investigations to determine the mechanism of laryngeal pitch led him to depart from the well known

[4] *Anatomical Record*, Vol. 106, No. 2, 1950. p. 86.

theory of pitch production, namely, linear tension which was first held by FERREIN in 1741, later mobified by J. MÜLLER in 1339 and further elaborated by HELMHOLTZ in 1862.

In his earlier studies, Professor STRONG had worked with frontal sections of ordinary cadaver material. JACOBSON's anatomical study of the vocal lip did not show any difference from the interpretation Professor STRONG gave of the material which he had studied. No further studies were in the literature (from the time of JACOBSON's study to the time of Professor STRONG's), which illustrated different relations from those shown by JACOBSON. Indeed most accounts accorded with his conclusions. Professor STRONG had also assumed them well founded. But later, Professor STRONG's studies uncovered evidence which forced him to disavow them. Although Professor STRONG had arrived at the correct theoretical explanation of pitch modulation at that time, he apparently erred (in his own words) in stating the precise manner of its function. He had assumed a more complex set of movements than his later studies disclosed to be warranted.

Subsequently, Professor STRONG was fortunate in getting some freshly preserved human material from a throat-cut case. Transverse sections of this material permitted Professor STRONG to view the microscopi[illegible]as in a third dimension which he had lacked earlier.

The investigation of pitch led Professor STRONG also to consider the physical factor encountered in his anatomical studies. He found that there was almost nothing known about the properties of living membranes as regards their vibration. This led him to make the discovery that fully elastic membranes, like the vocal ligament, do not rise in pitch when under linear tension.

Professor STRONG's observation of the fact that, in straccato singing and in the trill, each half or whole tone is isolated from the tone before and after it, with no glissando, (that is no intermediate frequencies audible) led him to the suggestion of a mechanism for modulation of pitch other than that of lineaı tension. *Linear tension* would furnish intermediate frequencies. The isolation of succeeding pitches indicated a fretting type of function. Professor STRONG had found evidence for this view in the "throat-cut" materials referred to above. This material may be considered as close to living membrane as it is possible to prepare. From section 6.2 upto section 7.4 in this Monograph, we present what Professor STRONG calls as his "1955 Summary".

The third chapter presented here is a revised form of my paper "The Determination of the ultimate 'Unit' of Speech" which was communicated by Professor Dr. Ing FRITZ WINCKEL (Technische Universität, Berlin) to *Phonetica.*

The first introductory chapter points out that acoustico-articulatory 'events' are really only 'instant-entities', and that each acoustico-articulatory 'event' in the last analysis constitutes a type of regularity which, in a deeper sense of the term, is *ultimate* and *non-causal.* The second chapter points out that LINEAR TENSION would furnish intermediate frequencies and that the isolation of succeeding pitches indicates a fretting type of function.

The third chapter indicates an experimental approach towards the more direct determination of the ultimate 'Unit' of speech — the alpha-phonoid. This is in addition to the two already existing suggestions towards the indirect determination of the ultimate 'Unit' of speech. It is contended that significant experimental investigations within the frame of reference of Neurophysiology would offer evidence for the acceptance of the alpha-phonoid as a physical entity.

Though not in itself a piece of experimental investigation, the chapter clearly points out the present concepts in Neurophysics so that newer techniques could be evolved within the perspectives opened by our own Theoretical Studies relating to Structure in Speech and Structure in Perception. It is suggested that the determination of the ultimate 'Unit' of speech, through what is at present a purely theoretical or rather thought-experiment, would give a *physical significance* to the mathematical concept of the continuum due to *Veronese*.

Finally, three lines of newer neurophysiological investigations and a few experiments are referred to in conclusion, demonstrating thereby the unified allegory of several disciplines.

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25th September 1965.

Acknowledgement

I have first to name in gratitude Dr. S. M. KATRE, my esteemed colleague for twenty-six years as well as Director and Honorary Professor of Indo-European Linguistics of the Deccan College Postgraduate and Research Institute, for his numerous acts of kindness during all my investigations and for his generous undertaking to publish this work as one of the Building Centenary Monographs of the Deccan College Postgraduate and Research Institute.

I am also deeply indebted to the able printers and proof-readers as well as the block-makers.

I am most obliged to the Editors of the *Anatomical Record,* The Wistar Institute Press, Philadelphia, Pa, U.S.A. for their generous permission to reproduce here Professor LEON H. STRONG's original abstract published in the *Anatomical Record* Vol. 76, No. 2, pp. 53-54 and the joint-contribution of Professor LEON H. STRONG and Dr. ERNEST M. GOLD in the *Anatomical Record* Vol, 106, No. 2, 1950, p. 86 as well as to refer to Professor STRONG's papers "The Mechanism of Laryngeal Pitch" (*The Anatomical Record* Vol. 63 No. 1 August 1935, pp. 13-28) and "Muscle Fibers of the Tongue Functional in Consonant Production" (*The Anatimical Record* Vol. 126, No. 1, September 1956, pp. 61-79).

To Professor STRONG and to his former student the late Professor Martin F. PALMER of the Institute of Logopedics, Wichita University, I owe indeed a deep debt of gratitude for the most sympathetic encouragement they have been showing me in my work. Above all, I am highly obliged to Prof. Dr. Ing. FRITZ WINCKEL, Technische Universität, Berlin for the timely help he has rendered to me.

I wish to record too my indebtedness to the Librarian and the other staff of the Library of the Deccan College Research Institute for the enjoyment of many special library facilities such as the Inter-library loan, given to me ungrudgingly. I am thankful to Dr. M. M. PATKAR of the Dictionary Department, Deccan College, and Lecturer in Anthropological Linguistics, Poona University for his most valuable help to me in the matter of micro-filming the diagrams.

Finally, I thank also Mr. K. S. Sampat, the Scientific Assistant of the Phonetics Laboratory, Mr. Shripat Maruti Sawale, the attender of the Phonetics Laboratory, all my past and present students and last but not least the typist who has prepared the MSS. for the press.

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25th September 1965.

Chapter I

EXPERIMENTAL TECHNIQUES, METHODS & ANALYSES IN PHONETICS

1.0 There is a hierarchy in the science of Phonetics. We have envisaged a level at which Phonetics and Phonemics are not viewed in isolation, but form together a unified discipline comprehended by a single abstract geometrical physical theory[1]. Within the framework of such a theory, the usual classifications of Speech Vibrations into the acoustical, neurophysiological and psychological events, not to speak of our familiar notion concerning speech sounds, which leads in its turn, to divide them into neatly fitted categories of consonants and vowels, breaks down.

However, the science of Phonetics, as it is generally known and studied, is quite often at the empirical level where it is usually classified into the linguistic or descriptive Phonetics and experimental Phonetics. It is again conveniently divided into acoustical, articulatory and auditory Phonetics. In this context, mention must be made of the very recent contribution of Professor H. Mol in the direction of auditory Phonetics, as it is most stimulating and thought-provoking in that it challenges the time honoured conception of Fourier Analysis of Speech-sounds by the ear[2].

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[1] C. R. Sankaran, *Phonemics of Old Tamil*. Deccan College Monograph Series 7, 1951, pp. 28-31.

[2] H. Mol, *Fundamentals of Phonetics*.

1: The Organ of Hearing. Janua Linguarum Studia Memoriae Nicolai Van WIJK dedicata edenda curat cornelis H. Van Schooneveld Stanford University Series Minor NR. XXVI, 1963. Mouton and Co, The Hague, Cf. also C. R. Sankaran, Process of Speech, Deccan College Monograph Series 27, 1963, pp. 69-70.

Both articultory and acoustic Phonetics had been known to Pāṇnini, the greatest of the descriptivists India had produced in far ancient times[3]. Even information-theorists, while operating with phonetic elements, follow closely the linguisticians, so far as the description of speech sounds are concerned, although they pay very great attention to the acoustic composition of the sounds.

1.1 The position of the lips and the tongue and the state of the vocal cords form mainly the articulatory aspects of Phonetics and these give fairly reliable description of the mode and place of production of speech-sounds.

But it is almost impossible to restrict to a purely articulatory description of speech sounds without the allied study of the acoustical phenomena as well, as for instance, when we attempt at a description of aspiration in purely atriculatory terms. In general any vowel with a stress-accent (i.e., higher intensity) is accompanied by 'aspiration'. 'Aspiration' here signifies the physical process of high velocity air flow through any cross-sectional opening. Thus the 'articulation place' for 'aspiration' is not necessarily the glottis. A greater velocity of air across any cross-sectional opening is equivalent to a smaller velocity of air across a smaller cross-sectional opening, so far as 'aspiration' (intensity) is concerned. In many Indo-European and perhaps Dravidian Languages too, this aspiration is associated with one particular 'place of articulation'. But the syllabic series *ha*, *hi*, *fu*, *he* and *ho* in Japanese clearly points out that the 'place of articulation' for 'aspiration' may be near about the region of the lips and teeth, under which conditions the combination of *h* with the vowel *u*, necessarily gives *fu* instead of *hu*. Further, there is frequent alteration between *ha* and *wa*, and *he*

[3] C. R. Sankaran and P. C. Ganeshsundaram, A Critique of Experimental Methods in Phonetics. *Indian Linguistics*, 17, 1957, p. 70.

and *ye*. All these suggest that the 'place of articulation' for the Japanese *h* is nearer the lip-teeth region than near the glottis. In general, therefore, for the production of 'aspiration' the only criteria necessary seem to be the velocity of air flow and the cross-sectional area of the opening at the place of articulation wherever it be. Under these conditions the aspirate could be 'voiced' or 'voiceless'[4].

1.2 An interesting simple experiment shows clearly the relationship between the fricative *s* and the non-glottal aspirate ***h***, when we set up the tongue-position for *s* and withdraw the tongue very minutely and without jerkiness. We eventually arrive at *h*. Thus, the cross-sectional opening for *s* is much smaller than that for *h*, the 'place of articulation' being the same.[5]

Earlier, from our detailed analysis of the duration and pitch of *ahā* under two emotional conditions, viz., plain utterance and utterance in anger, we deduced:—

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[4] Branco Van DANTZIG, Voiced or Voiceless?
Archives Néerlandaises de Phonétique Expérimentale 5, 1930, pp. 77-88.

Cf. too "The 'place of articulation' remaining the 'same', if the cross-sectional opening varied, different sounds are produced, such as *s*, ***h***, etc, thereby demonstrating the invalidity of the articulatory (i.e., the 'place of articulation') criterion".

C. R. SANKARAN, Study of the Problem of the Ancient and Modern Structure in Speech. *Indian Linguistics,* 25, 1964, p. 40.

[5] P. C. GANESHSUNDARAM has shown "that not only the 'articulation place' but also the 'dimensions of the cavities' are, in addition to being *sufficient* for the production of speech-sounds, also *necessary* to allow for the variation of pitch and intensity that take place during the speech process without affecting the 'individual character' of speech sounds".

P. C. GANESHSUNDARAM, The Structure of Speech-sounds *Bulletin of the Deccan College Research Institute* 17, 1955-56, pp. 118-121.

1. The pitch and the duration of the initial vowel are less than those of the final vowel irrespective of the emotion.

2. The medial aspirate is increased both in pitch and duration; it is voiced in both cases but more so in emotions.

3. The duration of the initial vowel, however, is shorter in emotion than in neutral utterance. (This may be a compensation for the increase in the energy of the final vowel.)

4. The total duration of the whole utterance, however, is greater in anger than in neutral utterance.

5. The pitch is raised for the whole utterance for anger; the rise is prominent for the final vowel. This means an accentuation of the terminal syllable in emotion[6].

2.0 We are also forced to realise that the fact that the 'same' vowel may be produced by different articulatory positions is sufficient indication that articulatory criteria, in the very nature of things, cannot furnish a description of speech to the greatest degree of precision[7].

l̤ appears also to give rise to various difficulties. This speech-sound

2.1 The question of the articulatory description of the Tamil can be produced within a whole range of tongue positions. In terms of articulatory description, therefore, it can only be said that the Tamil l̤ is a post-alveolar or retoflexed (voiced or voiceless)

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[6] C. R. SANKARAN, P. C. GANESHSUNDARAM, B. C. DEVA and A. D. TASKAR, A Study of Accent in Relation to the Alpha-Phonoid Theory. *Indian Linguistics,* 16. 1956, pp. 200-203.

[7] G. Oscar RUSSELL, Synchronised X-ray, oscillograph, sound and movie experiments, showing the fallacy of vowel triangle and open-closed theories.

Proceedings of the Second International Congress of Phonetic Sciences, London, 1935, pp. 198 ff.

See also C. R. SANKARAN, *Phonemics of Old Tamil.* Deccan College Monograph Series 7, 1951, pp. 12-13.

C. R. SANKARAN, *Process of Speech,* Deccan College Monograph Series 27, 1963, p. 45.

speech-sound is uttered in a meaningful chain with other sounds, or (3) both[9].

2.3 We, therefore, deduce that articulatory and even acoustical criteria alone, at the purely empirical levels, cannot furnish precise description of speech-sounds. It is in fact the 'Phonetic' context characterised by the psychological and neuro-physiological background acquired during the process of speech-learning, that holds the key to our perception of speech-sounds.[10] As different dynamic articulatory movements[11], however, may yield the same acoustic resultants, we have to consider a description in terms of only dynamic acoustical quantities[12]. That is, on the consideration that all human speech-sounds could be classified to belong to either the vowel or the consonant category, we can easily say that if any vowel is considered as a vector, any consonant will just be transitions from one value to another.[13]

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[9] C. R. SANKARAN, *Process of Speech,* p. 46.

[10] C. R. SANKARAN and P. C. GANESHSUNDARAM, Structure in Speech - The Physical Reality of the Phoneme (with an addendum on the very nature of structure and the problem of existence by B. C. DEVA).

Nachrichtentechnische Fachberichte Band 3, Information Theory, 1956, pp. 63-71.

[11] G. Oscar RUSSELL, The Mechanism of Speech.

The Journal of the Acoustical Society of America, 1, 1930, pp. 83 ff.

Cf. also P. C. GANESHSUNDARAM, The Vowel-triangle and the formant structure. *Indian Linguistics Bagchi Memorial* Volume, 1957. pp. 35-45.

[12] C. R. SANKARAN, *Process of Speech,* p. 47.

[13] P. C. GANESHSUNDARAM, A Cascade Modulation Theory of Speech formants, *Zeitschrifts für Phonetik und Allgemeine sprachwissenschaft* 10, 1957, pp. 1-7.

3.0 In purely empirical investigations, the articulatory movements or positions are studied in different ways. Cinematography is pressed into service for studying the movements of lip and tongue[14]. Palatography forms the most important part of articulatory phonetics. This provides a fairly good estimate of the spread of the tongue at the points of contact with the roof of the mouth. When photographed, it gives the projection of the area of contact in the horizontal plane.[15] Almost all the references we have at our disposal for palatography suggest the use of either hard rubber or metal for the material used in preparing the artificial palate.[16] Plastic palates can also be prepared. The type of pigment to be used is given variously by different authors[17]. A detailed instruction for preparing an artificial

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[14] PANCONCELLI-CALZIA, Die Experimentelle Phonetik in ihrer Anwendung auf die Sprachwissenschaft. ("Strobo-stereo Photographien" facing page 32). Berlin 1924, Verlag von Walter De Gruyter and Co.

[15] L. KAISER, The shape of the Palate and its effect on speech-sounds. *Proceedings of Second International Congress of Phonetic Sciences.* pp. 22 ff.

Carlo TAGLIAVINI, *Introduzione alla Glottologia*, Bologna, 1950.

Eugen DIETH, *Vademakum der Phonetik,* Francke Verlag, Bern, 1950.

F. WETHLO, Experimentelle lautforschung im Gelande. *Zeitschrift für Phonetik* 1, 1947, p. 24 ff.

PANCONCELLI-CALZIA, Die Experimentelle Phonetik. Berlin, 1924. pp. 69-89.

[16] POIROT, *Handbuch der Physiologischen Methodik* 3, Band 6, Abteilung, Die Phonetik, Leipzig, 1911. pp. 45-48. for metal or hard rubber palate covered with "Ouramine".

[17] As for example, 'mit Brei aus Mehl und Gummi arabicum bestrich', 'Grutzner bestreicht die getrocknete Zunge mit einer Aquarellfarbe (carmin, chinezische Tusche, Ultramariablau O. dgl)', 'Gutzmann bestreicht umgekehrt den Gaumen mit farbe', (POIROT, ibid, pp. 45-48), 'magnesia'

(PANCONCELLI-CALZIA, *op. cit.* p. 69). white powder of 'Mehl, Magnesium, usw', (E. DIETH, *op. cit.* p. 26).

palate is given by F. WETHLO[18]. GRÜTZNER[19] had, as early as in 1879, suggested a modification for palatographic work by painting tongue instead of the palate. FIRTH and ADAM[20] have also described a palatogram projector.

3.1 But less than a decade ago, a newer method known as the "Direct Palatography" has been brought into vogue. Peter LADEFOGED[21] has also made a comparative study of the palatograms taken by "Direct Palatography" method with the corresponding X-ray diagrams. It is necessary to point out the following pregnant observation of LADEFOGED[22]; — "only occasionally do X-rays reveal major differences between the positions of the centre and sides of the tongue. These differences are of greatest importance in the study of fricatives. Thus, the articulation of [*S*] as in *Saw* in the author's speech is as shown in Figure 5. The continuous line indicates the position of the sides of the tongue as shown by the limits of the contact areas in the palatogram (which are unlikely to be due to the vowel in this word) and the dotted line represents the data obtained from an X-ray photograph showing the position of the centre of the tongue during the fricative. . . . This diagram is a good illustration of the way in which palatographic and X-ray evidence supplement one another. In the examination of many sounds, the two techniques are not mutually substitutable but are complementary, each providing data which are

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18 F. WETHLO, *Zeitschrift für Phonetik. op. cit.* p. 26.

19 GRÜTZNER, Physiologie der Stimme und Sprache. Hermann's Handbuch der physiology I, Leipzig, 1879. p. 204.

20 FIRTH, J. R, and ADAM, H. J. F., Improved Techniques in Palatography and Kymography. *Bulletin of School of Oriental and African Studies* 13, 1950. pp. 771-774.

21 PETER LADEFOGED, Use of Palatography. *Journal of Speech and Hearing Disorders* 22, 1957, pp. 764-774.

22 PETER LADEFOGED, *ibid*, pp. 769-773.

not revealed by the other. . . . Palatography remains one of the most useful methods of obtaining information about articulatory positions, particularly in investigations involving the detailed study of the pronunciation of a single speaker. In addition, the articulations of different speakers may be investigated by comparing the relations between the articulations which occur during the pronunciation of a series of words by one speaker with the relations between the articulation which occur when the same set of words is pronounced by other speakers. Thus, a study of the pronunciation of the words *tay, tray* and *jay* by 32 students at Edinburgh University showed that 21% made the plosive in *tray* further forward than that in *tay,* and 18% made it more retracted; and only 6% made the contact for the plosive in *jay* appreciably further back than that in *Tay*. In another investigation a comparison of the pronunciation of the minimal pair *sip, ship* by 164 speakers has shown that for every speaker the articulation of the voiceless fricative in *sip* involves the formation of a narrower channel (which is usually also further forward) than that in *ship*. These studies of the relations between articulations are at the moment the most profitable way of comparing the articulations of similar sounds spoken by a number of people."

3.2 X-ray photography is pressed in service to find out in a vertical plane how the tongue carries itself in the sagittal section, with respect to the other parts of the mouth and its cavity[23].

It may be noted here that the vowel sounds produced by the voice are due to the vibrations of two cartilaginous plates, the 'vocal chords' placed at the top of the windpipe, edge to edge, a narrow slit between them; air blown through this slit from the lungs keeps the plates vibrating. The apparatus is really a

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[23] G. Oscar RUSSELL, *op. cit.,*

free reed[24]. For the same modification in the vocal tract two different vowels are produced.

3.3 The vowel formant production has been considered as an eigen-value problem by W. MEYER-EPPLER and G. UNGEHEUER[25]. They start with WEBSTER's horn-equation:

$$\frac{\partial^2 y}{\partial x^2} + \frac{d}{dt}\left\{\log \sigma(x)\right\} \cdot \frac{\partial y}{\partial x} - \frac{1}{v^2} \cdot \frac{\partial^2 y}{\partial t^2} = g(x, t)$$

[24] C. R. SANKARAN, *Phonemics of Old Tamil.*
See Plate I X-ray diagram fig. 12. showing different modification of the vocal tract besides the normal state of the vocal tract. figures 11 and 13 show that for different modification or different size- cavities in the vocal tract the same vowel is produced. (p. 12).

Cf. also MEYER-EPPLER and G. UNGEHEUER, Die Vokal-articulation als Eigenwert problem. *Zeit. für Phonetik*, 10, 1957, p. 24.

[25] *ibid.*
Here it may be noted that valuable data in support of "the suggestion that vocal fold thickness constitutes an important determinant of fundamental frequency of phonation" are now illustrated by Harry HOLLIEN in his paper "vocal fold thickness and fundamental frequency of phonation" in the *Journal of Speech and Hearing Research* 5, 1962, pp. 237-243. Much important and significant work is done by Harry HOLLIEN and others in this direction. The following papers deserve special mention:

[1] Harry HOLLIEN, Vocal Pitch Variation Related to changes in Vocal fold Length. *Journal of Speech and Hearing Research* 3, 1960. pp. 150-156.

[2] Harry HOLLIEN, Some laryngeal correlates of vocal Pitch. *Journal of Speech and Hearing Research* 3, 1960, pp. 52-58.

[3] Harry HOLLIEN *et al*, Elevation and Tilting of vocal folds as a function of vocal pitch. *Folia Phoniatrica* 14, 1962, pp. 23-36.

[4] Harry HOLLIEN, Measurements of the vocal folds during changes in pitch. *Journal of Speech and Hearing Research* 3, 1960, pp. 157-165.

[5] Harry HOLLIEN and James F. CURTIS, A Laminagraphic study of vocal pitch, *Journal of Speech and Hearing Research* 3, 1960, pp. 361-371.

[6] R. W. WENDAHL, G. P. MOORE and H. HOLLIEN. *Comments on Vocal Fry. Folia Phoniatrica* 15, 1963, pp, 251-255.

[7] Harry HOLLIEN, Laryngeal Research by Means of Laminagraphy. *Archives of Otolaryngology* 80, 1964, pp. 303-308.

where y is the velocity potential of the wave propagation in the vocal tract, v the velocity of sound in the air inside the vocal tract, $\sigma(x)$ is the function denoting the variation of the cross section of the vocal-tract with distance along the length of the tract and $g(x, t)$ is the vocal cord tone.

According to W. MEYER-EPPLER and G. UNGEHEUER, the eigen values corresponding to this equation represent the formant frequencies. This approach has the very important advantage of describing the entire speech-production unifying articulatory and acoustical processes, unlike the parallel cascade modulation process which is only a 'terminal analog' corresponding to the end-product of speech-production.

However, in the present form of the treatment of this equation by W. MEYER-EPPLER and G. UNGEHEUER, the inner-structure within each formant has not been accounted for. Instead, only the formant positions are indicated. But, unlike the parallel cascade modulation theory which accounts only for three formants, their treatment accounts for all the possible formants.

It is suggested here that the factor responsible for the inner-structures within the formants is the yielding character of the soft walls of the vocal tract, which factor is taken (at least partially) to be the origin of the vibrato in the present modified version of the cascade modulation theory. This factor of the yielding soft walls makes the cross-section function $\sigma(x)$ not a function of distance along the vocal tract alone but it is also a function of time and has to be denoted as $S(x, t)$ in the modified horn-equation.

Since the vibrato is a periodic variation, we may represent the cross-section function as:

$S(x,t) = \sigma(x) \sin 2\pi ct$ or in general as:

$S(x,t) = \sigma(x).R(t)$, where c is the frequency of the vibrato. We believe that the horn-equation, with this modification, will give the needed solution representing not only the formant positions but also their inner structures[26].

While the treatment of the formants by W. MEYER-EPPLER and G. UNGEHEUER as the eigen values corresponding to the wave-propagation taking place in the vocal tract is capable of explaining all the formants with respect to their relative position, though not (in the present formulation of this theory) with respect to the inner-structure of the individual formants, P. C. GANESHSUNDARAM's cascade-modulation Theory of Speech-formants[27], on the other hand, is capable of differentiating between the voice and the vowel characteristics based on the inner structure and the first three formants, although it cannot account, in its present formulation, for higher formants nor for the relatively decreasing amplitudes as we go from the lowest to the successive higher formants[28].

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[26] C. R. SANKARAN and P. C. GANESHSUNDARAM, A Note on the Fine Structure composition of vowel-spectrum. *Zeitschrift für Phonetik und Allgemeine Sprachwissenschaft* 11, 1958, pp. 320-322.

C. R. SANKARAN, Study of the Problems of Ancient and Modern Structure in Speech. *Indian Linguistics,* 25, 1964. pp. 35-36.

[27] P. G. GANESHSUNDARAM, *Zeit. für Phonetik,* 10. pp. 1-7. See also C. R. SANKARAN, *Process of Speech,* p. 50 and footnote 129.

[28] J. L. FLANAGAN, Note on the Design of 'Terminal Analog' Speech Synthesizer *JASA* 29, 1957, pp. 306-310. The synthesis of vowel sounds by lumped - constant electrical networks having transfer functions similar to the transmission properties of the vocal tract is considered by FLANAGAN. A comparison is made between cascade and parallel connection of simple electrical resonators for producing vowel sounds. The cascade arrangement of resonators is shown to yield vowel sounds having formants of proper amplitude when information specifying the formant frequencies is only known. The function relating U_1 volume velocity of the glottis and U_2 the volume velocity of the lip is represented in LAplace transform equation ar rational function.

Perhaps the best solution, capable of providing a nearly complete picture of the formant-spectrum of vowel sounds, lies in a suitable combination of the eigenwert problem (which is capable of giving the positions of *all* the formants) and the cascade modulation theory (which can account for the *inner structure* of the formants)[29].

An effective way of studying the vibrations of the vocal cords is through what is known as Laryngoscopy[30].

4.0 In order to estimate at what frequency the vocal cords are vibrating, we have to turn to acoustic measurements. These acoustic measurements can be made with many different types of instruments. We have already indicated the recent developments in this direction. These are the cathode-ray oscilloscopes and the sound spectrograph[31].

4.1 One of the most frequently used acoustic-phonetic instruments of the classical type is the kymograph. It is used for studying:

1. The vibrations of the mouth cavity.
2. The vibrations of the nasal cavity.
3. The vibrations of the Larynx.
4. The vibrations of the chest (breathing movements), etc

Cf. also Gunnar FANT, Acoustic Theory of Speech-Production with calculations based on X-ray studies of Russian articulation. Description and Analysis of contemporary Russian. Mouton and Co. 'S-Gravenhage, 1960. pp. 113-114. fn. 3.

[29] C. R. SANKARAN, Study of the Problem of Ancient and Modern Structure in Speech, *Indian Linguistics* 25, 1964, p. 37.

C. R. SANKARAN, *Process of Speech,* p. 50.

[30] G. E PETERSON, Laryngeal Vibrations. *Manual of Phonetics. ed.* by L. Kaiser 1957. North - Holland Publishing Company. Amsterdam. p. 153. TSUTOMU CHIBA and MASATO KAJIYAMA. The Vowel, Its Nature and Structure. Phonetic Society of Japan. 652, Daita- ITCHOME, SETAGAYA, Tokyo, 1958, p. 11.

[31] C. R. SANKARAN, *Process of Speech.* Deccan College, Monograph Series 27, 1963.

The kymograph responds through the membranes of the attached tambours only to the change in air pressure; it does not respond to the vibrations of microphonic speech. The whole apparatus thus registers only the mass movements of the air from the mouth, nose etc.[32]

4.2 In all kymographic work the maximum accuracy that can be normally obtained is only about 50%. For, many errors are introduced into the system by several factors, such as, for example, the yielding of the walls of the rubber tubing, the multiple reflections along the tube and at the two extremities, etc., further the incrita of the rubber or mica diaphragm and that of the stylus as well as the friction of the point of the stylus at the surface of contact on the drum are all contributory to the distortion of the original sound-waves. For any high presision recording, therefore, the kymograph is highly unsatisfactory. It is unsatisfactory also particularly because there are no known means (and it is dffiicult to find any new means) of estimating the error involved due to various factors, thereby leaving the door closed for any correction[33]. The so called quantitatice measurements made on the kymograph, therefore, are at best *qualitative indications* showing in a rough way what apparently seems to take place in the mouth cavity, nasal cavity, larynx, lungs, etc.

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[32] E. W. SCRIPTURE, *Proc. II, International Congress of Phonetic Sciences,* London, 1935, p, 209 ff.

C. R. SANKARAN, and P. C. GANESHSUNDARAM, A Critique of Experimental Methods in Phonetics. *Indian Linguistics,* 17, 1957. p. 75.

[33] See for a thorough treatment of the sources of error in different types of experimental phonetic investigations. Professor Med. H. LOEBELL and F. WETHLO, *Fehlerquellen Bei Experimentell-Phonetischen Untersuchungen,* Leipzig, 1931. Also, for a thorough treatment of the technical improvement of the kymographic method, See VINCENZO COCCO, *Sul Comporta Mento Delle Membrane Nella Registrazione Dei Suoni Della Voce, Contributi Del Laboratorio Di Psicologia, Serie Ottava,* MILANO, 1940 pp. 511 ff.

5.0 The Fourier Analysis is an important mathematical analysis employed to account for the harmonics of the voice-frequency that is taken as the fundamental[34]. Practical Fourier analysis[35] is a tool for the calculation of the gross concentration of energy in particular frequency regions viz., the formants[36].

The vercelli analysis is only a refinement of the Fourier method[37]. But it reveals important inharmonic components in addition to the harmonics of the voice-frequency. It has the same limitations as the Fourier analysis.

5.1 As we have pointed out earlier[38], A. MAACK[39] has shown that "with vowels and diphtongs ascending melody curves tend towards convex shapes, with consonants towards concave forms without regard to neighbouring sounds. Descending melody curves show a tendency towards convex shapes at the beginning and end of words in all sound groups. Within words the curves are strongly deflected by the surrounding sounds which make for an equal frequency of both types. In the case of vowels and

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[34] A. G. WORTHING and J. GEFFNER, Treatment of Experimental Data. New York, John Wiley and Sons, Inc., London: Chapman and Hall, Ltd., Fourth Printing, 1947, pp. 108 ff.

C. R. SANKARAN, *Process of Speech.* p. 47.

[35] Edmund WHITTAKER and G. ROBINSON. *The Calculus of observations, A Treatise on numerical methods.* Blackie and Son Ltd., London and Glasgow, 4th Edition. 1946. pp. 260-284.

[36] C. R. SANKARAN, *Process of Speech,* p. 49.

[37] A. GEMELLI and G. PASTORI, Analyse Electrique Du Language. *Archives Néerlandaises De Phonétique Expérimentale* 10, 1934, pp. 1-29.

[38] C. R. SANKARAN, *Phonemics of Old Tamil.* Deccan College Monograph Series 7, 1951, p. 26.

[39] A. MAACK, Formen des Melodieverlauts neuhochdeutscher *Laute. Archiv für Vergleichende Phonetik* 3, 1939, pp. 27-37.

Professor F. WINCKEL (*Technische Universität Berlin*) *writes to me* in a personal communication dated 7th September 1965 :— "It is without doubt that consonants don't produce melody curves because they have noise character. This is the experience with the Vocoder and I realize it daily with my melody recorder of my own construction."

diphthongs doubly bent melody curves have their concave portion at the beginning, and their convex portion at the end of the sound during ascent as well as during descent. Consonants behave in the opposite way."

5.2 We give here below what P.C. GANESHSUNDARAM has so ably said on "the nonlinear oscillations of the tambura and the possible extension of the methods to the solution of speech-sounds" towards the conclusion of his paper "Some Mathematical Approaches to the Electro-Acoustical Analysis of Speech-sounds"[40]: – "The tambura is a simple stringed instrument with the only complication of having a peculiar type of bridge on one end. The bridge has a slight depression in which is inserted a thread. Beyond this depression there is a slight hump. When the string begins to vibrate it makes an intermittent contact with the hump once in each period of the fundamental. Thus the bridge reacts with the string, giving intermittent impulses to the vibrating string. C. V. RAMAN's observations[41] of the above phenomenon were summed up in a mathematical equation by K. C. KAR[42] in the wake of the theoretical analysis of impulses by E. BUDDE[43].

"KAR assumed that the impulses occur twice during each complete period of the fundamental, which is of course not the case in the tambura. The impulses occur in the tambura only

[40] *Bulletin of the Deccan College Research Institute*, 17, 1955, pp. 38-41.

[41] C. V. RAMAN, On Some Indian Stringed Instruments. *Proc. Ind. Association for Cult. of Science* 7, 1921-22, p. 29 ff.

[42] K. C. KAR, The Dynamical Theory of the Bridge of a certain class of stringed Instruments. *Phys. Rev.* 21 (2)), 1923, pp. 695-698; also *Phys. ZS*, 24, 1923, p. 63.

[43] E. BUDDE, Resonanzerregung durch periodisch Wiederholte Impulse. *Phys. Zeits.* 18, 1917. pp. 69-73.

once in each period of the fundamental. GUNNAIYA and SUBRAHMANIAM[44], taking KAR's equation obtained an expression by assuming that there is only one impulse during each period of the fundamental so that while KAR's equation accounted for the intensification of all the odd harmonics with a corresponding diminution of all the even harmonics, the expression derived by GUNNAIYA and SUBRAHMANIAM showed that not only the odd but also the even harmonics were intensified. We actually find in the tambura that all the harmonics are intensified. It is, however, found that there are not only odd and even harmonics but also odd and even half-multiples of the fundamental. Even the physical presence of a sub-harmonic of order 2 was found by the familiar rider test. The sub-harmonic may either be due to the intermittent reaction of the bridge or to the resonating box or to both. It is quite evident, however, that the action of the bridge is more responsible for the production of all these inharmonic components, since, it is found that, when the thread is removed, most of these inharmonics almost completely disappear.

"Our observations on the vibrating string show that the string is in contact with the bridge at the intermittent point of contact for nearly half the period of the fundamental so that, in comparison with the period of the fundamental, the reaction of the bridge is not instantaneous but it extends over a considerable duration. Thus the reaction can not be treated as an impulse in the strictest sense, as is required in BUDDE's derivation. However, as a first approximation the impulse is assumed to extend over half the period of the fundamental in deriving an expression in the wake of BUDDE, KAR, GUNNAIYA and SUBRAHMANIAM, as it is found fairly to account for the presence of all the inharmonics we have observed.

[44] D. GUNNAIYA and G. SUBRAHMANIAM, *Phys. Rev.* (2) Vol. 25, 1925, pp. 99 ff.

"Further, when the duration of the impulse tends to zero in this expression, the expressions due to KAR and GUNNAIYA and SUBRAHMANIAM are obtained as limiting cases. But it must be admitted that this method of derivation is not quite accurate for a non-linear phenomenon of the type met with in the vibration of the tambura string. Such a non-linear vibration does not lend itself to Fourier Analysis except with great difficulty in determining the fundamental period (which, as we discovered in the preliminary oscillograms we have taken, is not constant). It is also obvious, even to the naked ear, that no frequency generated by the tambura has a steady intensity. The intensity is waxing and waning at a few cycles per second, with different periodicities for different frequencies. It is believed that the methods of operational calculus alone will prove suitable solutions for this non-linear vibration. MATHIEU functions have been used to the analytical description of the non-linear vibrations of strings subjected to continuous periodic variations of tension, etc., giving rise to a sub-harmonic frequency of order 2 or 3. In tambura we have to deal with intermittent impulses rather than with continuous periodic variations.

"Another interesting observation we have made on the vibrating string of the tambura (and, which in spite of several attempts, we have been able to photograph only with moderate success), is that the string does not vibrate in a single plane, but has components in perpendicular planes and these are fluctuating in their amplitudes, now greater in one plane, now greater in the perpendicular plane, and so on.[a44] The non-linear

[a44] Professor F. WINCKEL in his personal communication to me (referred to above in footnote 39) writes :—"The vibration of strings in perpendicular planes is a general characteristic and is treated for the piano by Oskar Vierling, Dissertation "Das elektroakustische Klavier" Berlin Technische Hoshschule 1936. I am very doubtful in the analogy of the function of the vocal ligament". I may say here that Professor F.

vibration of the string in two perpendicular planes naturally suggests an extension to three mutually perpendicular planes in the case of speech-sounds. Any particle on the string has only two degrees of freedom, whereas any particle of air has at least three degrees of freedom. The mathematical expression that fully describes the non-linear oscillations of the tambura, specifying all the frequencies generated, harmonic and inharmonic alike, can, by a further generalization be extended to speech-sounds, thereby accounting for the innumerable inharmonics in vowel-sounds."

P. C. GANESHSUNDARAM had observed too still earlier [45]:– "J. R. Tolmie, in his paper on the vibrato, has indirectly paved the way for a possible explanation of the vowel sounds in the wake of which we may consider the voice frequency and the 'Essner formants' (i.e., the static formants) as being modulated in frequency and amplitude simultaneously by a series of simple tones of different frequencies and different phase differences, yielding Bessel coefficients which are themselves functions of these frequencies, thus suggesting that any speech-sound is, instant to instant, a different one, the spectral distributions at any instant being different from that at any other. The implications on this statement are far-reaching and they could be tackled only at the philosphical level." This is the *raison d'être* of our declartion even recently towards the end of our monograph 'Process of Speech' that "it is needless once again to emphasise here in

Winckel is mistaken in thinking that in the case of TAMBURA, the chord is fixed over the bridge in such a way that it oscillates with ½ λ instead of λ. If that were so, there would be no real subharmonics, as Professor Winckel observes.

[45] P. C. GANESHSUNDARAM, The Structure of Speech Sounds, *Bulletin of the Deccan College Research Institute* 17, 1955-56, pp. 116-121; see especially p. 120

conclusion that our acoustico-articulatory 'events' are really onl 'instant-entities' and that each acoustico- articulatory 'even in the last analysis constitutes a type of regularity which, in deeper sense of the term, is *ultimate* and *non-causal*"[46].

[46] C. R. Sankaran, *Process of Speech*. 1963, p. 70

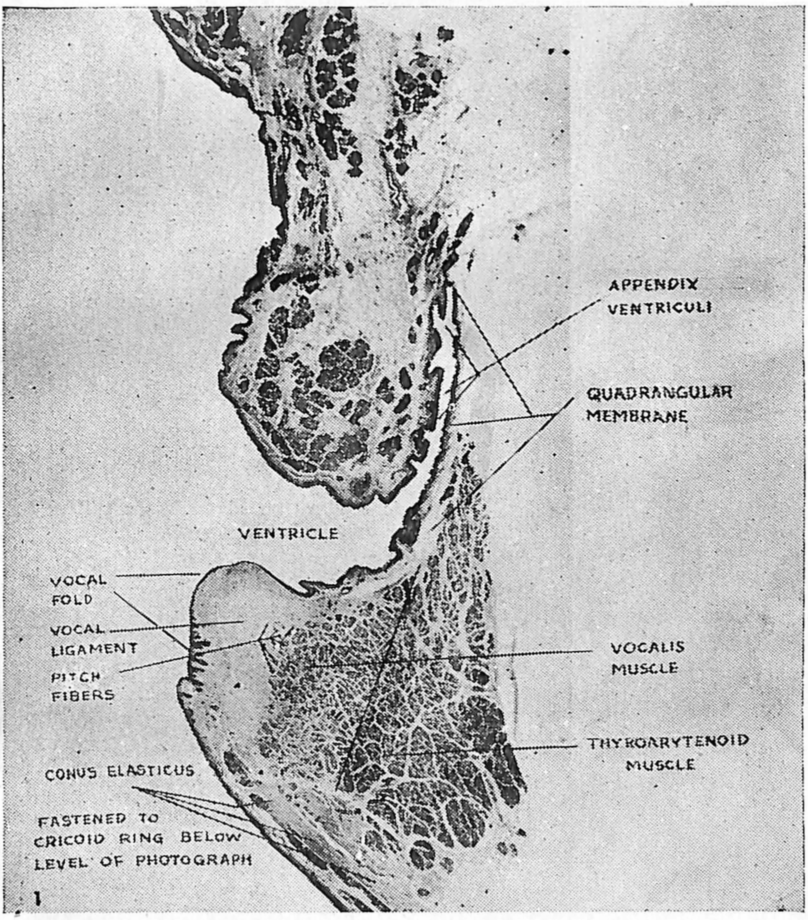
APPENDIX VENTRICULI
QUADRANGULAR MEMBRANE
VENTRICLE
VOCAL FOLD
VOCAL LIGAMENT
PITCH FIBERS
VOCALIS MUSCLE
THYROARYTENOID MUSCLE
CONUS ELASTICUS
FASTENED TO CRICOID RING BELOW LEVEL OF PHOTOGRAPH
1

DIAGRAM 1

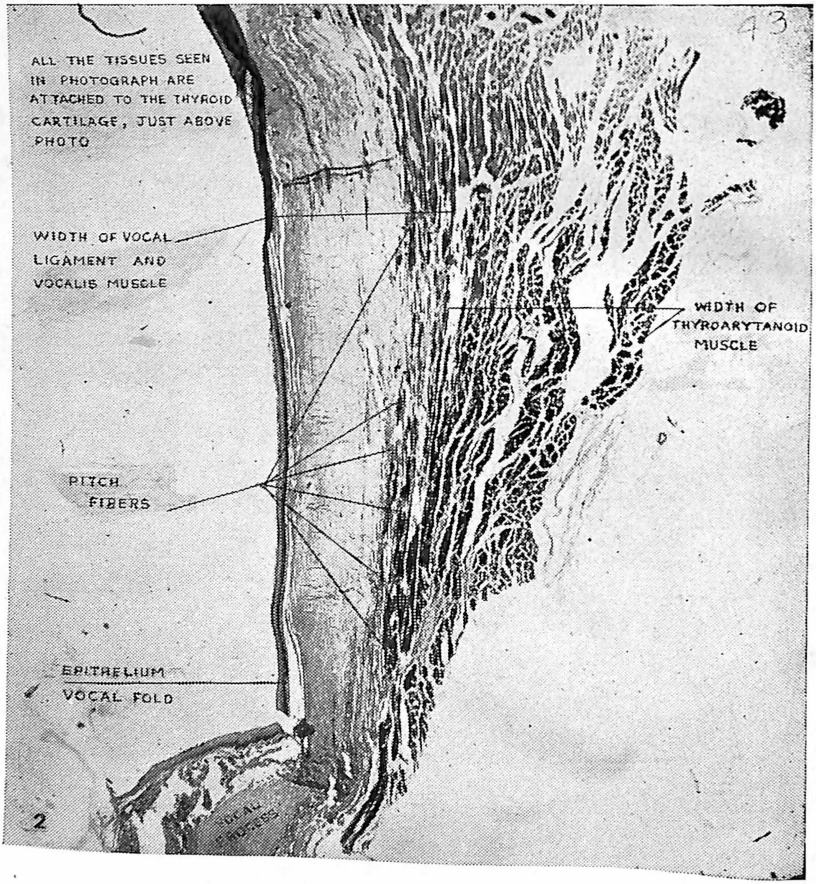
ALL THE TISSUES SEEN IN PHOTOGRAPH ARE ATTACHED TO THE THYROID CARTILAGE, JUST ABOVE PHOTO
WIDTH OF VOCAL LIGAMENT AND VOCALIS MUSCLE
WIDTH OF THYROARYTANOID MUSCLE
PITCH FIBERS
EPITHELIUM
VOCAL FOLD
2

DIAGRAM 2

CHAPTER II

THE ANATOMY OF SPEECH APPARATUS

6.0 The laryngeal vibrator is a portion of the elastic membrane of the larynx. The elastic membrane, in textbooks, is usually separated into three different parts and described as separate entities. But they are all one structure - a sheet which changes its direction during its course. In order to make any sense out of the mechanics of the situation, they need be kept in mind as a single structure. Separating the membrane from the air stream is the epithelium, the Vocal Fold. This is so intimately bound to the elastic membrane where vibration takes place that the two may be considered as a single physiological structure, and we do so consider them and treat them as an entity. The three parts of the elastic membrane are the following: (1) the Conus Elasticus (triangular membrane). This is fastened below (inferiorly) to the ring of the cricoid cartilage. From there, the conus passes upward to the level of the vocal process of the arytenoid cartilage. Ventrally, it is fixed to the thyroid cartilage just lateral to the midline and at the middle of the thyroid angle; dorsally, it is attached to the lower medial border of, and the vocal process of, the arytenoid cartilage. From one attachment to the other, the sheet is thickened. The thick part is (2) the Vocal Ligament. The sheet turns next laterally and forms the floor of the laryngeal ventricle. The sheet turns again superiorly and forms the lateral face of the ventricle and of its appendix. There, it is called (3) the Quadrangular Membrane. The whole sheet is approximately a millimeter in thickness over most of its course. But where it stretches from the vocal process of the arytenoid cartilage to the thyroid cartilage, the sheet suddenly

In the Bell Telephone cinematograph of 1940, the vocal ligament turns in vibration into the ventricle, so that it almost strikes the ventricular floor. This picture was made at 4000 frames per second. It shows much that all students of phonetical activity should be appraised of. In order to do this, the liquid ligament is spun out between the reduplicated layers of the epithelium.

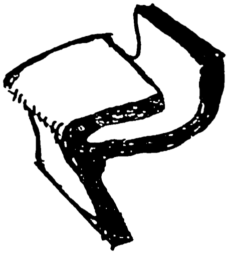

Fig. 3

So far we have discussed the vibratile mechanism.

6.1 We now turn to the mechanism of pitch modulation. The vocal ligament is the initiator of vibration only. The musculature herein operative which modulates pitch warrants a detailed consideration which follows.

Adjacent to, and adherent to, the base of the vocal ligament and upper part of the conus elasticus lies a mass of straight muscle fibers which are attached to the thyroid cartilage ventrally at the same level as, but lateral to, the vocal ligament. These straight fibers pass dorsally in contact with the vocal ligament and parallel to it. Mostly they insert just lateral to the vocal process of the arytenoid cartilage, and into the oblique fovea of that cartilage still more lateral. Some fibers are attached to the vocal process itself. The whole mass of fibers is about 3 or 4 millimeters wide. It is called the Vocalis Muscle. Adjacent to the

Vocalis Muscle, and lateral to it, is the somewhat larger sheet-like Thyroarytenoid Muscle. However, the thyroarytenoid fibers cross the vocalis fibers at about 45 degrees, so that the two muscles are readily separated in dissection. The thyroarytenoid fibers are attached ventrally to the thyroid cartilage adjacent to the vocalis fibers and dorsally to the arytenoid cartilage.

The two arytenoid cartilages are freely movable each on a vertical axis where they pivot and, in addition, they slide ventrally and laterally somewhat, and tilt backwards. Their back surfaces are triangular and curved in the vertical plane. The cartilages are separated normally from each other in the midline by about 5 millimeters.

Attached to their curved back surfaces is the Arytenoideus Muscle mass. When it contracts, it pulls the two cartilages in apposition with each other and, in general, closes the glottis. This closure is augmented by the Thyroarytenoideus on each side. Thus, there is a sort of potential sphincter around the glottic opening. The Vocalis Muscle fibers are of two functional groups. Most of the fibers have a straight dorsiventral pull. But a number of fascicles located across the base of the vocal ligament do not. On the contrary, they pass medialward invading the vocal ligament, then course dorsally within the ligament for various distances, and finally they pass laterally out of the vocal ligament to join the general straight muscle mass from which they originated. Thus, they are bowed fibers with the two ends lateral outside of the ligament, and the center of the bow medial within the vocal ligament. These fibers have been called Fasciculus Modulans, but we call them pitch fibers.

In diagram 1, the pitch fibers appear isolated in the vocal ligament. Cut in cross section, they are round or oval. In diagram 2, a longitudinal section of the muscle fibers, they appear like long bows, nearer the dorsal limit of the muscle mass. This is just one bow of many which we were lucky enough to cut almost in entirety. In diagram 1, the tip of the vocal ligament is pointed superiorly for it was cadaver material which had hardened *in situ* under pressure. The tip, of course, should be pointed directly medial. Note the thin contact of epithelium around its tip. It is only 3 or 4 cells thick. In the longitudinal section No. 2, the epithelium has been cut slanting and appears thicker than *in vivo*. In the phonating position, we shall draw two schemata. The horizontal one is the more instructive. The vertical one is merely a check on it.

Section A B

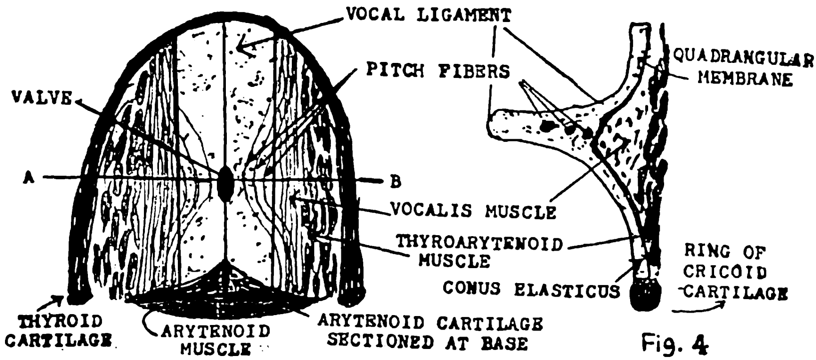

Fig. 4

One can now see how the bows of the pitch fibers operate. Their ends are fixed. When they contract, the bows shorten and pull laterally on the vocal ligament. The sphincteric pressure just equals the air pressure from below. Thus, the air pushes through the area of lessened pressure and escapes through the valve formed. This valve is of a definite length. It vibrates at a definite number of cycles. To lower the pitch, more muscle fibers are innervated, checked through the acoustic apparatus; this pulls open a longer valve. To increase the pitch, still fewer fibers would receive innervation.

There are many observations of the phonating larynx made by cinematograph. These are very hard to interpret since one looks down into the throat and nothing of the mechanism but the vocal ligament can be seen. In such views, the increase in the length of the vocal ligament, as pitch increases, is a seeming contradiction to our view. But because the length of the vocal ligament increases with pitch, it does not mean that the vibrating segment has increased. No motion pictures display the vocal lip in such a manner that any judgement of its length change can be made, except in that of G. Oscar Russel, cited in "The mechanism of laryngeal pitch"[46b]. In the literature, no attention has been paid to the length of the vibrating segment. The statements made simply indicate that as the pitch rises, the vocal ligaments insrease in length.

6.2 *The Modulation of Pitch in the Human Larynx*

"1955 Summary"

The analysis of the physiology of pitch modulation shall be discussed now.

One turns to the well known physical laws governing the pitch of vibration in substances to envisage the process of vibration in the vocal apparatus. In the physical condition known as the standing wave, tone is emitted as the fundamental or lowest

[46b] *Ibid.* p. 25.

Professor F. Winckel in his personal communication to me (referred to above in footnotes 39 and 44a) draws my attention to the excellent research in a modern form, regarding a number of fascicles located across the base of the vocal ligament and the pitch fibers, of K. Goerttler "Die Anordnung, Histologie und Histogenese der quergestreiften Muskulatur im menschlichen stimmband."—*Zeitschrift für Anatomie und Entwickelung,* 115, 352, 401, 1950.

tone that can be given out by a given length of the substance (rod or tongue). This fundamental is a function of the volume of the rod; the less the volume, the higher the pitch.

It is a well known physical fact that in fully elastic membranes, the elastic limit exceeds the ultimate strength of the material. In substances like latex rubber and the vocal ligament, (the most fully elastic structure in the human body), no amount of tension therefore can permanently deform it.

In a metal string linear tension is accompanied by a decrease in diamenter, that is, the cross section is reduced, somewhat. This leads to a decrease in the volume of a unit of string, which is accompanied by a rise in pitch. In rubber, on the other hand the volume decrease is almost zero. Hence no amount of linear tension could possibly lead to a change in pitch. This is readily verifiable by anyone as follows: if one takes a common three inch rubber band, cuts it in two, and stretches a segment of it, say an inch and a half long, two or three times that length, there will be no change in pitch. The total length of the vocal ligament subject to stretching is only about 5 mm. In our study, transverse sections of the human larynx, from freshly killed material (throat cut), cut parallel to the ventricular surface of the vocal lip, show that the most medial fibers of the vocalis muscle invade the vocal lip medially and ventrally, remain parallel to, for various distances, then leave the ligament to rejoin the mass of the vocalis fibers, laterally. Such fibers have a vector of force perpendicular to, and lateral to the long axis of the vocal ligament. This force, pulling on any point along the glottic margins while they are in contact, diminishes the force responsible for the medial contact along the vocal ligament. The lateral force, which acts to put the glottic margins in contact medially is the sphinctoric action of the arytenoideus muscle dorsally pulling the arytenoid cartilages together coupled with the vocalis laterally. These muscles are aided by the cricoarytenoid muscle, both posterior and lateral. Wherever such force pulls the ligament, the ligament is rendered less resistant to any pressure of the tracheal air below, which impinges upon the vocal lips, mutually in contact. In consequence of this lowered lateral pressure, any point or continuous area of the vocal lips so reduced in lateral force, permits the escape of the pneumatic blast from the lungs. Forced upward by the air, with the release of the pressure momentarily, the vocal lips return to their former position by their own recoil, since they are composed of tissue of great elasticity. Their elasticity is so great that the free margins of the vocal lips, in their lateral swing in vibrating almost touch the ventricular surface of the laryngeal ventricle, as shown by speed cinematography (4000 frames per second). It is by this passive action that the vocal lips are set into vibration.

6.3 Cinematographs show that the vibrating segment of the vocal ligament works as if the connective tissue constituent of the margin of the vocal lip moved back and forth all along its length from a base more rigid than the vibrating edge of the connective tissue. The vocalis fibers threading through the vocal ligament render the ligament at its attachment to the muscle less labile than elsewhere. A linear pivot of the ligament along this attachment is thus present. This long pivotal line permits the marginal part of the ligament to swing freely. Any definite length of the glottic margin set into vibration, will lead to an intonation of a definite number of cycles per second. Since the muscle fibers are voluntary, the control of modulation can be accomplished willfully.

This type of modulation is therefore a fretting system as opposed to the old linear tension system of Helmholtz who was unaware of the unique property of either latex rubber, or living elastic membranes.

7.0 Modulation in the human larynx is evidenced to be of the type above by the fact that, a staccato scale may be sung, with no intermediate frequencies appearing between half or whole tones. Without this fretting mechanism singing would simulate the sound of a plucked string being adjusted for pitch. Each half tone in the human voice may be isolated. There are no intermediate frequencies necessarily uttered; no glissando. To make a glissando acceptable to the human ear one must undergo special training. Lack of glissando is equally well attested in the accomplishment of the perfect trill.

7.1 To accomplish the fretting effect, there are certain nervous pathways. They work on a near or wholly automatic basis. Within the brain, the set-up for control of the muscles controlling pitch modulation is as follows. Between the acoustic nerve (hearing) and the cranial part of the accessory nerve (controlling the vocalis muscle) there is a direct nerve fiber connection which permits automatic control of the pitch modulating fibers. In the center for voluntary control, the brain first maps out the succeeding pitches of a tonal sequence and delivers them to the centers controlling the muscles for their adjustment. The spiral organ (Corti) is the analyzer of pitch. Once the spiral organ has analyzed any particular pitch, immediately the nerves controlling the vocalis muscle are stimulated to contract in such a manner that they apply the exact increment of force which acts to alter the length of the vibrating segment, and so to modulate the pitch.

Thus no message has to travel up to the brain and then be acted upon wilfully, for each pitch.

7.2 One must recall some physical factors of intonation as well as just muscular adjustment. A tone voiced at the mouth travels by air to the ear a distance of half a foot in about one two thousandth of a second. Recall that sound travels about

1100 feet per second. This is far quicker than the acoustic nerve can convey the sensation of a definite analyzed pitch to the center of voluntary control in the brain.

Pertinent to the analysis of the intoning process, it is interesting that the spiral organ is competent immediately after birth. It is an integral structure at birth, but some little time must elapse before the ear ossicles can be cleared of their embryonic debris.

The universal love of tone and harmony attests the fact that the human ear has been evolved in a manner so that tone makes a significant appeal to all persons but the very minor few who are born tone deaf. The harmonic appeal of the major triad is all but universal. This is made evident by the fact that in cooing babies, if brought together and disturbed enough to cry, after a period of disquiet with shrieks and haphazard tonality, they finally settle to a cooing harmony. It is thus that the genesis of tonal modulation occurs. One learns to intone correctly at a very early age. First by trial and error with an emotional focus on harmony. This is endlessly repeated, so that by early childhood mastery over the intervals of the diatonic scale is accomplished. PAVLOV's experiments in conditioning dogs to distinguish between 800 and 812 cycles per second indicates the sensitivity of this mechanism.

7.3 The very early perfection of the pitch analyzer is responsible for the fact that of all the arts only music produces the child genius. In sculpture, in painting, in literature we find no Mozart, with matured competence in early childhood. These other artistic abilities depend not upon a single receiving apparatus for function, but upon several which slowly grow to maturity.

It is to be borne in mind that modulation of pitch has to do with vibration rates only. Amplification of vibration rate be-comes necessary before it issues from the mouth, if it is to be readily appreciated by the ear. Amplification is of two kinds. First, we may speak of induced resonance. This is the result of the sound wave travelling down the trachea and impinging against the inside of the chest wall through the lungs. This sets the hard parts of the body into harmonic vibration (One feels this with his hand on his chest or head in singing). In consequence a larger surface is set into vibration. Hence the sound is amplified. The second type of amplification is that of pure resonance. This is mediated by the pipe system both below and above the vibrating vocal lips. Below, the larynx, trachea, stem bronchi and bronchial tree form a continuously variable system. Above, the larynx, pharynx, mouth and nose form another continuously variable system. The larynx raises itself from rest into a set position at the initiation of intonation and it then moves upward in a straight line with increase of pitch. This movement appears to be logarithmic.[46B1]

7.4 The muscular walls of the pharynx contract; reducing it to the proper caliber to make it an optimum resonator for any particular pitch. Note the difference in quality of a tone given out in an ordinary "register" and the same pitch uttered in true falsetto by the first harmonic from a fundamental of an octave below. The amplifier of the latter pitch, that is, the pipe which resonates it, is made by a different configuration of musculature. Pure tone results from the absorption of any scattered wavelengths which are absorbed by the wet walls of the resonating tubes. The evidence of Prentiss[46B2] seems to show that the various air sinuses of the head are not resonators. The

[46B1] SECORD's unpublished Ph. D thesis which is the counterpart of L. H. Strong's explanation of pitch.

[46B2] With respect to this problem, we are not able to trace the original paper of the late Dr. C. W. Prentiss who was Professor of Anatomy at Iowa State University U. S. A. for many years.

control of the air blast below the glottic lips is made possible by the musculature of the diaphragm and the abdominal wall contracting reciprocally, aided in a minor way by the muscles attached to the thoracic wall.

The beautiful tone of an organ pipe is the product of science both in the manufacture of the pipe itself and of the means of the initiation of its air supply, which causes it to vibrate. Science (basic knowledge) applied to the study of voice culture has as much to offer the voice teacher as it has to the manufacturer of pipes. Neglect of this sort cannot go unchallenged. There *is* a voice science[46c].

[46c] We have a word of caution about L. H. STRONG's "1955 summary". In 1961, Dr. von LEDEN at a personal meeting with L. H. STRONG considered that the matter of pitch had been settled by cinematographic observations. Cinematography shows that the vocal lips are increased in length in passing from certain pitches to other higher pitches. Therefore, the assumption has been made that increase in length of the vocal lips is responsible for pitch modulation. This would be evidence for a theory of linear tension. L. H. STRONG's explanation is different. In order that the optimum physical condition for higher and higher vibration would occur, the vibrating structure must be extremely tenuous so that it is spun out into a thin film. It is thus that tension produces that optimum tenuity.

But all this says nothing about the part of the vocal lip which is the vibrating segment and it is that which decreases with pitch. L. H. STRONG's observations of Professor Russell's vibrating vocal lips with the laryngoscape, as well as the cinematograph of them, showed that the higher the pitch the smaller was the valve between the vocal lips emitting the pitch.

One very good reason that L. H. STRONG has not published on speech beyond 1956 is that he could not afford the time to verify with rapid cinematography this point more fully.

In L. H. STRONG's 1935 paper, he seems to have missed, as he thinks he has, a most important significant publication in the literature of 1904. The reason was that this was a paper in histology which hid a gross anatomical implication. This was the fact that the muscle fibers of the vocalis muscle could be responsible for segmental effects upon the vocal lip. However, just this bold statement was mentioned in passing and no discussion of its significance noted. It is important when L. H. STRONG's 1935 paper is studied, its correction shown in the 1940 abstract is emphasized concern-

8.0 *Muscle Fibers Controlling Pitch in the Human Larynx*[47]

Transverse sections of the human larynx, from autopsy material cut parallel to the ventricular surface of the vocal lip, show that the most medial fibers of the vocalis muscle invade the vocal ligament, remain parallel to, for variable distances, then leave the ligament to rejoin the mass of the vocalis

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ing the method of application of the forces operating upon the vocal lip.

Although JACOBSON's paper, by implication, gave L. H. STRONG the hint that segmentation of the vocal lip in vibration was the key to pitch modulation, the former's material was macerated and has been called into question since then. Its date is 1887, so modern work makes it obsolete. Several fine papers have corrected his findings notably: WUSTROW of Würtemburg, *Zeitsch. f. Anat. u Entwicklges.*, 1952, Band 116, S. 506-522; *Zeitsch. Laryin. Rhinol. Otol.*, 1953, Heft 10, S. 571-577; and *Zeitsch. Laryng, Rhinol. Otol.*, 1956, Heft 2, S. 126-130.

The 1904 or rather the 1905 paper, Professor L. H. Strong had missed in his own 1935 paper, is "The elastic fibers of the human larynx" by Dean LEWIS in *Am. Jour. Anatomy,* Volume 4 1905, pp. 175 – 191.

Lewis was a very careful worker and his description of the relation of the vocalis muscle to the vocal ligament is quite correct. His assumption was also correct about segmental innervation to produce falsetto. What he failed to see was that segmental innervation could also account for normal modulation as well.

Professor F. WINCKEL in his personal communication to me (referred to above in footnotes 39, 44 a and 46 b) writes: — "I have some doubts about '1955 summary'. Is there anybody who has examined this theory by experiments? Controlling the vocalis muscle by the cochleo – recurrential circuit is only one factor, the other perhaps more important is the tactile control especially for singing which is not mentioned.

"Relating the statement about harmony, our present research in neurophysiology and practical experiences are not in agreement.

"We know exactly that 'sound waves travelling down the trachea' setting 'the hard parts of the body into harmonic vibration' is no amplification. This is no air sound but 'Körperschall'".

[47] *Anatomical Record,* Vol. 76, No. 2, 1940. pp. 53-54.

muscle, laterally. Such fibers would have one component of force perpendicular to, and lateral to, the vocal ligament. This force applied at any point along the glottic edges while in contact would produce a differential in the physical state of the vocal ligament, rendering it wherever operable, less resistant to any pressure by the air from below against the contact edges of the vocal lips. In consequence of this, any point or contiguous area of the vocal lips, so reduced in resistance, would permit the escape of the pneumatic blast and thereby be set into vibration. A definite length of the glottic edge set to vibrating under voluntary control would determine a definite number of cycles per second.

Longitudinal tension of the vocal ligaments with other factors constant could not possibly produce changes in pitch since, in fully elastic substances, the elastic limit exceeds the ultimate strength of the material, and pitch change is a phenomenon which accompanies molecular strain, only.

The elastic (physical) fibers of the vocal ligament course in parallel strands decreasing gradually from some three millimeters in width anteriorly to one millimeter at the vocal process of the arytenoid cartilage.

9.0 *Force Components of the Tongue Musculature, with Emphasis on the Intrinsic Fibers, Especially Those used in Speech.*[48]

Gross dissection of the adult and fetal human tongues upon

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[48] Leon H. STRONG and Ernest M. GOLD, Department of Anatomy, The Chicago Medical School, USA.

Anatomical Record, Vol. 106, No. 2, 1950. p. 86. Cf. also L. Henry STRONG, The Mechanism of the Laryngeal Pitch. *Anatomical Record,* Vol. 63, No. 1, August 1935, pp. 13-28.

L. H. STRONG, Muscle Fibers of the Tongue Functional in Consonant Production. *Anatomical Record,* Vol. 126, No. 1, September 1956, pp. 61-79.

thick sectioned material in three planes has brought to light a series of force components which will (1) revolve the apex of the tongue 180° around its anteroposterior axis so that the inferior surface of the tongue touches the palate as may be demonstrated by living subjects with training and (2) pattern precisely the contacts obtained in palatograms of consonants.

Functionally significant findings hitherto not recorded are: Verticales linguae fibers are vertical only at the tip of the tongue, elsewhere they are diagonal between dorsum medially and the inferior surface laterally, or they describe curves from dorsum medially to margin or inferior surface laterally; the *superior* transversus linguae fibers are directed in series dorsolaterally from the septum to the dorsum, from almost the midline to the upper limit of the margin laterally; no genioglossus fibers reach the tip of the tongue, the most superior fibers inserting about a centimeter dorsal to the midventral point of the tongue; after the longitudinalis inferior, the styloglossus, and the hyoglossus fibers enter the deep musculature of the tongue, their course is completely inferior to the transversus linguae, and is bounded above by it.

The indefinite description given to the apex linguae by anatomists calls for precise redefinition of that region.

THE ULTIMATE 'UNIT' OF SPEECH

10.0 The indirect determination of the ultimate 'unit' of speech—the Alpha-Phonoid—from the view point of the 'Cascada Modulation theory of speech-formants' was first suggested by P. C. GANESHSUNDARAM[49] and this was followed by yet another suggestion to measure the alpha-phonoid from the method of orthogonal polynomial fitting[50].

A proposed attempt within our theoretical frame-work to investigate more directly the alpha-phonoid—the ultimate 'Unit' of speech—is indicated in this chapter.

In the wake of the suggestions towards neurophysiological investigations following Norbert WIENER[51] and more particularly C. L. MEADER and MUYSKENS in their conception of the hypha—the 'Unit' of speech[52]—which we have already indicated sufficiently[53], we think, we wish now to deal with two significant lines of investigation in neurophysics, as they bear an

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[49] P. C. GANESHSUNDARAM, A. Cascade Modulation theory of Speech-formants. *Zeitschrift für Phonetik und Allgemeine Sprachwissenschaft* 10, 1957. pp. 1-7 (See especially p. 5).

[50] C. R. SANKARAN, *Process of Speech*, 1963. pp. 10, 25 and 36.

[51] Norbert WIENER, *Cybernetics or control and communication in the Animal and the Machine*. The Technology Press, John Wiley and Sons., Inc., New York, Hermann et cie 7th printing 1949, Paris, p. 142.

[52] Cf. "The setting forth of the hypha as a unit of speech brings the neuro-muscular processes of speech into harmony with all the other movements of the body". C. L. MEADER and J. H. MUYSKENS, Handbook of Biolinguistics Pt. I, Section A. Toledo 2, Ohio, 1950. p. 281. Cf. also *ibid.* pp. 29-30 and see also page 290 b.

[53] Cf. C. R. SANKARAN, *Process of Speech*, Section 2.9 pp. 11-12.

intimate relation to our work concerning structure in speech.[54]

10.1 The first of these two investigations is the promising theory of CRAGG and TEMPERLEY[55]. This theory considers the functional structures of the cerebral cortex in terms of 'cooperative phenomena' which belong to the domain of statistical mechanics. The work of CRAGG and TEMPERLEY discusses analogue processes in the form of extra cellular current flow in the central nervous system. This is over and above the digital interaction between neurons through synapses[56]. The theoretical framework provided by CRAGG and TEMPERLEY, very well fits in with the differentiation of the whole system in domains defined by equal values of membrane potential. Energetic considerations favour in such a system the assumption of a domain pattern with a minimum of free energy. Levels of excitation are consequently not only dependent, on the pattern of afferences, but also on the distribution of domains over the whole system. In turn, impulses impinging upon the central nervous system alter the domain pattern of the entire system; the neat theoretical model of CRAGG and TEMPERLEY gets an experimen-

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[54] Cf "Speech-structure may normally mean the structure of speech (viz. the physical structure) as well as the structure in speech (viz. the mathematical structure). We obviously refer to the latter here". C. R. SANKARAN and P. C. GANESHSUNDARAM, Structure in Speech—The Physical Reality of the Phoneme. NTF Band 3. 1956. Information Theory p. 67, and footnote 9a on page 69.

[55] B. G. CRAGG and H. N. V. TEMPERLEY, *Electroencephalography* and *clinical Neurophysiology,* 6. 1956, p. 85.

As Professor F. WINCKEL rightly observes in his personal communication to me (referred to above in footnotes 39, 44a, 46b and 46c), "We have now the method of averaging and autocorrelation for the potentials in the neuron network to give better quantitative results".

[56] Cf. also here the very interesting conclusion of John VON NEUMANN that the human brain operates in part digitally and in part analogically, but uses a peculiar statistical language unlike that employed in the operation of man-made computers. (John VON NEUMANN, The Computer and the Brain. New Haven: Yale University Press, 1958.)

tal confirmation in the work of LILLY[57] on travelling waves in the central nervous system, as LILLY's observations cannot be explained on the basis of ordinary digital automata theories. The demonstration of CRAGG and TEMPERLEY, therefore, points out that the formal apparatus of the thermodynamics of cooperative phenomena is apparently more adequate for the representation of events in the central nervous system than any other existing form of theoretical neurophysiology[58].

10.2 The subject of communication theory is the amount of information and the quantitative relations describing its transmission. Assuming a finite number of events whose *a priori* probabilities of occurrence (pi) are known, the amount of information obtained can be defined by knowing which of these events actually occurred, as $H = -\sum_{i=1}^{n} pi \log_2 pi$ (in bits). This defiinition bears a close formal resemblance to the statistical definition of the entropy of a closed system. In fact, the two definitions would bear a formal identity, if we concede that the 'configuration number' is the number of *a priori* equally probable states which are compatible with the macroscopic description of the state. In other words, the entropy of the system corresponds to the amount of (micro-state) information that is missing in the macrospic description. The theory was developed

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[57] J. C. LILLY, Instantaneous Relations between the Activities of closely spaced zones on the cerebral cortex—Electrical Figures During Responses and Spontaneous Activity. *American Journal of Physiology* 176, 1954, pp. 493-504.

[58] Cf. G. WERNER, An Examination of Axiomatization and Information Theory Application in Neurophysiology. *The Journal of Scientific and Industrial Research,* Vol. 18A, 1959, p. 469.

in this form by SZILARD[59] and SHANNON[60] and is of great value in all cases in which information is processed, as for instance in transmission lines and computers.

In this particular sense, computers are looked upon as circuit elements with characteristic transfer functions for information. Considering the obvious similarity between impulses conducted in peripheral nerves and signals transmitted in electronic network, it has become now customary to represent events occurring in the central nervous system in terms of concepts of information theory.

The notion of feedback (i.e., transfer of a fraction of the output signal to the input terminals in suitable phase relation) has proved specially useful for designing models with goal seeking behaviour[61]. In all these cases the central nervous system was considered to be a 'black box' and only input—output relations were discussed.

10.3 Now SHANNON's theory completely leaves open the question involved in the qualitative characterization of messages, i.e., their meaning to the recipient, as the theory exclusively deals with quantities of information, definable as logarithmic measure of the statistical unexpectedness of a message.

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59 L. SZILARD, Über die Entropieverminderung in einem thermodynamischen System bei Eingriffen intelligenter Wesen. *Zeitschrift für Physik* 53, 1929, pp. 840-856.

For a satisfactory phenomenological formulation of the entropy law, see K. R. POPPER, Irreversibility; or, Entropy since 1905. *The British Journal for the Philosophy of Science* 8, 1957, 153-155, in which he has demonstrated the unsatisfactory nature of SZILARD's discussion on Maxwell's Demon. Karl R. POPPER's concluding comments are illuminating.

60 C. E. SHANNON, A Mathematical Theory of communication. *The Bell System Technical Journal* 27, 1948, pp. 379-423, and 623-656.

61 W. Ross ASHBY, *Design for a Brain*. Chapman and Hall Limited. London. 1954. p. 53.

For a much fuller discussion on Information theory application in Neurophysiology, see G. WERNER, *op. cit.* pp. 469-471.

10.4 A profoundly 'biological' approach to this problem was suggested by MACKAY[62]. He conceives quite justifiably, we think, that meaning is closely tied up with the behavioural consequences a message produces in the recipient. The meaning of a message, therefore, depends upon the recipient's past knowledge.

Measurement of meaning may conveniently be based on the selective function of a message on the ensemble of possible 'conditional probability matrices' which describe the set of behaviour patterns of an organism.

Thus the 'classical' information theory of SHANNON is extended to the domain of meaning, as we now see that 'meaning' can be given a quantitative place within an enlarged framework of information theory[63]. It is possible to define 'meaning' quantitatively, for we can experimentally determine it as logarithmic measure of the size of change caused by the selective operation of a message on the ensemble of possible outcomes (in pure biological terms, conditional probability matrix of organismic behaviour).

In geometrical interpretation, the meaning of a message can be pictured as a vector in the 'information space' where each

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[62] D. M. MACKAY, The Place of 'Meaning' in the Theory of Information. *Third Symposium on Information Theory* edited by Colin CHERRY (Butterworths Scientific Publications, London, 1956, pp. 215-225).

[63] Cf also "*The Fundamental* idea of information theory has been to treat the amount of information of a message as a function of the number of possible alternative messages. The fundamental idea of CARNAP and BAR-HILLEL has been to work with a semantical analogue to this, namely information as a function of the number of possible conditions under which the message would be true".

Rulon WELLS, A measure of subjective Information. *Proceedings of Symposia in Applied Mathematics,* Vol. 12. Structure of Language and its Mathematical Aspects.

American Mathematical Society, 190 Hopestreet, Providence, Rhode Island, 1961. p. 238.

point stands for a particular state of the represented organism. We may, however, point out here that the similarity of basic idea of MACKAY to the 'semantic reaction' of KORZBYSKI is apparent. For, information looked upon from the point of view of the past knowledge of the recipient turns into semantics.

This concept is extended into the experimental realm in the work of HERNANDEZ-PEON[64], SCHERRER and JOUVET[65] who pursued the idea that the electrical response of various areas in the central nervous system is one of the measurable indices of 'meaning' of a real-life stimulus situation.

These investigators made observation in animals with permanently implanted electrodes and it became clear from their recordings, to what extent temporal succession of identical and simultaneously competing stimulus patterns alter the electrical response, i.e., direction and absolute size of the Vector representing the 'meaning' of physical stimulus patterns in the 'information space' of the observed organism. We may do well to remember at this stage that both the theory of CRAGG and TEMPERLEY referred to earlier in this paper and the theory of MACKAY, as G. WERNER[66] points out, are "not yet sufficiently formalized as to provide a generalized abstract representation of neurological events."

10.5 We have already observed as follows in a far earlier paper of ours:—"It is proposed to determine the minimum duration of a 'unit information cell' in the physical stimulus as well as in the neurological and psychological responses; the minimum common duration of all these three will then serve

[64] R. HERNANDEZ-PEON, *Communication Association Latin American de ciencias Fisiologicas*, Montevider. 1957

[65] R HERNANDEZ-PEON, H SCHERRER and M JOUVET, "Modification of Electric Activity in Cochlear Nucleus during 'Attention' in Unanesthetized cats." *Science*, 123. 1956. pp. 331-332.

[66] G. WERNER, *op., cit.*, p. 471.

as the Key 'interval' for the *basic* representation of speech-structure (the alpha-phonoid)".[67]

10.6 Now an experiment similar to the one of M. H. GOLDSTEIN, JR., N.Y.—S. KIANG, and R. N. BROWN[68] by which they had attempted to determine the electrical responses from the cat-auditory-cortex to low-intensity repetitive clicks and bursts of noise, is suggested for the determination of the ulti-

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[67] C. R. SANKARAN and P. C. GANESHSUNDARAM, Time and Speech-Structure, *Bulletin of the Deccan College, Research Institute* 12, 1952. p. 410.

Cf also C. R. SANKARAN and P. C. GANESHSUNDARAM, Structure in Speech— The Physical Reality of the phoneme. *Nachrichtentechnische Fachberichte* NTF Band 3, *Information theory*, 1956, p. 69 footnote 6a.

Cf. too C. R. SANKARAN, *Process of Speech*, p. 17 footnote 32.

[68] M. H. GOLDSTEIN, Jr. N.Y.—S KIANG, and R. M. BROWN, Responses of the Auditory cortex to Repetitive Acoustic stimuli. *The Journal of the Acoustical Society of America* 31, 1959, pp. 356-364.

Cf also the following:—

N. Y—S KIANG, M. H. GOLDSTEIN Jr. and W. T. PEAKE, Temporal coding of Neural Responses to Acoustic stimuli. *IRE transactions of the Professional Group on Information Theory*, volume IT-8, Number 2, February 1962, pp. 113-119.

W. T. PEAKE, N.Y.-S KIANG and M. H. GOLDSTEIN Jr., Rate Functions for Auditory Nerve Responses to Bursts of Noise: Effect of Changes in stimulus Parameters, *JASA* 34, 1962, pp. 571-575.

W. T. PEAKE, M. H. GOLDSTEIN, Jr., and N.Y-S KIANG, Responses of the Auditory Nerve to Repetitive Acoustic Stimuli *JASA* 34, 1962, pp. 562-570.

N.Y-S, KIANG and M. H. GOLDSTEIN Jr. Tonotopic Organisation of the cat Auditory cortex for some complex stimuli *JASA* 31, 1959, 786-790.

W. A. CLARK, R. M. BROWN, M. H. GOLDSTEIN Jr., C. E. MOLNAR, D. F. O'BRIEN & H. E. ZIEMAN.

The average response computer (ARC) or Digital Device for computing averages and Amplitude and Time Histograms of Electrophysiological Response. IRE Transaction of Bio-Medical Electronics 1961, pp. 46-50.

LAWRENCE S. FRISHKOP and MOISE H. GOLDSTEIN Jr., Responses to Acoustic stimuli from single Units in the Eighth Nerve of the Bull frog *JASA* 35, 1963, pp. 1219-1228.

mate 'unit' of speech—the alpha-phonoid. In this theoretically envisaged experiment, as we are perforce to operate simultaneously with two orders of infinitesimals (viz., the acoustical stimulus and the auditory cortical response,) we would land into a Non-Archimedean time-order[69] in our final interpretation. It is, therefore, suggested that the determination of the ultimate 'unit' of speech—the alpha-phonoid-through what is only a theoretically-devised or a thought-experiment now would give a *physical significance* to what remains at present a purely abstract mathematical concept of the continuum due to VERONESE[70].

11.0 In conclusion, for the sake of completeness, we wish to refer, apropos of all that has been written above in connection with the proposed experimental determination of the ultimate 'unit' of speech—the alpha-phonoid—, to the following three lines of newer investigations in neurophysiology related to speech and musical Acoustics and Perception.

11.1 First, Fritz WINCKEL in his able paper "Kybernetische Funktionen bei der Stimmgebung und beim Sprechen"[71] discusses how "Cybernetics, as a theory of the reception, processing and transmission of speech derived from the processes of control engineering, is able to present speech as complex function of neural behaviour" and how "the various regulatory functions in speaking and singing are made clear and the ectosemantic influences disentangled."[72]

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[69] C. R. SANKARAN, and P. C. GANESHSUNDARAM, Time and Speech-Structure, *BDCRI.* 12, 1952, pp. 398-400.

[70] C. R. SANKARAN, *Process of Speech,* pp. 29-30.

[71] *Phonetica* 9, 1963, pp. 108-126.

[72] Cybernetic Functions in Phonation and speech. *Summary, Phonetica* 9. 1963, p. 125.

11.2 Next, we would draw G. WERNER's following pregnant observations[73]:—"Perception may remain relatively constant while the physical stimuli operating at the receptor level are varying drastically. Perception may vary while the physical stimulus input remains constant (i.e., reorganisation of the perceptive field under conditions of unaltered physical stimuli)". G. WERNER presents a neurophysiological model of perception as a drastic departure from the conventional stimulus-response, association, or reflex arc model, with an emphasis towards integration and autogenic activity, i.e., the capacity of a net work to hold up and to alter the characteristics of impulses transmitted to it, as the system of this kind determines within considerable limits the effective excitation which results when a change of physical energy impinges upon a receptive area.[74]

11.3 Lastly, we have already pointed out that rest and activity have a real one—one correspondence in what we call consonants and vowels in human speech[75]. For, a consonant is a concealed movement within a vowel and in its ideal or perfect state is silence.[76] In fact, rest and activity constitute a deeper physiological phenomenon in all our perception from moment to moment, although mostly we are un-

[73] G. WERNER, Perception; Epistemological aspects and neurophysiological foundation (unpublished).

[74] Cf. C. R. SANKARAN, Structure in speech and structure in Perception. *Bulletin of the Theosophy Science Study Group*. India 2, 1964, p. 21.

[75] Cf C. R. SANKARAN, Structure in speech and structure in Perception. *Bulletin of the Theosophy Science Study Group*, India 2, 1964. p. 34.

[76] P. C. GANESHSUNDARAM, A qualitative definition of the perfect conant and the perfect vowel. *Bulletin of the Deccan College Research Institute*. 14, 1953. pp. 243-248. esp., p. 247.

P. C. GANESHSUNDARAM, The Process of Existence concept and structure in speech. *Bulletin of the Deccan College Research Institute* 18, 1956 pp. 205-214.

aware of this process.[77]

We may do well to note here the significant observations of Sir Almroth WRIGHT[78]—"We may at this point, perhaps, not inappropriately ask ourselves why Nature has, as a whole, disposed it so that *afferent* nerve currents shall set up a condition of strain, and *efferent* currents a condition of physiological relief.

"The plain reason for this is that Nature requires to be supplied with force to carry out her work; and that if a normal sensory stimulus did not produce one or other of the forms of force which are represented by hunger and desire, and if fatigue did not invite rest, everything would be at cross purposes."[79]

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[77] Cf "Every moment the nervous system is different, is new" William GOODY "Cerebral Representation" *Brain* 79, 1956 p. 167 quoted by C. R. SANKARAN and P. C. GANESHSUNDARAM, "The co-existence of the Mind with the Dynamic Spatio-termporal patterns of Activity in the Cortex" *Indian Linguistics* Turner Jubilee Volume II, 1959, pages 46-47 footnote, 3 (see also the other references in this footnote).

[78] Sir Almroth WRIGHT, *Alethetropic Logic,* A Posthumous work presented by Giles J. Romanes William HEINEMANN. Medical Books Ltd., 1953. p. 21

[79] C. R. SANKARAN and P. C. GANESHSUNDARAM, The co-existence of the Mind with the Dynamic Spatio-Temporal Patterns of Activity in the cortex. *Indian Linguistics,* Turner Jubilee Volume II, 1959, p. 49 and footnote 4a.

Cf the following pregnant discussion in *Transaction of the Blavatsky Lodge of the Theosophical Society.* The Theosophy Company, Los Angeles, CAL, 1923, pp. 70-71.

"Q. What, then, is the Process of going to sleep?

"A. This is partially explained by Physiology. It is said by Occultism to be the periodical and regulated exhaustion of the nervous centres, and especially of the sensory ganglia of the brain, which refuse to act any longer on this plane, and, if they would not become unfit for work, are compelled to recuperate their strength on another plane or *Upadhi.* First comes the *Svapna,* or dreaming state, and this leads to that of *Shushupti.*

11.4 It is useful also to note finally that further experimental investigations into 'structure in speech and structure in perception'[80] not only confirm the validity of "the hypothesis that native speakers of a language have at their disposal a built-in pattern which enables them to determine within rather narrow limits whether certain acoustic signals are acceptable vowels",[81]

Now it must be remembered that our senses are all dual, and act according to the plane of consciousness on which the thinking entity energises. Physical sleep affords the greatest facility for its action on the various planes; at the same time it is a necessity, in order that the senses may recuperate and obtain a new lease of life for the *Jagrata,* or waking state, from the *Svapna* and *Shushupti.* According to *Raj Yoga, Turiya* is the highest state. As a man exhausted by one state of the life fluid seeks another as, for example, when exhausted by the hot air he refreshes himself with cool water; so sleep is the shady nook in the sunlit valley of life.

"Sleep is a sign that waking life has become too strong for the physical organism, and that the force of the life current must be broken by changing the waking for the sleeping state. Ask a good clairvoyant to describe the aura of a person just refreshed by sleep, and that of another just before going to sleep. The former will be seen bathed in rhythmical vibrations of life currents—golden, blue, and rosy; these are the electrical waves of Life. The latter is, as it were, in a mist of intense golden orange hue, composed of atoms whirling with an almost incredible spasmodic rapidity, showing that the person begins to be too strongly saturated with Life; the life essence is too strong for his physical organs and he must seek relief in the shadowy side of that essence, which side is the dream element, or physical sleep, one of the states of consciousness'.

[80] Cf C. R. SANKARAN, Process of Speech, pp. 19-22.

[81] A. COHEN, I. H. SLIS and J. T., HART, Perceptual Tolerances of Isolated Dutch vowels, *Phonetica* 9, 1963, pp. 65-78. It is of special significance too "that formant structure is not the decisive factor in sound recognition". F.-W. OLKEN, Kritisches Zur Formanttheorie der Vokale (Some critical observations on the Formant Theory of vowel Recognition) *Phonetica* 10, 1963, pp. 22-33.

Cf C. R. SANKARAN, Process of Speech, p. 69.

but also go a long way to demonstrate the unified allegory[82] of several disciplines.[83]

Also "it is evident that in running speech the listener is, as regards vowel identification, on very weak phonetic ground and that he needs extra-phonic cues in order to identify the sentences. In view of the generally admitted success of voice communication one is led to believe that there will be less overlap between some consonants as their pronunciation suggests less freedom than that of the vowels. We must, however, thoroughly check this hunch by experiments before we content ourselves with such an explanation".

H. MOL, on the Phonetic Description of the Phoneme. *Lingua* 11, 1962, p. 293.

[82] G. HOLTON, Science and the changing Allegory of Motion. *Scientia* Annus 57, Series 6, 1963, pp. 191-200. See especially pp. 193-195.

[83] This third chapter in an earlier presentation was submitted for reading at the Physiology Section of the combined 51st and 52nd Session 1965 of the Indian Science Congress and is also now published in *Phonetica*.

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AUTHOR INDEX

1. In Anat., Record 1945 (long before Goerttler, see above p. 34 footnote 46b) vol 91, No. 4, p. 40, L. H. STRONG wrote an abstract for a paper he had presented before the American Association of Anatomy, showing that neuromuscular spindles were present in a part of the vocal ligament, removed from any pulling effect and pointed to the spiked sensory endings in the ligament. L. H. STRONG had suggested that they were the proprioceptive apparatus of the ligament.

2. SCHLOSSAHUER *et al (Zeitschrift für Anatomie und Entwickelung* B. 120 S. 456-465, 1965) assume that Goerttler was the first to prove that muscle fibers invaded the vocal ligament contrary to the view put forward in the text books. But L. H. STRONG had announced this fact some years before (see the supplementary note 1 above).

3. A word about nomenclature. It concerns the thyroarytenoid muscle. In the earlier literature, this muscle was described in two sections, a lateral, thyroarytenoid externus and an inner thyroarytenoideus internus. The latter is now the vocalis. Jakobson used the term aryvocalis, we believe for the fibers which enter the vocal ligament. We use only vocalis, and the term pitch fibers for the bowed fascicles. We have no firm opinion about those fibers which enter the vocal ligament and break up there, except those far medial fibers ending in spikes or neuromuscular spindles. There are many other items concerned with the relation of the vocal ligament and the muscle mass of which we are ignorant. There are many facts and factors concerning the whole vocal anatomical and physiological framework of which we know nothing. Diagrams 1 and 2 section 6.0 facing pages 28 and 29 respectively in chapter II of this monograph demonstrate laryngeal picture of relations which will have to be explained away before any one can deny the bases of the theory of modulation of pitch which L. H. STRONG has proposed.

C. R. SANKARAN
25th September 1965

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The Faunal Remains from the Microlithic Site of Langhnaj (Gujarat) by Juliet Clutton-Brock ..	BC 107
Ancient Human Skeletons from Langhnaj (Gujarat) by Sophia Erhardt	BC 108
Word Hunting in Seven Continents by S. M. Katre	BC 82
Kharia Phonology by H. S. Biligiri	BC 83
Morphology of Verb and Noun in Spoken Sinhalese by D. N. Shankara Bhat	BC 84
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Historical Phonology of Russian by Gordon H. Fairbanks ..	BC 96
Descriptive Analysis of Tulu by D. N. Shankara Bhat ..	BC 95
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