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INTONATION, PERCEPTION, AND LANGUAGE

by

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Submitted to the Department of Modern Languages and Linguistics on January 10, 1966 in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

A theory concerning the linguistic status of intonation is proposed, and physiologic, acoustic, perceptual, and syntactic data are presented in support of the theory. It is suggested that underlying all intonational patterns is a feature which is termed the breath-group. The unmarked or "normal" breath-group of American English is characterized at the articulatory level by a relatively steady tension of the laryngeal muscles throughout a bounded expiration of air from the lungs. At the end of phonation the subglottal air pressure abruptly falls and hence the frequency of the vibration of the vocal cords (the fundamental frequency) also decreases rapidly. The intonation pattern that is a consequence of this breath-group is, of course, the one that has been described as characteristic of declarative sentences in English and numerous other languages. The marked breath-group is differentiated at the articulatory level by an increase in the tension of the laryngeal muscles at the end of phonation which counteracts the falling subglottal air pressure to produce a not-falling terminal fundamental frequency contour. The intonation pattern of the marked breath-group is the characteristic intonation pattern of the "yes-no" question of English and other languages.

Evidence is presented to show that the breath-group is a basic feature in the hierarchy of phonologic features. The articulatory and acoustic correlates of the unmarked breath-group can already be discerned in the innately determined crying behavior of neonates, and the breath-group is one of the first elements of language over which an infant gains control.

The scope of the breath-group is suprasegmental. A generative syntactic analysis of English shows that it can "span" or delimit any constituent of the derived phrase marker though it most often spans the "primary" constituents like the sentence, since it requires less articulatory effort to use longer breath-groups (unless they become so long that they interfere with ventilation). The breath-group is an explicit characterization of the traditional "phonemic phrase". The syntactic analysis also shows that the sentence final breath-group is marked in the superficial phrase marker when certain morphemes that occur in the deep phrase marker of "yes-no" questions are deleted. Observations of other languages (Russian, Japanese, Finnish, etc.) suggest that similar processes may occur universally.

A second, segmental feature [$+P_s$] is also isolated for American English. This feature is lower in the hierachy of phonologic features. The articulatory correlate of [$+P_s$] is an increase in the subglottal air pressure which may be placed on a vowel. This articulatory maneuver can result in a higher fundamental frequency and a higher amplitude in the acoustic waveform. An increase in the duration of the vowels also often accompanies the other acoustic correlates in English. The increase in duration appears to be an independent articulatory maneuver.

Other articulatory maneuvers can also be used by a speaker to produce these acoustic effects. Speakers can, for example, produce the subglottal air pressure function that characterizes the breath-group without pausing for inspiration at the end of each breath-group. However, psychoacoustic data for the perception of intonational signals by Swedish and American English listeners suggests that the intonational signal is perceived in terms of the "archetypal" or primary articulatory correlates of [$+P_s$] and the marked and unmarked breath-group. The listener may employ a feedback mechanism of the analysis-by-synthesis type which involves a knowledge of the grammar of the language as well as the purely "motor" aspects of speech production.

The presence of emphatic morphemes in the underlying phrase marker is frequently reflected by the presence of the feature [$+P_s$] in the superficial phrase marker. The segmental feature [$+P_s$] is also one of the phonetic outputs of the phonologic stress rules. New experimental evidence concerning the perception of stress is discussed and it is shown that, in the absence of linguistic information, even skilled listeners can make only binary judgments. The performance of listeners improves dramatically as soon as they are allowed to hear the words making up the sentences. These facts are explained by hypothesizing certain universal principles of stress subordination. Listeners apparently make use of this principle, the specific stress rules of the grammar, and the constituent structure of the derived phrase marker, to "perceive" the intermediate degrees of stress.

The results of the investigation thus show that intonation has a central rather than a peripheral linguistic status and that it must be the product of an innate rather than of an acquired mechanism.

Thesis Supervisor: Morris Halle
Title: Professor of Modern Languages

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INTRODUCTION

Objectives and Methods

The object of this study is to undertake a linguistic analysis of American English in terms of mechanisms, i.e., features and rules that underlie the observable phenomena, rather than to develop a notation that can be used for intonation. The two features that are discussed in this study are not sufficient to specify all the observable phenomena of American English intonation. However, we have tried to show that people actually produce, perceive and use some aspects of intonation as a linguistically referenced signal in terms of these features. Although notations have been devised that are sufficient to describe all the observable phenomena of intonation (the standard musical notation with minor modifications is, for example, suitable) they do not reflect the mechanisms that people use when they deal with intonation as a linguistic signal. These notations tell us no more about the linguistic competence of speakers of American English than a Fourier analysis of a violin sonata would tell us about its musical structure. The physical output signal would be specified as a function of time but the notation would not reflect the underlying musical structure.

We have also tried to show that intonation has a central rather than a peripheral linguistic status and that it must be the product of an innate rather than of an acquired mechanism. Although one of the features that we discuss in detail, the feature $[P_s]$, probably occupies a comparatively low position in the hierarchy of phonologic features, the other feature that we discuss, the <u>breath-group</u>, has universal aspects that are applicable to many languages. We have used a number of different techniques to demonstrate the universal characteristics of this feature which seems to have a central status in the hierarchy of phonologic features.

These methods are innumerated below,

(1) The anatomical and physiologic aspects of the human respiratory system are examined with regard to their role in the production of intonation. Some of the perceptual constraints of the human auditory system are also discussed insofar as they are directly relevant to the intonational signal. These constraints suggest how the intonational signal might be structured at the articulatory and acoustic levels.

(2) The results of physiologic and acoustic studies of the cries of newborn infants are discussed. These studies show that the universal aspects of the normal or unmarked breath-group are manifested in these innately determined vocalizations. The terminal falling fundamental frequency contour of the unmarked "archetypal" breath-group apparently follows from a condition of minimum articulatory control at the end of expiration. The laryngeal muscles are not tensioned to counteract the terminal falling subglottal air pressure. Developmental studies of the early utterances of children and phonetic studies of related and unrelated languages are cited that show that intonational signals have a linguistic reference in the first year of life.

(3) Detailed physiological and acoustic data for American English is presented and discussed. This data indicates that the unmarked

breath-group of American English is quite similar to the innately determined cries of newborn infants. The marked breath-group of American English is differentiated from the unmarked breath-group by the presence of an increase in the tension of the laryngeal muscles at the end of the breath-group where the subglottal air pressure falls. The data also demonstrates that the scope of the breath-group is supra-segmental. The articulatory correlate of the segmental feature $[+P_s]$ is a momentary increase in the subglottal air pressure that occurs on a vowel.

Detailed psychoacoustic data for Swedish and American English is then discussed. The perceptual data is consistent with the physiologic data. It indicates that listeners interpret the intonational signal in terms of these features through a process of analysis-by-synthesis. The perceptual recognition routine moreover considers the total linguistic knowledge of the listeners. The Swedish listeners interpret identical intonation signals as though they were using an additional feature that is not operant in American English.

(4) Phonetic data for a number of related and unrelated languages is examined which shows that the formation of questions is quite regular if the deep phrase markers and the syntactic rules are considered. The marked breath-group is apparently used in sentence-final position when the morphemes Q and Wh are deleted from the deep phrase marker. A detailed syntactic analysis of English is then presented which relates the phonetic facts to syntactic features of the utterance.

Although the detailed data of the study is for the most part directly relevant only for American English, we have attempted at each stage of the analysis to examine acoustic, perceptual, phonetic, and syntactic data for other related and unrelated languages. We have also tried to formulate our hypothetical features in terms of the inherent anatomical, physiologic, and perceptual constraints that are common to all mankind. We have moreover tested our hypotheses in terms of the available data regarding the vocalizations of infants and young children which may reflect the innate human linguistic competence under certain conditions. At each step of the analysis we have tried to identify the language specific and the universal aspects of our features and rules. Thus, though our analysis is most relevant to American English, it may also be pertinent to some degree to the general problem of intonation.

Our analysis is obviously not definitive since we can not account for all the observable phenomena that characterize American English intonation. We have isolated only two of the features that may underlie the intonation of American English. We have not, for example, characterized the minute variations in the fundamental frequency of the vowels that occur within each breath-group. We do not even know whether all of these variations have a linguistic reference. In many other languages features exist which produce "tones" on individual vowels. Similar features may also exist in American English. Our study is also not definitive in the sense of having exhaustively analyzed the intonational system of every language on earth. We have moreover avoided, for the most part, the emotional aspect of intonation. It is apparent that emotion is manifested in the intonational signal but this problem is beyond the scope of this study.

We have, however, attempted to resolve a number of problems in the course of this study. We have, for example, tried to characterize the traditional "phonemic phrase" in terms of the breath-group. The scope of the breath-group is suprasegmental. Though it often delimits the constituent sentence it can delimit any constituent in the derived phrase marker of a sentence. We have also discussed the possible implications of suprasegmental features on the syntactic component of the grammar. We have tried to characterize the production and perception of terminal fundamental frequency contours as well as the production and perception of contrastive stress and linguistic stress, and we have particularly tried to show that the perceptual recognition routines involve the listener's knowledge of the grammar as well as his knowledge of the mechanical aspects of speech production.

One last comment on the organization and content of chapters one and three should be made. This study is directed at both the linguist and the experimental worker in speech analysis and synthesis. Although a detailed knowledge of the physiology of the larynx and the perception of speech is essential to the analysis of intonation, the details are perhaps not of direct interest to many linguists. A summary of the most relevant aspects of the control of the larynx is therefore included in chapter one. A discussion and summary of the hypotheses and data in chapters one, two, and three is also presented at the end of chapter three. The reader who studies these chapters in detail is asked to forbear with these repetitions. Other readers who are well acquainted with the techniques of experimental speech analysis and synthesis will doubtless find other unnecessary repetitions. However, the general absence of elementary expositions in this area makes it difficult otherwise to prepare the general reader.

Chapter One

Physiologic, Acoustic, and Perceptual Criteria

In this chapter we shall discuss some of the anatomical and physiologic aspects of speech production in relation to the acoustic output of the larynx. We will also discuss some aspects of the perception of pure tones and other simple stimuli in psychoacoustic experiments. We will then examine intonation in terms of the constraints imposed by the speech production apparatus and the auditory system.

In considering these constraints we can avoid fruitless searches for phonetic distinctions that are impossible to produce or perceptually to resolve. This is indeed the traditional approach to phonetic analysis. No one would ever expect to find a vowel which was produced by constricting the pharynx with the tip of the tongue since it is impossible to place the tip of the tongue in such a position. The physiologic properties of the vocal tract are inherent properties of every well formulated phonetic theory. We will begin by examining the larynx and the sublaryngeal respiratory system since these parts of the vocal tract are most important for intonation.

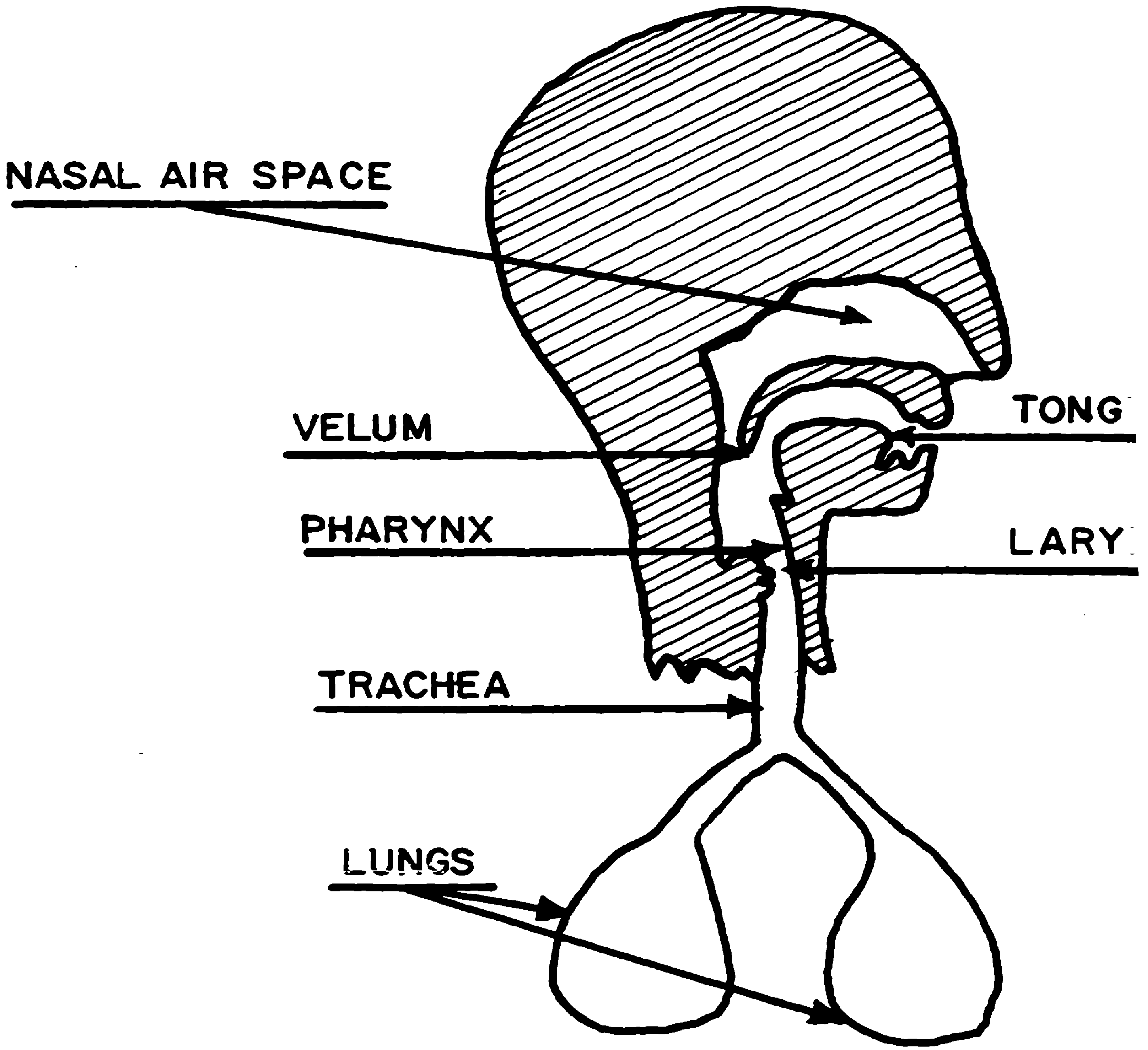
A - The Speech Production Apparatus

The larynx is the source of quasi-periodic energy that excites the vocal tract in the production of voiced sounds. Intonation, stress and prosody are primarily responses to the periodicity, amplitude, spectral character, and duration of the output of the larynx.

The vocal tract is really defined operationally in the sense that there is no set of organs exclusively adapted to the production of speech. The chest, trachea, larynx, pharynx, mouth and nose all form part of the respiratory system whose main function is, of course, ventilation. The lips, teeth, jaw and tongue are necessary to ingest food. The nose also contains olfactory sense organs while the tongue has taste receptors. The larynx in certain lower forms is simply a valve that prevents solids and liquids from entering the lungs.

The respiratory system can be conveniently divided into three parts for the purpose of describing the production of speech (Fig. 1). The supraglottal respiratory system consists of the oral pharynx, nasal pharynx, nose and mouth. The jaw, lips and tongue can all modify the interior shape and volume of the mouth while the velum can open or close the nose to the oral cavity. It is usual to designate the upper respiratory system and the larynx as the "vocal tract" since phonetic studies are usually concerned only with articulatory gestures that distinguish different vowels and consonants. The phonetic quality of differing vowel and consonant sounds is primarily due to the configuration assumed by the upper respiratory system.

The sublaryngeal respiratory system consists of the lungs and trachea. The larynx functions by converting the relatively steady movement of expiratory air that flows out from the lungs through the trachea into a series of "puffs" of air. The "puffs", which can occur at a relatively steady rate or fundamental frequency, excite the upper respiratory system. The upper respiratory system acts as an acoustic filter. The sequence of "puffs" of air, i.e., the volume velocity waveform that is the output of the larynx, contains energy at the fundamental frequency and many of its higher harmonics. The physical configuration of the upper respiratory system for each vowel or



SCHEMATIC OF RESPIRATORY SYSTE

Fig. 1

consonant results in an acoustic filter that has minimum attenuation at certain frequencies. Local energy maxima (Fig. 2) therefore occur at the mouth of the speaker in the vicinity of these formant frequencies which reflect the configuration of the upper respiratory system.

The volume velocity waveform from the larynx is always filtered by the upper respiratory system. However, the fundamental frequency and amplitude of the glottal volume velocity waveform are largely independent of the configuration of the upper respiratory system. For example, the vowel /a/ might have formant frequencies of 700, 1000 and 2500 cps for a particular talker. The talker would be able to vary his fundamental frequency between 90 and 200 cps while he preserved the vowel quality[1] of the /a/. He would vary the output of his larynx by making certain muscular adjustments in the larynx and the sublaryngeal system, keeping the configuration of his upper respiratory system unchanged. Conversely, he might maintain the laryngeal output and vary the configuration of his upper respiratory system producing different vowels or voiced consonants. He could, for example, produce /a/, /i/, /u/ or /l/ at a fundamental frequency of 130 cps.

B - Anatomy of the Larynx

We owe much of our knowledge about the larynx to the studies of Johannes Muller. Muller in 1848 pointed out that speech may be regarded as the modulation of the laryngeal source by the configuration assumed by the upper respiratory system. Muller noted,

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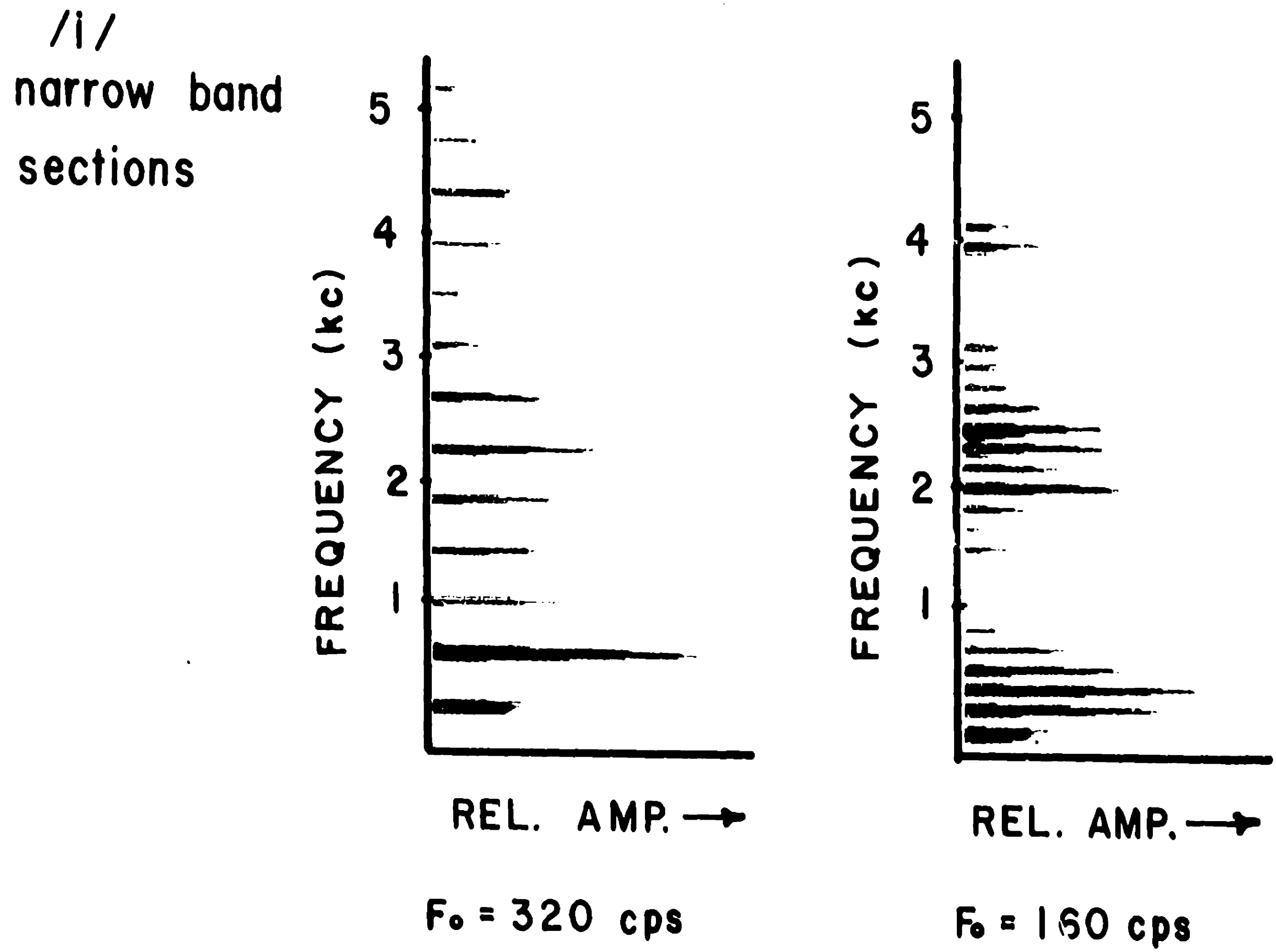
1. As a first approximation this is true. Vowel quality does change for extreme shifts in the fundamental frequency (Slawson, 1965).



SAME VOWEL AT DIFFERENT FUNDAMENTAL FREQ.

Fig. 2

> ...the correctness of the view which regards the glottis and the vocal cords which form the immediate boundaries of the glottis as the essential source of the voice; the trachea as the "wind chest" of the wind instrument, and the vocal tube in front of the glottis...and the air passages thence upwards to the openings of the mouth and nostrils, as the tube of a musical instrument by which the sound may be modified, but not generated (Muller, 1848, p. 1003).

This viewpoint is essentially correct for the production of vowels, liquids and glides, where the glottal sound source provides the primary excitation of the vocal tract. For many of the consonants, e.g., /f/, /p/, /s/, the vocal tract is excited by the noiselike energy generated by air turbulence at constrictions[1]. (Fant, 1960).

The larynx is a complex structure of several cartilages linked by a complicated system of muscles, ligaments and membranes. The larynx sits on top of the trachea, or windpipe, which connects the lungs to the larynx. The cricoid cartilage, which is shaped like a signet rings is one of the primary elements of the larynx. It is attached to the top of the trachea. Its narrow end faces the front of the neck. Two smaller cartilages called the arytenoids are flexibly attached by ligaments to the cricoid cartilage. The two arytenoids face each other since they are each attached to the opposite sides of the cricoid cartilage towards its rear (Fig. 3). One arytenoid is attached to each side of

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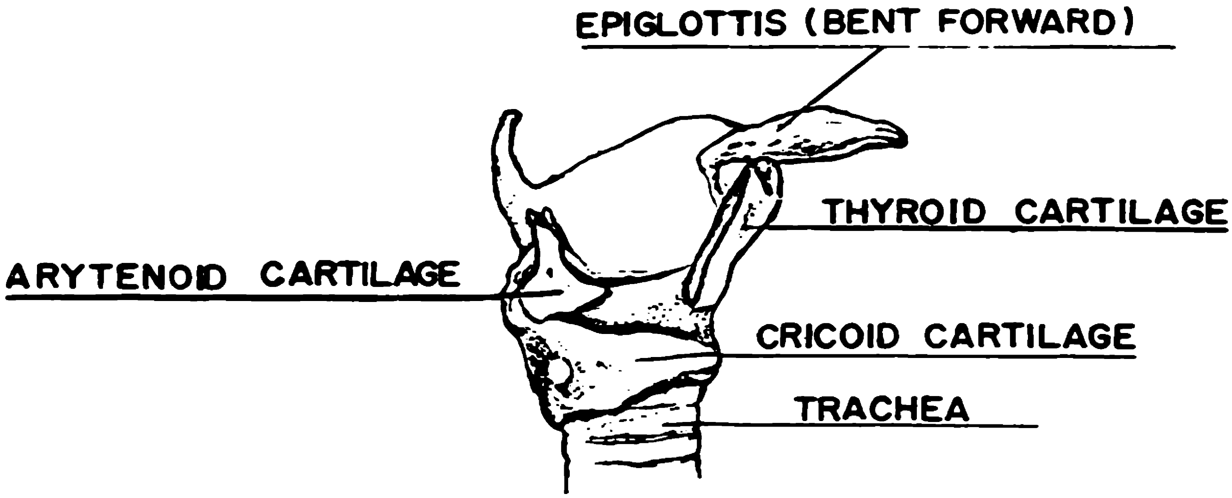
1. Other consonants are generated by means of the glottial source and turbulent energy, e.g., /z/; other consonants are generated by means of the quasi-periodic excitation of the glottal source, e.g., /m/.

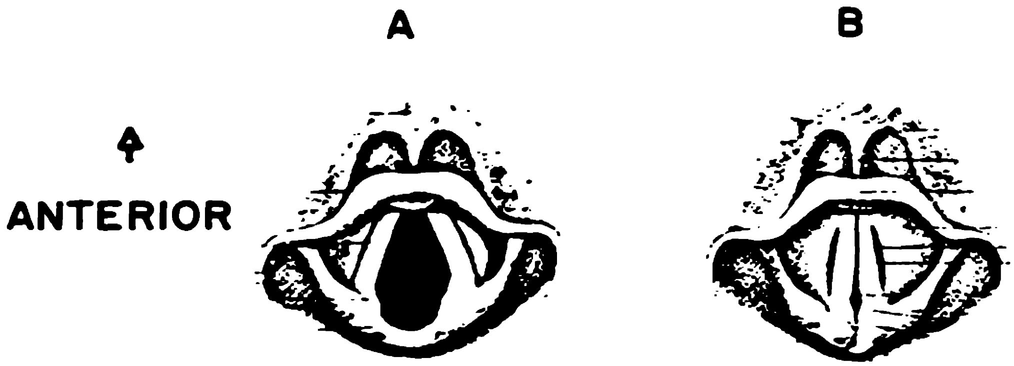


LATERAL VIEW OF LARYNX
— PART OF RIGHT THYROID REMOVED
(AFTER PIERSOL, 1907)

Fig. 3

the upper surface of the cricoid cartilage. One larger cartilage, the thyroid, is flexibly attached to the front of the cricoid. The vocal cords, each of which consists of muscular tissue (the vocalis muscle) and a ligament, extend from the thyroid cartilage to the arytenoid cartilages. One end of each vocal cord's ligament is attached to the free end (vocal process) of each arytenoid. The vocalis muscles lie beside the ligaments and extend to the thyroid cartilage. They form the body of the vocal cords. In Fig. 4 photographs looking down at the vocal cords through a laryngeal mirror are reproduced. (A laryngeal mirror is a small 45 degree mirror which may be placed at the back of the mouth against the soft palate so that the vocal cords can be examined under suitable conditions.) The arytenoid cartilages are actually embedded in the vocal cords. The opening between the vocal cords is called the glottis. The arytenoids form the margin of the rear or posterior portion of the glottis which is the widest part of the opening during respiration. The anterior portion of the glottis, that part towards the front of the neck, is bounded by the two vocal ligaments. The anterior portion of the glottis which is bounded by the flexible vocal ligaments is the portion of the glottis whose motions are usually responsible for phonation.

A complex set of muscles interconnnects the arytenoids, thyroid and cricoid cartilages. The cricothyroid muscles, for example, can stretch the vocal cords. The interarytenoid muscles can draw the arytenoid cartilages, which support the vocal cords, together . The posterior cricoarytenoids can separate the arytenoid cartilages. For our purposes



LARYNX SEEN THROUGH LARYNGEAL MIRROR

A – GLOTTIS OPEN B – GLOTTIS CLOSED

(AFTER PIERSOL, 1907)

 Fig. 4

it is sufficient to know that the laryngeal muscles can position the vocal cords within the larynx so as to enlarge or decrease the size of the glottal opening. The laryngeal muscles also can adjust the tension of the vocal cords. The thickness, or cross section of the vocal cords, is also a function of the tension applied to the vocal cords. At low tensions the cross section is comparatively large (about 2mm for an adult male) but as tension increases the vocal cords stretch and become thinner.

C - Some Observations of Laryngeal Activity

Johannes Muller first noted that the frequency at which the vocal cords vibrate is a function of both the tension of the vocal cords and the magnitude of the subglottal air pressure. Muller never saw the vocal cords operate during normal phonation since the laryngeal mirror was not invented until 1854 (Garcia, 1855). His remarkable analysis of the larynx was instead obtained by means of experiments in which he applied tensions to the muscles of larynxes excised from cadavers while he blew air through them. He formed hypotheses concerning the control of the larynx and tested these hypotheses by generating sound with an excised larynx. Muller's account of his experimental procedure is quite straightforward.

> "Experiments on the separated larynx are in first attempts attended with extreme difficulty; all the parts are movable, and it is not at first apparent how the uniform tension and the uniform fixed position of the cartilages, so necessary for attaining any degree of accuracy in the experiments, can be given; and at the same time how the position once given can be made capable of alternation as the experiment may require. With a little contrivance, however, these objects can be accomplished. The first thing to be done is to obtain a fixed point in the larynx. The anterior wall is

naturally mobile in the greater part of its extent, and the posterior wall at its upper part. The thyroid cartilage can be moved towards the cricoid cartilage, and the arytenoid cartilages also; and by either movement the vocal cords are rendered tense. The arytenoid cartilages being the most movable parts, and those by the wrong position of which an error in the experiments might most easily be caused, my first aim is to fix them. With this view I pass an awl or pin transversely through the base; doing this with very great care, in order that, when afterwards extended, the two vocal ligaments may have an equal degree of tension; and also making the transfixion in such a manner that, when the two cartilages are approximated on the pin, the anterior processes at their base may touch each other. The larynx, with a small portion of the trachea attached, being thus prepared, is fixed, with its posterior wall downwards, to a board by means of the cricoid cartilage; and the pin which transfixed the arytenoid cartilages (these being put into any position or degree of approximation that may be wished) is also firmly tied down to the board. The posterior wall of the larynx being thus fixed, any degree of tension required may be given to the vocal cords by exerting traction on the anterior wall formed by the thyroid cartilage. To avoid the resistance which might be offered by the attachment of the thyroid to the cricoid cartilage, it is well carefully to separate their connections. As a means of drawing away the thyroid cartilage from the posterior wall of the larynx, and thus of making tense the vocal ligaments, I fix a thin cord to the angle of the thyroid cartilage immediately above the attachment of the ligaments, and passing it over a pulley connect with it a scale; by putting different weights into this scale I can accurately regulate the tension exerted. The epiglottis, superior ligaments of the glottis, the ventricles of the larynx, the capitula laryngis of Santorini, the ligaments aryteno-epiglottica, and even the upper portion of the thyroid cartilages, not being essential to the production of the vocal sounds, are all cut away to render the vocal cords and aperture of the glottis more easily visible. Besides, it is necessary to determine first what can be effected by the vocal cords alone, before investigating the influence of the superior part of the cavity of the larynx. A wooden tube for the experimenter to blow through is inserted into the portion of trachea left attached to the larynx."

Muller made many detailed observations of the larynx and we shall quote only a few of the more relevant ones.

"Vocal sounds can be produced not only when the lips of the glottis are separated by a narrow interval, but even when they are quite in contact especially if the chordes vocales are much relaxed...." (p. 1010)

"The height of the notes is regulated by the length and tension of the vocal cords. The notes are, caeteris paribus, lower in pitch in proportion to the length of the glottis; but deep notes may be obtained from a glottis much shortened by its lips being pressed together with forceps, if the vocal cords be at the time relaxed; and a very long glottis will yield high notes, if the chordae vocales have a great deal of tension." (p. 1011)

"Two perfectly distinct series of tones can be produced in a larynx separated from the body...one of these series of tones has the most perfect resemblance to the tones of ordinary voice; the notes of the other series are generally higher than those of the former, and are the highest that can be produced; they are in every way similar to the falsetto notes. When the vocal cords have a certain degree of tension, both these kinds of notes may be produced; sometimes one kind, and sometimes the other kind is heard. A certain tension of the cords is always productive of notes with the falsetto tone, whether the air be blown through the glottis forcefully or feebly. When the vocal ligaments are much relaxed, the tones are always those of ordinary voice, however feebly or forcefully we blow. If a slight tension of the ligaments is maintained, it depends on the manner of blowing whether the note be of the ordinary tone or falsetto; (the falsetto note being most easily produced by blowing very gently:) and the two different notes thus produced may be very distant from each other in the musical scale, even as much as an octave." (p. 1013)

"There are other modes of producing high notes, without increasing the tension of the vocal ligaments so much as to cause them to give out falsetto notes. One is to blow with greater force, by which means the notes may without difficulty be raised through a series of semitones the extent of a 'fifth'...." (p. 1014)

These observations have been quantitatively confirmed in many subsequent experiments. Van den Berg (1954, 1956, 1957, 1958, 1960) has, for example, replicated Muller's experiments with excised larynxes using modern methods that permit a better approximation to the real situation. High speed motion pictures of the human larynx during normal phonation have confirmed Muller's explanations regarding the basic pattern of activity during phonetion and the difference between the falsetto and normal registers (Farnsworth, 1940; Timcke, von Leden and Moore, 1958; Moore and von Leden, 1958; von Leden and Moore 1960; Soron and Lieberman, 1963). Acoustic analyses of the speech signal have quantitatively confirmed that fundamental frequency increases with increased vocal effort (Denes, 1959; Harris and Weiss, 1963; Draper, Ladefoged and Whitteridge, 1959). Ladefoged (1961), for example, monitored the subglottal air pressure in normal subjects during phonation. He showed that the fundamental frequency rises linearly as the subglottal air pressure rises[1].

There have been many other facts noted about the activity of the larynx. The "opening quotient", for example, was defined (Farnsworth, 1940) as the fraction of each fundamental period that the glottis is open. We know that the opening quotient varies greatly during phonation. In particular it decreases as the degree of vocal effort increases (Timcke, von Leden, and Moore, 1958). Acoustically, this means that the high frequency content of the glottal source should increase (Flanagan, 1958) and it is no great suprise to find that independent acoustic analyses confirm that the high frequency content of speech increases with increased vocal effort (Harris and Weiss, 1963).

Other independent experiments have determined the glottal excitation function by accounting for the effects of the upper respiratory tract

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1. The relationship between intensity and pitch was know to ancient Greek science. Archytas of Tarentum, a contemporary of Plato, notes, "So it is with sounds. Those that are projected by an intense breath are loud and sharp, while those projected with weak breath are soft and low." (Cohen and Drabkin, 1958).

(tongue, lips, jaw, nose etc.) on the acoustic signal radiated from the speaker's lips. These experiments use a technique of inverse filtering in which the effects of formants are removed by anti-resonances (Miller, 1956; Fant, 1961; Holmes, 1963). These studies, which demonstrate the extent to which the output of the glottis may vary, also show that the opening quotient decreases as the intensity increases.

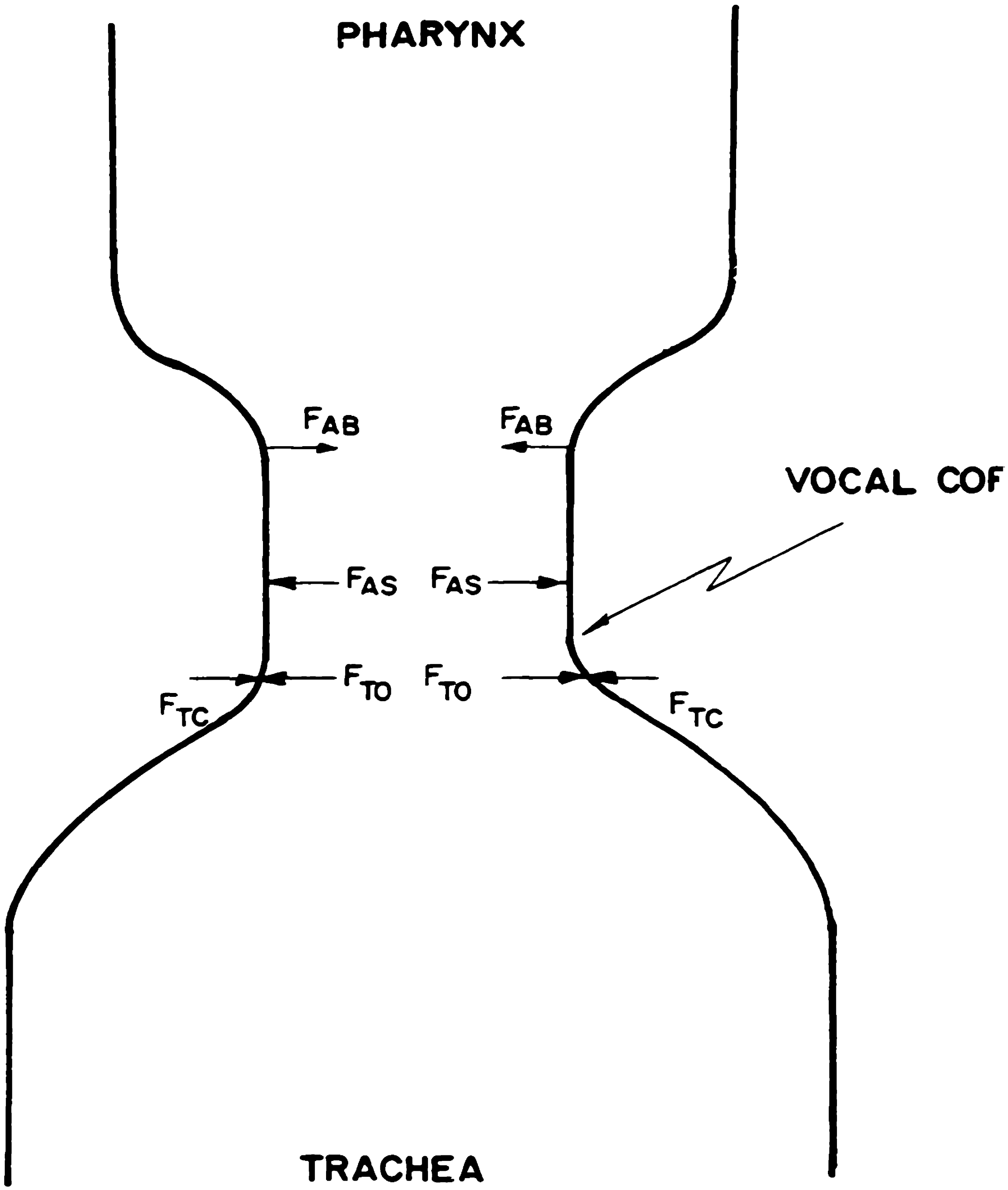
D - The Myoelastic - Aerodynamic Theory of Phonation

Though the activity of the larynx has been studied in detail for more than a century there still remains a great deal of confusion regarding the mechanism of phonation. We certainly do not know all that we might want to know about the larynx. However, much of the confusion is unwarranted and stems from the phenomenological approach of many studies. Experimental data is often not related to any explicit theory of phonation. This is often true of modern studies in which careful observations of the larynx in vivo are made. Muller had to formulate specific hypotheses regarding the mechanism of phonation since he had to manipulate the excised larynxes to produce sounds. Muller, for example, knew that tensioning the vocal cords would produce a rise in the fundamental frequency, all other things being constant. When the larynx is observed during normal phonation by means of a laryngeal mirror it is often difficult to infer causal relationships especially when the experimenter has no clearly formulated model. We will briefly outline, in a qualitative form, a theory of laryngeal activity, the myoelastic - aerodynamic theory of phonation. This theory, which derives from Muller, owes much to the recent work of van den Berg.

With the exception of a few experiments that we will discuss later, it is consistent with our present knowledge and relates many observations that are superficially incompatible.

As Stevens (1964) succinctly notes, "The vibration of the vocal folds is maintained through a rapid alternation of forces in opposite directions...." In order for phonation to take place the vocal cords must first be brought towards each other from the open position that is maintained during quiet breathing. The laryngeal muscles bring the vocal cords to this position which we shall call the "phonation neutral position". This closing motion seems to be comparatively slow in comparison to the rate at which the vocal cords move during phonation. Observations from high speed laryngeal motion pictures of three male speakers, for example, show that it takes about 100 msec for the vocal cords to move inwards from their open respiratory position (Soron and Lieberman, 1963). During phonation the vocal cords will stay at their neutral position if the air flow from the lungs is interrupted (Rubin, 1960).

Two types of forces act on the vocal cords. The aerodynamic and aerostatic forces can act to displace the vocal cords from their phonation neutral position. The tissue forces always act to restore the vocal cords to their neutral position. In Fig. 5 a schematic diagram of the vocal cords and these forces is presented. Note that the neutral position of the glottis is open. This diagram portrays the vocal cords after they have moved inwards from the open breathing position but the glottis is not completely closed. The force exerted



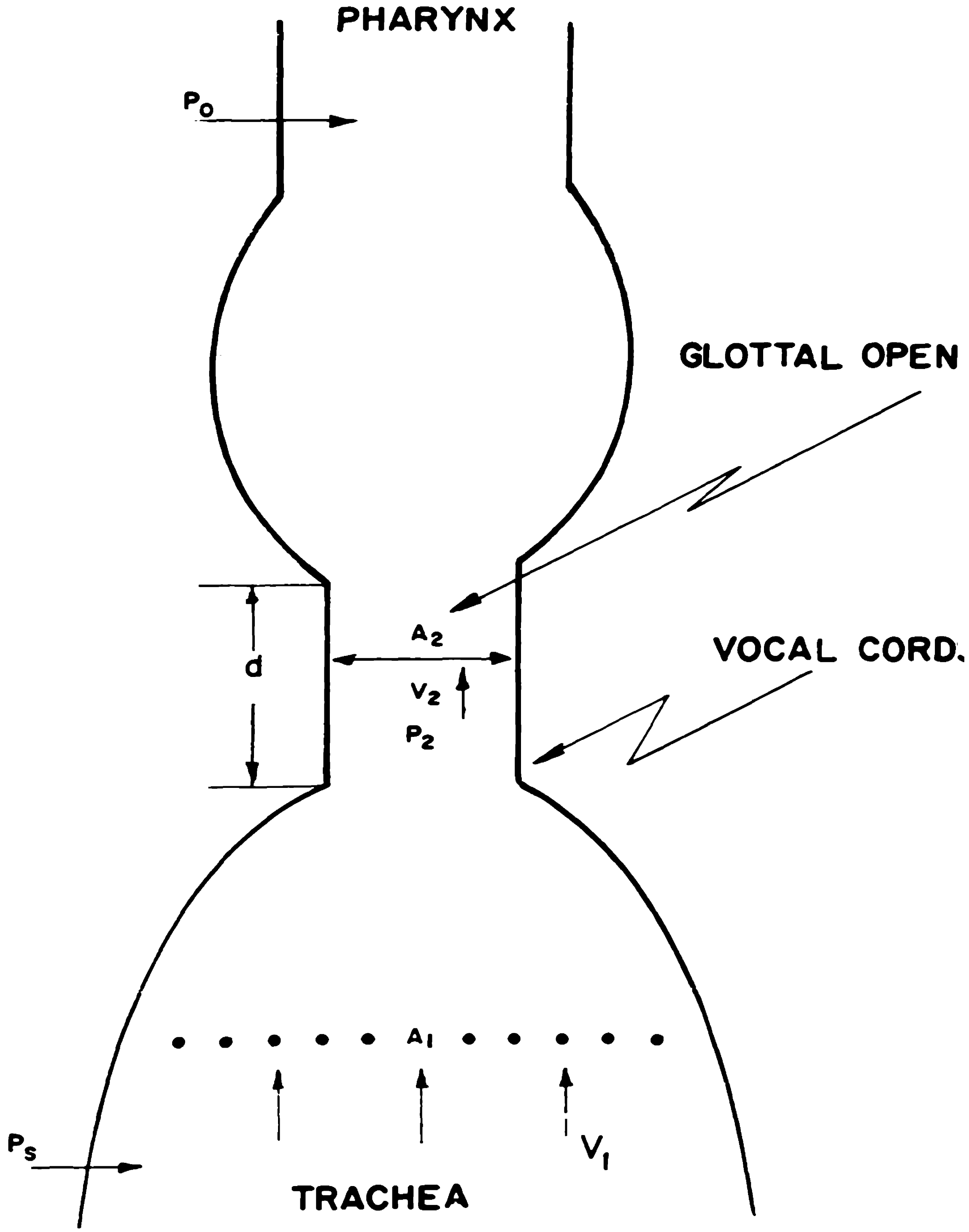
SCHEMATIC REPRESENTATION OF VOCAL CORDS
(SIDE VIEW, OPEN REST POSITION)

Fig. 5

by the positive subglottal air pressure on the vocal cords is represented by the vector F_{as}. When the glottis is closed or almost closed this force acts to displace the vocal cords outwards from their neutral position. The vector F_{ab} represents the Bernouilli force that is a consequence of the negative pressure created in the glottis by the high velocity air flow. The vectors F_{to} and F_{tc} represent the forces due to the tension of the vocal ligaments that act to restore the vocal cords to their neutral position. We will briefly discuss these forces before we discuss their interaction during phonation.

The aerostatic force, F_{as}, arises from the positive subglottal air pressure that is exerted against the vocal cords. This force reaches its maximum when the glottis is completely closed since the positive subglottal air pressure presumably acts upon the maximum surface area when the vocal cords are completely closed. The subglottal air pressure is usually constant to within 5 percent during each glottal opening and closing cycle. The maximum subglottal air pressure, however, occurs when the glottis is most constricted (van den Berg, 1956), which probably enhances this effect.

The Bernouilli effect which generates force F_{ab} is a special case of the general principle of the conservation of energy. Suppose that the air flow through the glottal constriction in Fig. 6 can be approximated by the uniform, frictionless flow of an incompressible fluid. The rate at which the fluid flows across section A_1 in Fig. 6 is equal to $A_1 V_1 \rho$ where ρ is the density of the fluid. A_1 is the cross sectional area of the trachea, and V_1 the velocity of the fluid.



SCHEMATIC REPRESENTATION OF VOCAL CORDS

Fig. 6

If the stream is steady, the same mass must travel per unit time through the constricted portion of the pathway so that,

$$(1) \quad A_1 V_1 \rho = A_2 V_2 \rho$$

where A_2 and V_2 are the cross sectional area and particle velocity at the glottal constriction. Since the density ρ is constant, $A_1 V_1 = A_2 V_2$.

Let us consider the rate at which energy is transferred across sections A_1 and A_2. The mass being transferred across A_1 per unit time is $A_1 V_1 \rho$. The kinetic energy being transferred across section A_1 is therefore,

$$(2) \quad 1/2 \ (A_1 V_1 \rho)(V_1^2).$$

The rate at which work is being done by the fluid across section A_1 is equal to the force exerted by the fluid across A_1 which is $A_1 P_s$, where P_s is the subglottal air pressure multiplied by the particle velocity V_1. The total rate at which mechanical energy is being transferred across section A_1 is therefore,

$$(3) \quad 1/2 \ A_1 \rho V_1^3 + A_1 P_s V_1 .$$

if we neglect the potential energy due to the force of gravity. The rate at which energy is being transferred across section A_2 is similarly

$$(4) \quad 1/2 \quad A_2 \rho V_2^3 + A_2 P_2 V_2 \; .$$

Since energy is being conserved in this system,

$$(5) \quad 1/2 \quad A_1 \rho V_1^3 + A_1 P_s V_1 = 1/2 \quad A_2 \rho V_2^3 + A_2 P_2 V_2$$

but $A_1 V_1 = A_2 V_2$ so that

$$(6) \quad 1/2 \rho V_1^2 + P_s = 1/2 \rho V_2^2 + P_2 .$$

The particle velocity in the glottal constriction, V_2 will be larger than the particle velocity in the pharynx V_1 since,

$$V_2 = \frac{A_1 V_1}{A_2} \quad ,$$

where A_2 is the cross sectional area of the constriction. The kinetic energy of the fluid in the constriction,

$$1/2 \rho \left(\frac{A_1 V_1}{A_2} \right)^2 \quad ,$$

will therefore be higher in the constricted portion of the air passage. The potential energy must decrease as the kinetic energy increases since the sum of the kinetic and potential energies must remain constant. What this means physically is that the pressure of the fluid in the constriction, P_2, decreases.

The pressure in the constriction, P_2, thus may fall below atmospheric pressure as the cross section of the constriction decreases. If the walls of the air passage were flexible they would tend to be "sucked" together by the pressure differential between P_2 and the atmospheric pressure which is maintained on the outside of the body. The pressure differential would become still greater as the walls collapsed and A_2 becomes smaller since V_2 would become larger as A_2 decreased. The flow of air through the glottis is, however, not frictionless and the resistance of the glottis increases as it becomes more constricted (van den Berg, Zantema, and Doornenbal, 1957) so the Bernouilli Force F_{ab} increases only up to a certain point as the glottis becomes smaller. Some of the other assumptions regarding incompressibility and laminar flow are also only approximations[1] (Flanagan, 1958). However, the idealized case predicts the correct qualitative effects.

The static tissue forces, F_{to} and F_{tc}, arise from the stretching of ligaments and muscles. The magnitude of these forces would be directly proportional to the displacement if the muscles and ligaments behaved like idealized springs, but this may not be the case. However,

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1. Flanagan points out that the incompressibility assumption is reasonably valid, "...if the dimensions of the oriface are small compared with the wavelength of an acoustic disturbance in the medium, and if the mean velocity is much smaller than the speed of sound...."

it seems safe to say that the magnitude of these forces increases as the vocal cords are displaced from the phonation neutral position.

E - Phonation in the Chest Register

Let us consider how these hypothetical forces might interact during normal phonation in the chest register.

The "chest register" is the range of fundamental frequencies that a person normally employs during speech. Functionally, the chest register involves the Bernouilli Force in the operating cycle. The vocal cords are relatively lax and they have an appreciable thickness (dimension d in Fig. 6) so that the air flow through the glottis involves a constricted passage in which a pressure drop can occur.

During breathing the glottal opening is quite wide. The posterior portion of the glottis is open wide (Fig. 4). Before phonation starts the arytenoid cartilages swing inwards, closing the posterior portion of the glottis and bringing the two vocal cords near each other.

The subglottal air pressure then builds up. If the vocal cords' "neutral" position at the onset of phonation is closed, F_{as} initially blows them apart. F_{as} is opposed by the static tissue force F_{tc} and the Bernouilli force, F_{ab}, which begins to act as the airflow starts through the glottis. The static air pressure force, F_{as}, decreases as the glottis opens while the tissue force, F_{tc}, increases.

The opening motion proceeds until F_{as} is counterbalanced by the sum of the Bernouilli and the static tissue forces and the vocal cords start to move inwards. As the vocal cords move inwards the Bernouilli force, F_{ab}, increases to a point, as the glottal opening decreases.

The Bernouilli force, of course, ceases abruptly when the vocal cords close since the air flow stops momentarily. The static pressure force, F_{as}, then reopens the glottis and the cyclic activity continues.

If the vocal cords' "neutral" position on the onset of phonation is open, an additional component of the static tissue force is present, F_{to}, which opposes movements that tend to move each cord inward from its neutral position. The operating cycle is similar to the simpler case where phonation starts with the vocal cords closed except that the initial movement is inwards (Farnsworth, 1940; van den Berg, et.al,1957; Soron and Lieberman, 1963). The arytenoid cartilages bring the vocal cords together from their open breathing position but they do not completely close the glottis. The subglottal air pressure, P_s, builds up and air starts to flow through the glottis. The airflow through the constriction results in the Bernouilli force, F_{ab}, which initially draws the vocal cords together. The Bernouilli force is opposed by the static tissue force, F_{to}. As the glottis is narrowed the Bernouilli force increases faster than the opposing tissue force so that the cords close[1]. When the vocal cords close the Bernouilli force ceases abruptly and the static air pressure force, F_{as}, which is at its maximum, and the static tissue force, F_{to}, open the glottis. The glottis continues to open as the vocal cords move past their neutral position. The static tissue force, F_{tc}, then opposes the opening movement and the vocal cords return to their neutral position and the cycle repeats.

We have grossly oversimplified many aspects of the dynamic operation of the vocal cords. There are, for example, energy losses that tend to

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1. If the tissue forces are greater than the Bernouilli force the vocal cords will not close.

damp the vibrations of the vocal cords. These energy losses arise from the inelastic collision of the vocal cords, the flexing of muscular tissue, and the aerodynamic resistance of the glottis (van den Berg, 1958; von Leden and Moore, 1960). When, for example, certain types of pathologic masses increase the losses caused by the collision of the vocal cords, they have marked effects on glottal activity (Lieberman, 1963).

F - The Falsetto Register and Mechanisms for Intensity Change

The falsetto register illustrates how the laryngeal musculature can modify the basic mode of operation of the vocal cords by adjusting the effective mass that vibrates, increasing the magnitude of the static tissue forces and decreasing the importance of the aerodynamic forces (Muller, 1848; Pressman and Kelemen, 1955; van den Berg, 1960; Proctor, 1964). In the falsetto register the laryngeal muscles stretch the vocal cords. Dimension d in Fig. 6 becomes quite small and the vocal cords are stretched. The Bernouilli force, F_{ab}, in Fig. 5 therefore decreases since there must be a relatively long constricted passage in order to generate the negative air pressure because of air resistance effects (van den Berg, et. al., 1957). The effective mass that vibrates also decreases because of the increased tension of the laryngeal muscles and the static tissue forces obviously are greater than they are in the chest register.

The behavior of the larynx is quite different in the chest and falsetto registers. Isshiki (1964), for example, noted that for low and medium fundamental frequencies (the chest register) the sound pressure level goes up as the subglottal pressure increases but the flow rate remains relatively constant. We may reasonably infer that the opening quotient decreases as the aerodynamic and aerostatic forces F_{ab} and F_{as} increase with the increasing subglottal pressure. This would raise the sound pressure level while the flow rate remained relatively constant. In contrast, Isshiki notes that in the falsetto register both the sound pressure level and the flow rate rise as the subglottal air pressure rises. We may reasonably infer that for the falsetto register the opening quotient does not decrease as the subglottal air pressure increases.

Isshiki's study shows how the lack of an explicit model of phonation can lead to inappropriate conclusions from data that was obtained by extremely well planned experimental procedures. Isshiki notes that in the chest register the opening quotient must decrease as the subglottal air pressure increases since the flow rate does not change though the intensity increases. He states that, "It appears that in order to keep the glottis closed longer (smaller opening quotient), withstanding the increasing pressure below the glottis, greater force to close the glottis is required." We know that the Bernouilli force, which tends to close the glottis, increases as the subglottal air pressure increases (van den Berg, 1957; Timcke, von Leden, and Moore, 1958). Isshiki, however, neglects the Bernouilli force in his study. He seems to believe that the only force that can close the vocal cords is the tissue force (F_{tc} in Fig. 5) and he therefore concludes that "...at very low pitch, intensity is controlled mainly by the larynx while at very high pitch (Falsetto), the expiratory muscles may be more important in controlling intensity." That is, special laryngeal gestures always control intensity in the chest register. This conclusion does not follow from Isshiki's observations. Isshiki's observations seem to support the previous indirect observations of van den Berg, Muller and Timcke, Moore and von Leden, which suggest that the decrease in the opening quotient in the chest register may be a direct consequence of the increased subglottal air pressure. The lack of an explicit model for laryngeal activity in Isshiki's study obscures this relationship.

Both our qualitative model and experimental observations thus indicate that the opening quotient may decrease as a direct consequence of an increased subglottal air pressure without any adjustment of the laryngeal muscles. However, we do not want to imply that the laryngeal muscles can not independently change the opening quotient. Our model, for example, indicates that the force with which the glottis closes will increase if the vocal cords are fully approximated in the phonation neutral position. The only component of the static tissue force that will act will be F_{tc} and the mean value of the Bernouilli force, F_{ab}, will also tend to be larger than it would be if the glottis were open in the phonation neutral position since the Bernouilli force increases as the glottal opening decreases.

Several independent experimental studies have shown that the opening quotient can be independently adjusted by the laryngeal muscles. Van den Berg (1958), for example, demonstrated this effect in his studies with excised larynges. Mead, Proctor, and Bouhuys (1965), in experiments where the subglottal air pressure was monitored during phonation, noted that the sound pressure level sometimes increased though the subglottal pressure remained constant or decreased. The opening quotient apparently changed by means of the activity of the laryngeal muscles. Katsuki (1950) in electromyographic studies on the vocal muscle of the hemilaryngectomized found that increased action potentials were observed in that muscle as the intensity of the sound increased. Fink (1962) in an independent study obtained results that supported this finding. On the other hand Faaborg-Anderson (1957) found no significant difference in the action potentials of the intrinsic laryngeal muscles as the intensity of the sound increased. These seemingly contradictory results are explicable in terms of our model, which predicts that the intensity of the speech signal radiated from the speaker's lips can be increased by means of adjustments of the laryngeal muscles which decrease the opening quotient, or by means of increases of the subglottal air pressure which also reduce the opening quotient. Both mechanisms probably act concurrently during normal phonation. High speed motion pictures of the vocal cords, for example, show that phonation can occur at virtually any degree of vocal effort at almost any fundamental frequency (Farnsworth, 1940; Timcke, von Leden, and Moore, 1958; Moore and von Leden, 1958; von Leden and Moore, 1960; Soron and Lieberman, 1963). It therefore would not be surprising to discover many intermediate cases and much of the past controversey on the number of vocal registers (van den Berg, 1960), chest, head, falsetto, etc., may reflect these intermediate adjustments.

G - Summation - Laryngeal Activity

In short, the larynx consists of a number of cartilages, connected with muscles and ligaments, which by their relative positions change the tension, position and effective vibrating mass of the vocal cords. The larynx can be considered as a mechanical system whose activity is regulated by comparatively slow changes in the tension of its muscular system. The mechanical damping factor of this system is established by the accelerating masses of the vocal cords, the tensions of the muscular system, the air flow resistance through the glottis, and the inelastic collision of the vocal cords. The acoustic output of the larynx is determined by the air pressure against the glottis and the muscular adjustments.

The theory of laryngeal activity that we have described has come to be known as the myo-elastic aerodynamic theory of phonation. The activity of the larynx is regulated by the slowly varying tensions of its muscular system and the aerodynamic forces that result from the motion of air through it. Other theories have been proposed at various times since Ferrein compared the vocal cords to vibrating strings in 1741. Recently Husson (1950, 1955, 1957) proposed a new theory, the neuro-chronaxic theory. Husson assumed that a train of neural pulses was transmitted from the brain to the laryngeal muscles and that the vocalis muscle opened and closed the glottis in synchronism with this pulse train "coup par coup". Husson's theory is not, however, consistent with the vast body of experimental evidence that we have regarding the activity of the larynx. Other investigators, moreover, have been unable to replicate the particular experiments on which Husson based his theory (van den Berg, 1954, 1958; Rubin 1960).

H - The Subglottal System and Respiration

The main function of the subglottal system is gas exchange: to transfer oxygen into and CO_2 out of the blood stream. The trachea extends from the larynx and bifurcates into branches which supply each lung. The normal rate of breathing during quiet wakefulness is about 16 to 18 cycles per minute. Each expiration therefore lasts about 2 to 3 seconds[1]. A volume of about 500 cc (the Tidal volume) is exchanged on each breath. An additional reserve of about 1500 cc (for an adult male) can also enter into the respiratory cycle (Landois, 1923).

The pattern of muscular activity during respiration is rather complex. During inspiration the inspiratory muscles essentially expand the volume of the lungs and the subglottal air pressure, P_s, falls below atmospheric pressure. The inspiratory muscles have to overcome the elastic recoil forces that tend to collapse the lungs. During expiration the elastic recoil forces act on the lungs and expel air. The expiratory muscles can augment the elastic recoil force during expiration to expel air. The inspiratory muscles can also act during expiration to oppose the elastic recoil force and reduce the subglottal air pressure. The elastic recoil force is a function of the volume of the lungs. It is largest when the lungs are expanded to their maximum capacity (Agostoni and Mead, 1964). In the absence of phonation the inspiratory and expiratory phases of phonation are nearly equal in their time and flow patterns. During rest inspiration takes

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1. It is interesting to note that the duration of a normal sentence usually does not exceed two seconds, which matches this ventilation rate.

slightly less than half the cycle. During moderately heavy exercise the two phases are more nearly equal. Mead and Agostoni (1964) note that, "...the inspiratory muscles continue to act well into the expiratory phase, opposing the static recoil of the lungs and chest wall and, as it were, letting the system down gently." In Fig. 7 volume and pressure events during spontaneous breathing at rest are presented (c.f. Chapter 3). The volume of the air in the lungs and the air pressure in the lungs are presented (c.f. Mead and Agostoni, op. cit. p. 422). Since most of the pressure drop in the respiratory system takes place at the larynx (Proctor, 1964; Negus, 1949), the subglottal air pressure, P_s, also gradually rises and falls as the volume of air in the lungs rises and falls.

During phonation several deviations take place from the pattern of activity characteristic of quiet non-speech activity. The duration of a single expiration may be extended to as much as 40 seconds by using the reserve air capacity and by husbanding air (Meader and Muyskens, 1962). The average rate of breathing may decrease to 8 expiratory-inspiratory cycles per minute and inspiration may occur in a far shorter interval of time relative to the time taken up in expiration. Lenneberg (1964), notes that inspiration may be reduced to 0.15 of the total breath cycle. In Fig. 8 the volume of air in the lungs and the subglottal air pressure have been plotted for a male talker who was reading the sentence, "Joe ate his soup."[1] Note that the subglottal air pressure

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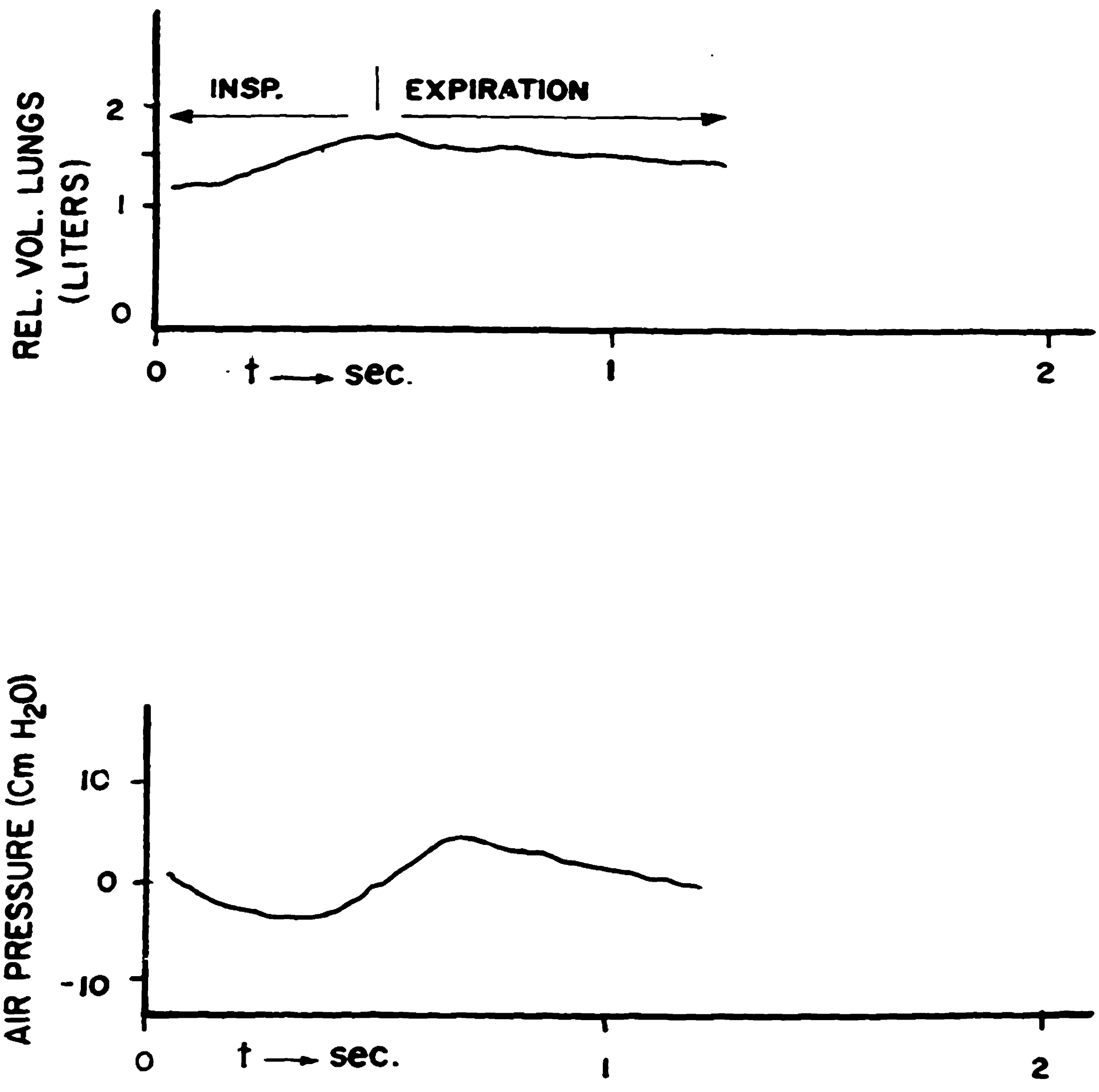
1. The procedure used to obtain this data is discussed in Chapter 3.



SUBGLOTTAL AIR PRESSURE IN Cm. H_2O AND RELAT VOLUME OF AIR IN THE LUNGS IN LITERS DURING QUI RESPIRATORY ACTIVITY.

Fig. 7

curve does not gradually fall. The subglottal air pressure instead remains relatively steady until the end of the expiration, where it abruptly falls. The inspiratory muscles are innervated to oppose the elastic recoil force when the lungs are full of air, and gradually lessen their activity as the volume of air in the lungs decreases so that a relatively constant subglottal air pressure is maintained (Bouhuys, Proctor, and Mead, 1965). The expiratory muscles are brought into play when the volume of air in the lungs falls to the point where the elastic recoil force alone is insufficient to maintain the desired subglottal air pressure. A relatively constant subglottal air pressure can thus be maintained by bringing different muscles into play as the volume of air in the lungs decreases. During singing and the production of unemphatic, short declarative sentences speakers tend to maintain a steady subglottal air pressure until the end of the expiration, where the subglottal air pressure abruptly drops. The subglottal air pressure has to fall abrutply at the end of the expiration since the air pressure in the lungs must be below atmospheric pressure during inspiration.

Momentary peaks in the subglottal air pressure occur during speech and it is possible to associate these peaks with phonetic promience[1]. It is, however, impossible to attribute these peaks to the activity of specific respiratory muscles without knowing the volume of air in the speakers' lungs. Stetson (1951) formulated a simple model of respiratory activity in which he assumed that the mean subglottal air

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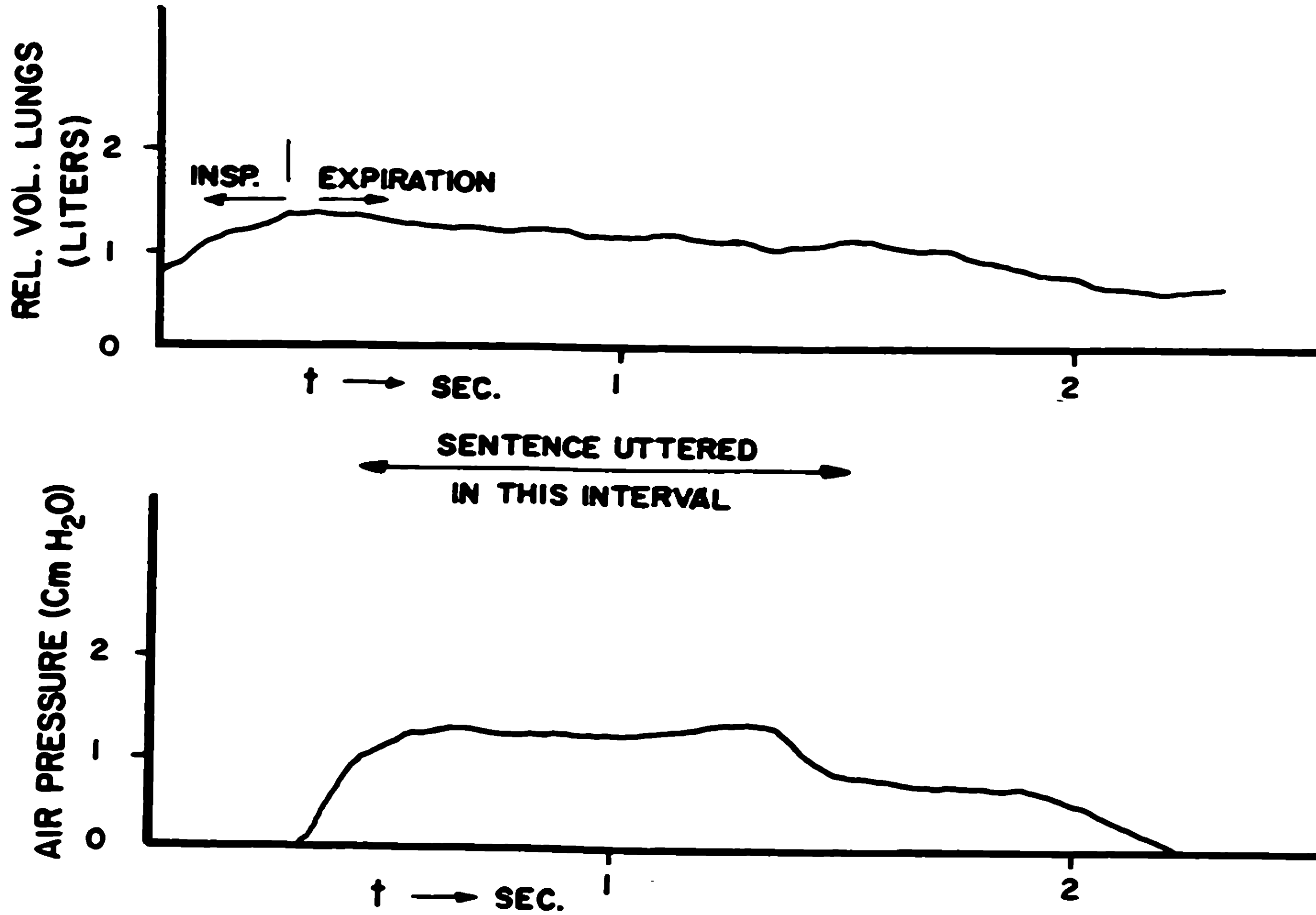
1. The analysis of phonetic promience and linguistic stress will be presented, in detail, in later chapters.



RELATIVE VOLUME OF AIR IN LUNGS AND SUBGLOTT
AIR PRESSURE DURING THE PRODUCTION OF SPEECH

(A SHORT, DECLARATIVE SENTENCE. SAME SPEAKER AS FIG. 7.

Fig. 8

pressure that is maintained throughout expiration is due to the activity of the abdominal muscles while the internal intercostal muscles produced additional separate pulses of air for each syllable. These assumptions are, however, incorrect[1].

I - The Breath-Group

The principal point that we want to make with regard to respiration and speech is that speech is organized in terms of the expiratory air flow from the lungs. Expiration during speech apparently involves the coordinated activity of several groups of muscles in the chest and abdomen. At the end of each expiration the flow of air out from the lungs ceases and the subglottal air pressure abruptly falls. As we noted before, the fundamental frequency of phonation is directly proportional to the subglottal air pressure. The other parameters that can affect the fundamental frequency of phonation are the tension and the phonation neutral position of the vocal cords. If the tension of the laryngeal muscles remains constant then the fundamental frequency of phonation will fall at the end of the expiration.

It is a universal of human speech that, except for certain predictable cases, the fundamental frequency of phonation and the acoustic amplitude fall at the end of a sentence. The physiological basis of this phenomenon may be a condition of least articulatory control. If the tension of the laryngeal muscles is not deliberately increased at the end of expiration where the subglottal air pressure falls, the fundamental frequency of phonation will also fall. One can

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1. c. f. Chapter 7 for a discussion of Stetson's Motor Phonetics.

see that, in some sense, less "effort" is expended in the articulatory control problem if the laryngeal tension is not deliberately increased precisely when the subglottal air pressure falls. The speaker simply maintains about the same laryngeal tension throughout the entire expiration. He does not bother to increase the laryngeal tension to counter the falling subglottal air pressure. This pattern of articulatory activity thus produces a prosodic pattern that is characteristic of the ones that are used to delimit the boundaries of unemphatic, declarative sentences in normal speech. We will term this pattern of articulatory activity the "archetypal normal breath-group".

We will show in chapter three that other articulatory maneuvers are used by adult speakers to produce breath-groups that are acoustically or perceptually similar to the prosodic patterns that result from the archetypal articulatory maneuvers. Adult speakers, for example, can produce a breath-group where the subglottal air pressure function is similar to the archetypal pattern though the speaker does not actually pause for inspiration at the end of the breath-group. Our data, however, shows that the adult speakers generally do produce breath-groups on a single expiration (about 90 percent of the time). The data in chapter three moreover shows that adult listeners perceive intonational signals[1] as though they had been produced by means of the primary or archetypal articulatory gestures. We will use the term "breath-group" to encompass all the intonational signals that are acoustically or perceptually equivalent to the archetypal breath-groups.

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1. We will discuss some of the perceptual constraints that may motivate the perceptual recognition routine in the next section.

Individual languages are undoubtedly characterized by specific coordinated patterns of activity involving the laryngeal and chest muscles in the production of "typical" breath-groups. In American English, for example, the tension of the laryngeal muscles in the basic, "least effort", normal breath-group appears to be constant throughout the entire breath-group. There is a fairly general agreement among most American linguists, (e.g., Pike, 1945; Smith-Trager, 1951; Stockwell, 1962, etc.) that the basic intonation contour of American English should be transcribed as [231#] in the "phonemic" notation developed by these linguists. The fundamental frequency of the vibrating vocal cords appears to be a function of the subglottal air pressure and rises from a medium pitch to a higher pitch at the stress peak (which occurs at the peak subglottal air pressure) and then falls as the subglottal air pressure falls at the end of the utterance[1].

In contrast these American linguists transcribed the basic British English (received pronounciation) intonation contour as [331#]. This is said to be one of the reasons why these linguists feel that pitch and stress are completely independent[2]. What seems to be happening in

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1. Detailed data on American-English breath-groups will be presented in Chapter 3.

2. Most of these linguists, however, admit that intonation and stress interact. Martin Joos (1962), for example, has noted that during World War II he was able to get satisfactory intonation from a Vocoder synthesizer about 90% of the time by having the pitch generator follow the amplitude of the acoustic signal. Where the amplitude increased the pitch went up.

British English is that at the start of each breath-group the laryngeal muscles are tensioned and then gradually relaxed in the course of the breath-group. The initial high pitch of the British English breath-group may be due to laryngeal muscle tension which is relaxed as the subglottal pressure builds up so that the high pitch is maintained through the middle of the breath-group. At the end of the breath-group both the laryngeal muscle tension and the subglottal air pressure have diminished, which results in a low pitch. Daniel Jones (1932) and most of the British phoneticians who recognize that stress and pitch are interrelated transcribe the American English contour as a monotone modulated by stress and British contour as a falling pitch contour modulated by stress.[1] This transcription seems to correspond to the' lay opinion which regards British English as having more inflection. The lay opinion has always bothered instrumental investigators who have correctly noted that the pitch range of British and American English is about the same. However, in terms of the necessary laryngeal muscular control American English may have less variation[2].

We are, in essence, hypothesizing the existence of a normal synchronized pattern of activity involving the respiratory and laryngeal muscles which forms a basic breath-group that characterizes the intonation of a language[3]. This hypothesis is supported by the experimental

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1. The English "tune" analyses of intonation are discussed in Chapter 7.

2. The normal breath-group of Russian may also be similar to the American English breath-group. According to Revtova (1965) the intonation of declarative sentences is similar in these languages.

3. This pattern of activity obviously must be synchronized with the activity of the supraglottal vocal tract. The speaker, for example, must manipulate his lips to produce the sound /p/ when air is flowing out from the lungs. The breath-group must be coordinated with the segmental phonemes. Different languages may also differ with respect to the details of this coordination.

evidence that has so far been obtained for the activity of the laryngeal and respiratory muscles. It is also supported by virtually all linguistic analyses of British English and American English (and to a lesser degree French, Thai, German and Swedish). These analyses (c.f. Chapter 7) invariably note that particular intonation patterns constantly recur and form the main part of the experimental corpus. The Tune I, Tune II system of Jones and Armstrong and Ward, in particular, support this hypothesis. We shall see how intonation can have certain linguistic functions which are realized acoustically by the use of this basic breath-group and simple modifications of it.

The presence of a basic synchronization between the laryngeal muscles and the chest muscles[1] to form a basic intonation contour for a language, of course, explains how children acquire a "native accent" so quickly. In the next chapter we will take up the question of the early development of speech in infants, which illustrates both the relation of the prosodic features to emotion and the acquisition and function of the normal breath-group.

J - The Effects of the Supraglottal Respiratory System and Perception

The output of the larynx is, of course, filtered by the upper respiratory system. The acoustic signal produced by a talker is modified by the transfer function of the upper respiratory system. This means that changes in the glottal volume velocity waveform may be drastically modified so that they are not directly apparent in the speech waveform. The amplitude of the volume velocity waveform, may,

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1. On the neurological level there is evidence for a direct pathway between the laryngeal and chest muscles which perhaps facilitates this synchronization (Lenneberg, 1964). However, the absence of such a pathway would not mean that synchronization was not possible.

for example, momentarily increase because the subglottal air pressure suddenly increased. However, the amplitude of the speech waveform may not increase because the vocal tract configuration has changed from the vowel /a/ to the glide /y/. The transfer function of the compact vowel /a/ (c.f. Jakobson, Fant, and Halle, 1952) results in a higher amplitude in the speech waveform even though the volume velocity waveform that excited the /a/ had a lower amplitude than the volume velocity waveform that excited the /y/. The listener must consider the transfer functions of the /a/ and the /y/ in order to assess the relative amplitudes of the volume velocity function.

We have noted that an increase in the subglottal air pressure can result in a glottal output that has a higher fundamental frequency. The perception of fundamental frequency is not adversely affected by the effects of the superglottal respiratory system. When listeners are asked to match the pitch of a sustained vowel to the fundamental frequency of a sinusoid they are capable of making very fine frequency discriminations. Flanagan and Saslow (1958) found that the dl or difference limen for fundamental frequency was actually finer for synthesized vowels than it was for pure tones. Fundamental frequency may thus be a more consistent acoustic correlate than amplitude for changes in the subglottal air pressure.

Acoustical analyses directed at isolating the acoustic correlates of stressed syllables that have phonetic prominence in American English (Lieberman, 1960) and Swedish (Hadding-Koch, 1961) show that increases in amplitude, fundamental frequency and duration are all cues to the perception of stressed syllables. The positive correlation between fundamental frequency and acoustic amplitude follows directly from the functional relationship between increases in the subglottal air pressure and the frequency at which the vocal cords vibrate.

Perceptual studies of phonetic prominence by Fry (1955, 1958) and Bolinger (1958), in which listeners heard synthesized vowel-like sounds, show that duration, amplitude and fundamental frequency are all acoustic correlates of perceived phonetic prominence in English. However, in languages like Czech or Estonian, where length is an operant phonologic feature, duration is not an acoustic correlate of prominence[1].

The increase in the durations of stressed syllables in languages where length is not a phonologic feature may follow from a match to the limitations of auditory perception[2]. A number of psychoacoustic experiments, e.g., Lifshitz (1933, 1935), Creelman (1963), have noted that under some conditions a listener's judgments regarding the loudness of clicks or short sinusoidal signals may depend on the durations of the signals as well as the intensity of the signals. If a listener hears two signals that have the same intensity he will judge the longer signal to be the louder one. Integral relationships hold for sinusoidal signals that are shorter than 700 msec. If a listener hears two signals that have different intensities and durations he will judge the signal having the

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1. Personal communication from Professor Roman Jakobson.
2. Traditional phonetic analyses make a distinction between stress timed and rhythm timed languages (e.g., Principles of International Phonetic Alphabet, 1949). In English, which is a stressed timed language, stressed syllables are not supposed to occur faster than a certain maximum rate. An acoustic "refactory period" perhaps exists. After a heavy stress a certain minimum time would have to elapse before the next heavy stress. This might result in stressed syllables being longer in order to allow the air pressure to build up again, However, no quantitative experimental evidence has been as yet presented which would support this speculation.

smaller intensity to be louder if its duration is sufficiently longer.

Stevens, Sandel and House (1962) also reported similar effects using two component noise bursts. The results of this last experiment moreover indicate that the context of a stimulus strongly affects its perception. The presence of a second signal in close proximity to a first signal strongly influences the perception of the first signal, and vice versa. The point that we wish to make is that one can not analyze the intonational signal in terms of "simple" components of amplitude, duration and fundamental frequency and expect to find that these "simple components can always be independently perceived[1].

The relationship of specific articulatory gestures to specific "simple" parameters of the speech signal is quite complex. As we have noted, changes in the subglottal air pressure can change the fundamental frequency, amplitude, and opening quotient of the glottal volume velocity waveform. Changes in the tension of the laryngeal muscles can also modify the opening quotient, amplitude, and fundamental frequency of the glottal volume velocity waveform. Thus it is often impossible to ascertain whether an increase in the fundamental frequency or the amplitude of the acoustic waveform radiated from the speaker's lips was caused by an increase in the subglottal air pressure or by a change in the tension of the speaker's laryngeal muscles. The acoustic correlates of these two articulatory gestures overlap. In chapter 3 we will present

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1. Jakobson and Halle (1956) point out that, "Languages where both length and stress appear as distinctive features are quite exceptional...." This constraint may reflect the integrating properties of the auditory system which relate intensity and duration at the perceptual level (though both can obviously be independently perceived outside of the range of the integrating effects). In Estonian, for example, where the length of a consonant or vowel is significant, the distribution of stress is quite restricted. The first syllable of a word is always stressed. The listener could thus interpret all other perceived durations (which might sometimes reflect the intensity of the speech signal as well as the duration of the segment) as manifestations of the feature <u>length.</u>

experimental data that indicates that intonation patterns are "decoded" by listeners in terms of an archetypal pattern. The listener "decodes" the intonation pattern as though it had been produced by means of either a "normal breath-group" or a "marked breath-group" and an additional segmental distinctive feature[1], prominence, $[+P_s]$, which corresponds on the articulatory level to a momentary increase in subglottal air pressure on a vowel[2]. The marked breath-group, [+BG], is differentiated from the normal, unmarked breath-group, [-BG], at the articulatory level by the presence of an increase in the tension of the laryngeal muscles at only one point in the breath-group, its end where the subglottal air pressure falls. The marked breath-group [+BG] in a sense represents the simplest contrast that can be consistently made in terms of the unmarked, normal breath-group.

Particular languages are characterized, in part, by modifications of the laryngeal tension function in the non-terminal parts of the breath-group, e.g., whether the laryngeal tension is relatively constant or whether it falls throughout the breath-group. Additional phonologic features that interact with the breath-group at the acoustic and articulatory levels may also occur in different languages. In American English our data shows that fundamental frequency prominences that occur in the non-terminal parts of the breath-group are interpreted

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1. For a discussion of distinctive features see Jakobson, Fant and Halle (1952).

2. These comments, of course, are relevant only for languages where these features occur. Different languages have different recognition routines.

as though they were produced by the segmental feature [$+P_s$]. In Chinese some of the fundamental frequency variations apparently seem to be interpreted as the acoustic manifestations of segmental "tone" features. The presence of these segmental features may affect the fundamental frequency function of the entire breath-group. However, the terminal fundamental frequency contour of the breath-group always is the acoustic correlate of the suprasegmental breath-group. Though the listener must consider the fundamental frequency contour in the non-terminal parts of the breath-group to deduce whether the breath-group is marked (-) or unmarked (+), the articulatory maneuvers that take place in the terminal part of the breath-group determine whether it is marked or unmarked.

The main point that we want to emphasize here is that the recognition routine based on a fixed archetypal articulatory pattern results in a unique "analysis by synthesis",[1] that is, an analysis in terms of the articulatory gestures that are permissable in a language, even though the acoustic signal being analyzed could have been produced by several different patterns of articulatory activity.

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1. "Analysis by Synthesis" is discussed by Halle and Stevens (1959). Stevens (1960) and Stevens and Halle (1964) with regard to speech perception in general.

K - Secondary Effects

In the preceeding discussion of the activity of the larynx we have tacitly assumed that its output can be determined without reference to the rest of the respiratory system if the subglottal air pressure is specified. This assumption is, for a first approximation, correct. However, the larynx is coupled to the rest of the respiratory system through both aerodynamic and mechanical effects.

Interactions with the Subglottal System

We have noted that the aerostatic and aerodynamic forces that act on the vocal cords (F_{as} and F_{ab} in Fig. 5) are functions of the subglottal air pressure. Under most conditions the subglottal air pressure varies less than 5 percent of its mean value within the duration of each glottal vibratory cycle (van den Berg, 1956). The subglottal system has certain resonant frequencies. Van den Berg has noted that the subglottal air pressure fluctuates rather markedly during each glottal cycle when a resonance at approximately 300 cps is excited (van den Berg, 1957, 1960).

In Fig. 9 the cumulative distribution of the durations of the fundamental period has been plotted for several normal male speakers reading the sentence, "Joe took father's shoe bench out," as a statement, a question, and a confidential communication. The abcissa is a scale of fundamental periods in msec and the ordinate shows the percent of fundamental periods that are less than the abcissa value. Thus 30% of speaker two's fundamental periods had durations less than or equal to 6.6 msec. Note that plateau in this distribution centered at 7.5 msec. Phonation seldom occurred at fundamental periods of 7.0 to 7.5 msec in this sample.

CUMULATIVE DISTRIBUTIONS OF FUNDAMENTAL PERIODS FOR FIVE ADULT MALE SPEAKERS

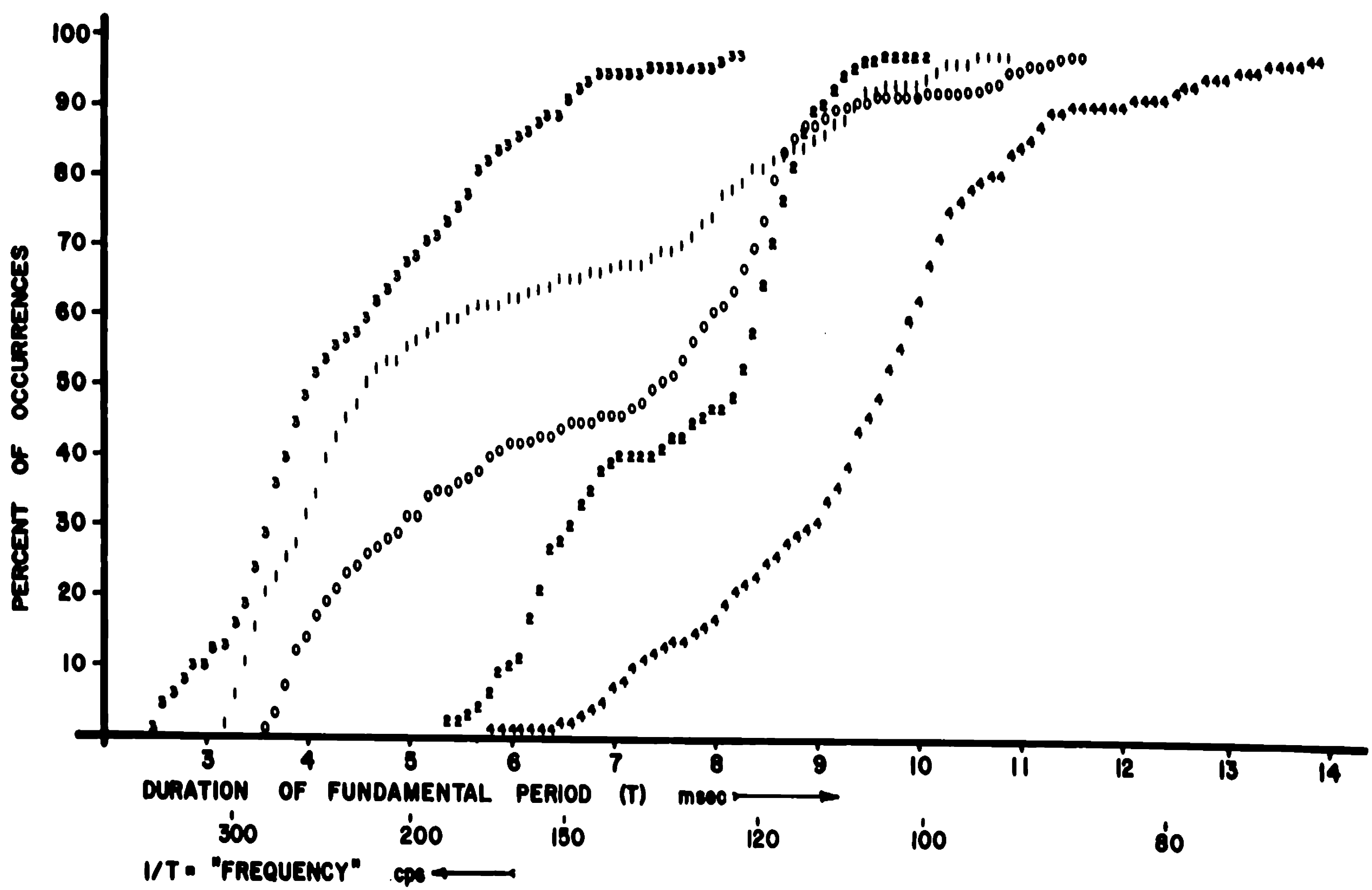

Fig. 9

Speakers 9, 1, and 2 all had plateaus in their cumulative distribution at about 7 msec. Speaker three's distribution is typical of most speakers with high pitched voices. The lowest fundamental frequency that his larynx produced is about 150 cps. Speaker four's distribution is typical of many speakers with low pitched voices. Note that his highest fundamental frequency is also 150 cps. All of this data is for phonation in the speakers' normal speaking voices. They did not use their falsetto registers when they read the test material. This discontinuity at approximately 150 cps has been noted to a greater or lesser degree for more than 60 speakers who often read the test sentences with different intonations (Lieberman, 1963). The speakers apparently avoided phonation at fundamental frequencies that would excite the 300 cps subglottal resonance. It probably is difficult to produce a normal glottal output when the subglottal pressure varies during each vibratory cycle. Johannes Muller, for example, performed experiments in which he coupled a "subglottal" resonator to the vibrating excised larynx. He noted that a certain fundamental frequencies, "... the note was not so perfect...." (Muller, 1848, p. 1020). Trendelenburg (1942) noted similar effects when he coupled long resonators to the mouth during normal phonation which caused the pharyngeal pressure to fluctuate during each glottal cycle. The excited sound "broke" when the fundamental frequency excited the modified superglottal resonance.

Risberg (1961) and Hadding-Koch (1961) have noted similar effects for spoken Swedish. Normal speakers tend to avoid phonation at certain fundamental frequencies that seem to correspond to the resonances of the subglottal system. The so called "phonemic" pitch levels described by Pike, Wells, Trager and Smith and others (c.f. Chapter 7) may merely reflect the phonetic effect of the discontinuities caused by the coupling of the subglottal system to the larynx. Hadding-Koch's results[1] are particularly suggestive as she was trying to find acoustic correlates of these "phonemic"pitch levels.

Interactions with the Supraglottal System

Let us again return to Fig. 7 and consider the energy relationships of the air flow. If the velocity of the air in the pharynx is relatively small compared to its velocity in the glottal constriction, the kinetic energy of the air in the pharynx and the trachea may be neglected. If we again assume that the distribution of velocity over the glottal oriface is uniform and that there is no viscous dissipation, the kinetic energy of the air in the glottis per unit volume is developed by the pressure difference $(P_s - P_o)$, and is

$$\rho \frac{v^2}{2} = P_s - P_o$$

(c. f. Flanagan, 1958).

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1. Hadding-Koch measured the extreme fundamental frequencies of sentences that she had transcribed with the Trager-Smith system. She found that these frequencies clustered into two groups (which usually centered about 150 cps) which corresponded to the pitch levels. Pitch levels 1 and 2 might fall into the low group for a particular speaker. A different speaker might have only pitch level 1 in the low group and levels 2, 3, and 4 in the high group. The groups were also more distinct for heavily stressed vowels. This follows from the subglottal interaction theory because the glottal waveform would have more energy with increased vocal effort at 300 cps when the fundamental was at 150 cps. The subglottal resonance would herefore tend to be excited to a greater degree with increased vocal effort and phonation at 150 cps would not occur very often. The plot of the speaker's fundamental frequencies would therefore show two peaks.

The pharyngeal air pressure, P_o, is atmospheric for open articulations, e.g., vowels, liquids and some voiced continuant consonants. The pharyngeal air pressure however rises when the vocal tract is obstructed. (Rousselot, 1898; Stetson, 1951; Harris, 1962.) In the limiting case the pharyngeal air pressure is equal to the subglottal air pressure when the vocal tract is completely closed[1]. The air flow under these limiting conditions, of course, ceases. For less extreme, momentary closures or for partial obstructions the pressure difference (P_s - P_o) decreases and the velocity of the air flow thus also decreases. The pressure in the glottis increases since $1/2 \rho V^2 + P = \text{Constant}$. The Bernouilli force which sucks the vocal cords together therefore decreases.

Measurements of the fundamental frequency of speech show that "pitch perturbations", or sudden fluctuations in the fundamental periodicity of the signal occur quite frequently (Lieberman, 1961). The pitch perturbations are not randomly determined and they usually are concommitant with the production of voiced stops and the onset and end of phonation (where the subglottal air pressure and the accelerating masses are changing). High speed motion pictures (Soron and Lieberman, 1963) of the vocal cords, for example, show that large variations in fundamental periodicity occur at the end of phonation, as the arytenoid cartilages, which support the vocal cords, swing open.

Pitch perturbations are apparently essential cues for natural speech quality. When speech is synthesized electronically these pitch

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1. In the absence of compensating articulatory gestures that increase the air volume of the supraglottal system. The larynx may, for example, descend (Troubetzkoy, 1939) or the pharynx may distend (Perkell, 1965).

perturbations must be preserved. If the pitch perturbations are removed, leaving only smooth pitch contours, listeners report that the synthesized speech has a "mechanical" quality (Cooper, Peterson, and Fahringer, 1957; Kersta, Bricker and David, 1960). They also appear to play some role in transmitting the "emotional" quality of the talker's voice (Lieberman, 1961; Lieberman and Michaels, 1962). The hoarse vocal quality associated with certain types of pathologic larynxes in which tumors or polyps occur on the vocal cords results, in part, from larger pitch perturbations. The pathologic masses on the vocal cords lower the mechanical damping factor of the larynx, making its acoustic output more sensitive to air pressure transients (Lieberman, 1963). The pitch perturbations are superimposed upon the fundamental frequency contour of the utterance. Though the pitch perturbations thus seem to be relevant in communications systems for the preservation of natural vocal quality, speaker identification and emotion, they do not appear to be the primary acoustic correlates of any linguistic information and we shall, for the most part, tacitly ignore their presence in our discussion of intonation.

Mechanical Coupling

The larynx is, of course, connected to the rest of the human body. There exists the possibility that movements of other parts of the body will mechanically interact with the larynx to change the tension and the rest position of the vocal cords. Sonninen (1956), for example, believes that a great number of extralaryngeal muscles can influence phonation, e.g., the pharyngeal muscles, the palatal muscles, the suprahyoids, sternohyoids, etc. As Proctor (1964) points out, this is undoubtedly true to a certain extent. However, the primary control of the larynx rests in the laryngeal muscles. A trained singer can, for example, control the quality of his phonation in virtually any posture.

Some of the movements of the larynx that are effected by means of the extralaryngeal muscles may however have a linguistic function. The larynx can move about two or three centimeters vertically in relation to the jaw. When it moves upwards it reduces, of course, the length of the supraglottal respiratory system. The formant frequencies that characterize specific vowels and consonants will therefore transpose to higher frequencies since the formant resonances are functions of the length and configuration of supraglottal vocal tract.

The larynx typically rises at the onset of phonation and descends at the end of phonation. These vertical laryngeal movements may be distinctive features in some languages, e.g., the "imploded" and "exploded" stops cited by Troubetzkoy (1939). The mechanism that effects these adjustments is still a matter for speculation. The vertical movement may be caused by the static subglottal air pressure pushing against the larynx or it may be the result of a deliberate muscular adjustment that pulls up on the hangers from the hyoid bone. The descent of the larynx can maintain a transglottal air pressure drop ($P_s - P_o$) when the upper respiratory system is obstructed and therefore may be a way of maintaining voicing during some stop sounds. However, there is relatively little data available that is relevant to these gestures and, as with most aspects of laryngeal activity, further study is necessary.

Chapter Two

Intonation in Infant Speech

In this chapter we will examine some aspects of intonation in relation to the early development of speech in children. We will present two main hypotheses: First, that there is an innate physiologic basis for the "shape" of the normal breath-group that seems to occur in so many languages; and second, that the chief function of the normal breath-group is to segment the speech signal into sentences. We will make several assumptions in connection with these hypotheses which seem reasonable and we will present observations that support both these assumptions and the main hypotheses. The data and discussion that is presented in the chapters that follow this one are also relevant to these hypotheses; we are not merely resting our case on the observations that we will discuss in this chapter. We want to suggest that the linguistic use of intonation reflects an innately determined and highly organized system rather than a set of unrelated facts that are fortuitouly similar in many languages. We will also briefly review some other aspects of the acquisition of language by children insofar as they explicate the line of reasoning that we wish to follow.

A - Some Observations of Adult Intonation

Although relevant phonetic or instrumental analyses are not available at present for most languages it is possible to generalize about intonation to the extent of stating that short declarative sentences usually end with a falling fundamental frequency contour. Detailed instrumental analyses by Jones (1909), Chiba (1935), Fonagy (1958), Hadding-Koch (1961), and Abramson (1962), for example, show that this is the case for English, Spanish, French, Finnish, Hungarian, Italian, Thai, Japanese, Swedish, and German. Perceptual phonetic studies, when they note the intonation pattern of a language, also indicate that the intonation pattern associated with normal declarative sentences is characterized by a falling intonation contour at the end of the sentence. For the most part phonetic studies rarely make any comments about the falling fundamental frequency contour that occurs at the end of a sentence, perhaps because the effect is so commonplace an occurrence that it does not warrant any special attention.

The normal breath-group, as we noted in chapter one, is a synchronized standard pattern of activity wherein the respiratory and laryngeal muscles act to produce phonation on the flow of expiratory air. The normal breath-groups of all languages are similar in that they end with a falling fundamental frequency contour.

Different languages differ, in part, in that they have different normal breath-groups and allow different admissable modifications of their normal breath-groups. The normal breath-group of Swedish is, for example, different from the normal breath-group of American English. Different deviations from the normal breath-group are admissable in Swedish and American English. In chapter three we will present experimental evidence that indicates that an identical signal may be interpreted differently by native speakers of Swedish and American English because both groups interpret the signal in terms of the different patterns of muscular activity that are admissable in their native languages.

For the moment let us, however, return to the central issue of this chapter, which is the common element of all these normal breath-groups. We will try to show that our first hypothesis accounts for the fall in fundamental frequency that always occurs at the end of the normal breath-group.

B - The Acquisition of Language by Children

We will begin by discussing some other aspects of the acquisition of language by children which demonstrate the argument that we want to follow. Jakobson (1942) pointed out that the acquisition of speech by children is of interest to linguistics and psychology since it may reflect the structure of their innate linguistic competence[1]. Jakobson identified two phases of speech development. The "babbling" stage, in which the infant simply exercises his vocal apparatus and makes sounds for the sake of making sounds, occurs first. The infant probably makes every sound that he possibly can in this stage whether or not it occurs in the adult speech that he hears. The adult speech that he hears may even have little to do with the form of his babbling. Deaf children, for example, babble quite normally for the first six or seven months of their life. The second stage in the development of speech often begins with a period of comparative silence when the child is from one to

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1. Occasionally one finds statements that seem to imply that language is some accidental phenomenon - that it has no innate basis. The usual "evidence" is the statement that no part of the speech generating apparatus is adapted exclusively for the production of speech as the heart, for example, is adapted to pumping blood. Therefore, so goes the argument, language is an "accidental" acquired facility. Quite aside from the preoccupation of this argument with the output devices - no one discusses the brain - the supposed data is erroneous. The results of studies in the comparative anatomy of the respiratory system, for example, of Negus (1949) demonstrate that in man the glottis has developed, "...for purposes of phonation...." (p. 40)

two years old. The child then begins to use speech sounds in a meaningful way and he employs the distinctions that are operant in the adult speech that he hears.

Jakobson points out that the distinctions that occur most often for all the languages of the world are the distinctions that the child first learns to use meaningfully. The order in which children learn to make meaningful speech distinctions thus mirrors the hierarchy of these features. The first distinctions are the most basic ones. Jakobson and Halle (1956) note,

> Ordinarily child language begins...with...the "labial stage". In this phase speakers are capable of only one type of utterance, which is usally transcribed as /pa/. From the articulatory point of view the two constituents of this utterance represent polar configurations of the vocal tract; in /p/ the tract is closed at its very end while in /a/ it is opened as widely as possible at the front and narrowed toward the back.... This combination of two extremes is also present at the acoustic level: the labial stop represents a momentary burst of sound without any great concentration of energy in a particular frequency band, whereas for the vowel /a/ there is no strict limitation of time, and the energy is concentrated in a relatively narrow region of maximum aural sensitivity. (p. 37)
>
> ...the infant preserves for a time a constant syllable scheme and splits both constituents of this syllable, first the consonant and later the vowel, into distinctive alternatives.
>
> Most frequently, the oral stop, utilizing a single closed tract, obtains a counterpart in the nasal consonant....
>
> The opposition of nasal and oral consonant, which belongs to the earliest acquisitions of the child, is ordinarily the most resistant consonantal opposition in aphasia and it occurs in all the languages of the world except for some American Indian languages. (p. 38)

Although every child develops differently Jakobson's observations appear to reflect the general trend of speech development in children.

Leopold (1953), for example, notes that, "...the speed and time of sound acquisition varies enormously between different children; but the sequence in categories and the relative chronology are always and everywhere the same, at least in great outlines."

Now the first "meaningful" element of speech behavior that can be noted in the behavior of children acutally occurs much earlier than from one to two years of age. In the very first months of life, during the babbling stage, and indeed during the very first minutes of life children employ "meaningful" intonational signals. The cries are at first meaningful only in that they have a physiological reference. We believe that these signals, which appear to be innately determined, provide the basis for the linguistic function of intonation in adult speech.

C - Infant Cries

Although human infants are speechless they communicate by means of sound from the moment of birth onwards. Although other sounds, e.g., flatulence, coughs, sneezes, squeaks, etc., occur, the most characteristic sound of the new born is the cry (Kurtz, 1963). The infant cry has a characteristic pattern. The pattern is apparently innately determined and is a characteristic human attribute. Mongoloid infants, for example, often lack these characteristic cries (Karelitz) and deviations from the normal pattern often signal other neurological abnormalities (Rubinstein, 1964). The infant cry has a rising-falling fundamental frequency contour. The duration of the cry is usually from one to two seconds and the fundamental frequency initially rises. The fundamental frequency then remains relatively steady or gradually falls until the end of the cry where it typically falls at a faster rate (Ostwald, 1963).

As Ostwald[1] points out, the infant cry is an attention-getting device. He notes that, "One can now appreciate why a parent must interfere with the baby's crying: this sound is too annoying to be tolerated beyond a short period of time...a cry cries to be turned off!" As the infant matures the vocalizations differentiate and various types of cries occur. Two types of cries can even be differentiated at birth, the "normal" cry and the "scream". The "scream" which occurs when the infant is excited has been described as an extremely loud cry in which the vocalization becomes atonal as it rises to its peak fundamental frequency (Kurtz, op. cit.).

In contrast to the cry infants produce other sounds, e.g., the gurgle noted by Kurtz, which do not induce adults to minister to them. Infants soon begin to babble. Irwin (1947) noted the start of babbling as the infant uttered /ae/ like sounds during the first few days of its life. The playful sounds of infants in general are quieter, they are not as shrill, and the perceived pitch often does not abruptly fall at the end of phonation (Kurtz, op. cit. Ostwald, op. cit., Rubinstein, op. cit.) There thus seems to be a dichotomy between vocalizations that have an immediate physiologic reference - that can be satisfied by the attention

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1. Ostwald reported that the peak sound pressure level at a distance of 10 inches ranged from 83-85 db. Peak energy occurred at 1400 cps.

of an adult - and the vocalizations that do not seek immediate attention.

The child, from the moment of birth, thus seems to have a referential cry which represents in Darwin's[1] terms (1872, p. 348), "...the direct action of the excited nervous system on the body, independently of will, and independently in large part, of habit." We will try to show that the infant's hypothetical innate referential breath-group furnishes the basis for the universal acoustic properties of the normal breath-group that is used to segment speech into sentences in so many languages.

D - A Hypothetical Innate Referential Breath-Group

Let us first consider the articulatory gestures that might characterize the hypothetical innate referential breath-group. We must make certain assumptions about the control of the laryngeal and respiratory muscles during the production of this hypothetical referential breath-group. We will try to avoid making any assumptions that do not seem warranted by the available physiologic and acoustic evidence. Where physiologic evidence is lacking we will assume that the infant uses the simplest pattern of articulatory activity when more than one pattern of articulatory activity could have been used to produce the same acoustic output.

The infant, like the adult, must initiate phonation by bringing the vocal cords inwards from their open breathing position and expelling air from his lungs. No other articulatory gestures can produce phonation.

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1. Hughlings Jackson (1915) in 1866 in his studies of aphasia also stated that the expression of emotion is innately determined, as did Sir Charles Bell (1808).

We will assume that the infant does not precisely control the tension of his laryngeal muscles once phonation starts. He merely maintains the tension of the laryngeal muscles at or near the tension that they had as phonation started. This assumption is not particularly crucial and the only pattern of laryngeal activity that we really must assume does not take place is a consistent, controlled increase in the tension of the laryngeal muscles at the end of the breath-group. Our assumption is, however, consistent with the available physiologic data. Bosma, Lind, and Truby (1964) in a study of 30 newborn normal infants combined cineradiography, sound recording, and esophageal pressure recording during pinch-elicited cries. It is impossible to quantitatively determine the subglottal air pressure from esophageal recordings without knowing the lung volume that corresponded to each pressure measurement as a function of time[1]. However, the esophageal pressure function does indicate when the subglottal air pressure is rising and when it is falling. The measured esophageal pressure functions for the cries all had a similar shape. The esophageal pressure gradually rose from the start of phonation to either a level or a slightly falling "plateau". The esophageal pressure then abruptly fell prior to inspiration. The infant cries observed by Bosma, et.al.,were quite protracted and "...commonly...continued longer than expiration[2], so that the vocalization is carried over into the succeeding inspiration." The "shape" of the

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1. For reasons that will be discussed in chapter 3.

2. The referential cry is probably prolonged as much as possible to effect the greatest response on the part of the hearer.

fundamental frequency contours of the cries was similar to the shape of the typical esophageal pressure contour. Qualitatively speaking, the gross variations of the fundamental frequency contour thus seem to be a function of the subglottal air pressure during infant cries[1]. The fundamental frequency, which rises initially as the subglottal air pressure builds up, remains level or slowly falls until the end of expiration where it abruptly falls. The respiratory muscles can maintain the subglottal air pressure at a relatively high level as the lungs gradually collapse during expiration. However, at the end of expiration when the lungs collapse to a certain critical point, a set of overriding respiratory reflexes automatically induce inspiration. The deflation or Hering-Breuer reflex[2], for example, induces inspiration when the lungs collapse (Widdicombe, 1964; Hering and Breuer, 1868). The subglottal air pressure must fall at a rapid rate as expiration ceases because the subglottal air pressure assumes a negative value during inspiration. If phonation is protracted until the last possible moment, the breath-group will therefore terminate with a falling fundamental frequency contour.

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1. The average tension of the expiratory muscles is probably a function of the "excited nervous system". The greater the excitement of the infant the greater will the subglottal air pressure and tension be. Infant "screams" therefore have a higher fundamental frequency and amplitude than infant cries.

2. Other reflexes that are directly triggered by the oxygen level in the lungs or blood stream also induce inspiration (Widdicombe, 1964). The relevant point is that inspiration is automatically induced by primary respiratory reflexes.

E - The Use of Intonation as a Meaningful Signal by Infants

In chapter three we will present experimental evidence that indicates that the normal breath-group of American English which has a linguistic reference is quite similar to our hypothetical innate referential breath-group. The reference for the innate breath-group is, of course, at first egocentric and is the state of the efferent nervous system. It seems likely that children gradually learn to associate other, more social, references to intonational signals. Löwenfeld (1927) and Bühler and Hetzer (1928), for example, reported that infants from the age of two months onwards responded positively to the human voice while infants from the age of three months onwards responded positively to friendly tones and negatively to angry tones of voice. The observed responses in these studies were eye and head movements.

The shift to intonation as a meaningful speech signal that has a reference to specific social situations is comparatively rapid. Schafer (1922) reported that a nine month infant who responded to the intonation of the phrase, "wo ist die Tick-tock?" by looking at the clock also looked at the clock when similar phrases like, "wo ist die lala?" were spoken with the same intonation. The same child played hand clapping games when the phrase, "mache bitte bitte," was spoken in "Ammenton", the exaggerated intonation of the nursery. The child would not respond when the phrase was spoken with a normal intonation. At ten months of age the child would respond when, "mache bitte bitte," was spoken with normal intonation. Lewis (1936) cites many examples where children first responded only to the intonation of a phrase and responded only to the words as they grew older.

It has often been noted that children soon mimic adult intonation.

Lewis (op. cit.), for example, often refers to this phenomenon. An experiment amined at confirming Lewis's subjective comments by quantitative acoustic measurements that are related to the imitation of intonation signals showed that mimicry of the average fundamental frequency range occurs at this age. A ten month old boy and a thirteen month old girl were recorded under several different conditions. The boy was recorded while he babbled alone in his crib and while he cried alone in his crib. He was also recorded while he babbled in an identical play situation with his father and his mother respectively. The child sat on his father's lap and the parent spoke to him while he played with his dog. After fifteen minutes he sat instead on his mother's lap while she talked to him. Four interchanges took place. The average fundamental frequency of the child's babbling under these conditions was measured. About twenty minutes of "conversation" occurred under each condition. The same experiment was then repeated with the thirteen month old girl who was beginning to speak. The girl was not recorded while she cried or spoke alone and she played with her cat while she sat on her parents' laps. The average fundamental frequencies are presented in Table 1. Note that the average fundamental frequency of the boy's babbling while he "spoke" to his father was 340 cps while his average fundamental frequency was 390 cps when he was with his mother. (The childrens' fathers used lower average fundamental frequencies than their mothers.) Both of these fundamental frequencies are lower than that of his solitary babbling or crying. The boy apparently lowered his fundamental frequency when he was with either parent and he lowered his fundamental frequency more when

TABLE I

Average Fundamental Frequency of Children's Babbling and Speech Versus Average Fundamental Frequency of Children's Crying

SUBJECT	CONDITION	UTTERANCE SPEECH	CRYING
10 month old boy	alone in crib	430 cps	550 cps
	playing with father	340 cps	500 cps
	playing with mother	390 cps	420 cps
13 month old girl	playing with father	290 cps	450 cps
	playing with mother	390 cps	450 cps

Note that the children's fundamental frequencies transposed towards the fundamental frequency of the parent with whom they were talking but the crying fundamental frequency remained high. The mimicry in speech perhaps represents a social use of speech while the crying is egocentric since it still has an emotional reference.

he was with the parent having the lower fundamental frequency. The girl also apparently attempted to mimic the fundamental frequencies of her parents.

Lewis (1936), Leopold (1953), Bullowa (1964) and others have pointed out that the first utterances of children must be regarded as one word sentences rather than as isolated words in the sense that the child later uses a more fully specified phonetic output to express similar thoughts. When a one year old child says mama he often wants to convey a complete request, like mama pick me up, mama feed me, mama hold me. The phonetic output mama is usually associated with other body movements. The child may lift his hands up so that he can be lifted, etc. The child only gradually uses the linguistic output as the primary cue to his underlying thought[1]. As Leopold (1953) notes, "Most children begin with sentences of one word... The word may be a noun, an adjective, a verb of the adult sentences, but it serves for the child as the vehicle of a complete statement." Lewis and Leopold also note that intonation is also one of the first speech signals that has a linguistic reference. Leopold, for example, states that, "The only syntactic device used early in my case was the interrogative intonation, it was employed to ask for information or, much more commonly, to request a permission, rarely to ask for the name of a thing." The child must, of course, first be consistently using the falling fundamental frequency contour associated with statements in order to make this contrast possible.

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1. The gradual separation of the linguistic from the non-linguistic outputs is clearly shown in the study reported by Bullowa, et. al. (1964).

At some point in the development of speech intonation takes on a linguistic reference. This occurs quite early, before the child has acquired many of the distinctive features of his linguistic environment. Lewis (1936, p. 115), for example, notes three stages in the development of language,

> (1) At an early stage, the child shows discrimination in a broad way, between different patterns of expression in intonation. (2) When the total pattern - the phonetic form together with the intonational form - is made effective by training, at first the intonational rather than the phonetic form dominates the child's response. (3) Then the phonetic pattern becomes the dominant feature in evoking the specific response; but while the function of the intonational pattern may be considerably subordinated, it certainly does not vanish.

Our second principal hypothesis is consistent with these observations. Children come to use the innate referential breath-group as the phonetic marker of complete sentences. It becomes the basis of the normal or "unmarked" breath-group of the language and it is used to mark the phonetic output of complete sentences which at first consist of single words or long babbled sound patterns accompanied with various body movements, i.e., pointing, hand waving, etc. The child then learns the permissable variation on the unmarked breath-group, e.g., the "interrogative" intonation.

We will state the form that this variation on the unmarked breath-group may take in the next chapter where we will present the results of physiologic and perceptual experiments that indicate that intonation is both produced and perceived in terms of the articulatory patterns of the unmarked breath-group, the "marked breath-group", and the other intonational features that are admissable in a particular language.

Chapter Three

Perceptual, Physiologic, and Acoustic Data

We have stated that intonation is produced and perceived in terms of an unmarked and a marked breath-group ([-BG] and [+BG]) and certain segmental features which interact with the breath-group because of the inherent constraints imposed by the human speech production apparatus and auditory system. In this chapter we will precisely specify some of the physiologic and acoustic correlates of the unmarked and the marked breath-group as well as the segmental feature [+P_s] and we will present experimental evidence that supports our hypotheses.

A - Perceptual Data for Swedish and American English

We will start by considering the results of an independent psychoacoustic experiment that was performed by Hadding-Koch and Studdert-Kennedy (1964). The experimenters were investigating the perception of the fundamental frequency contours that are usually associated with "yes-no" interrogative sentences and statements. They noted that, "In both Swedish and American English the fundamental frequency (f_o) of so-called yes-no questions tends to show a final rising contour, while the f_o of statements tends to show a final fall." The object of the experiment was to see whether the earlier portions of the fundamental frequency contour would influence the perception of the final portion of a contour.

The experimenters recorded the words For Jane on magnetic tape. These words were found to be acceptable to both Swedish and American listeners, so they served as the "carrier" phase. The magnetic tape was attached to an acetate loop, on which the contours of a systematically varied sequence of intonation contours were also painted. The signal on the tape was then processed with a Vocoder (Dudley, 1939) and the intonation was controlled by the painted contours on the acetate loop (c.f. Borst and Cooper, 1957). The net effect of the processing was a set of forty-two intonation contours that occurred with identical words. The amplitude of the speech signal was kept fairly level throughout each intonation contour. A schematic illustration of one of the contours is presented in Fig. 1.

The shape of the contours was based on Hadding-Koch's analysis of Swedish intonation (1961, p. 85 ff). The contours all started at 250 cps. This fundamental frequency was sustained for 140 msec. over the word For. The contours then rose to either 370 or 310 cps in approximately 100 msec. They then fell to one of three "turning points" at 130 cps, 75 cps or 220 cps in approximately 200 msec. The contours then proceeded to one of seven "end points" between 130 and 370 cps in 200 msec. The total duration of each complete fundamental frequency contour was 640 msec. The stimuli were presented to 25 Swedish and 24 American undergraduates who, in two separate sessions, were asked to indicate for each stimulus: 1) whether it would be best categorized as a statement or a question; 2) whether it ended with a rising or a falling pitch.

In Fig. 2 the percent of response in each of the indicated classes versus the fundamental frequency of the end point minus turning point is plotted for the responses of the American listeners to the stimuli that rose to 310 cps and fell to the 130 cps "turning point". The value of the terminal rise or fall end point minus turning point is plotted on the

SCHEMATIC ILLUSTRATION OF FUNDAMENTAL FREQUENCY CONTOURS

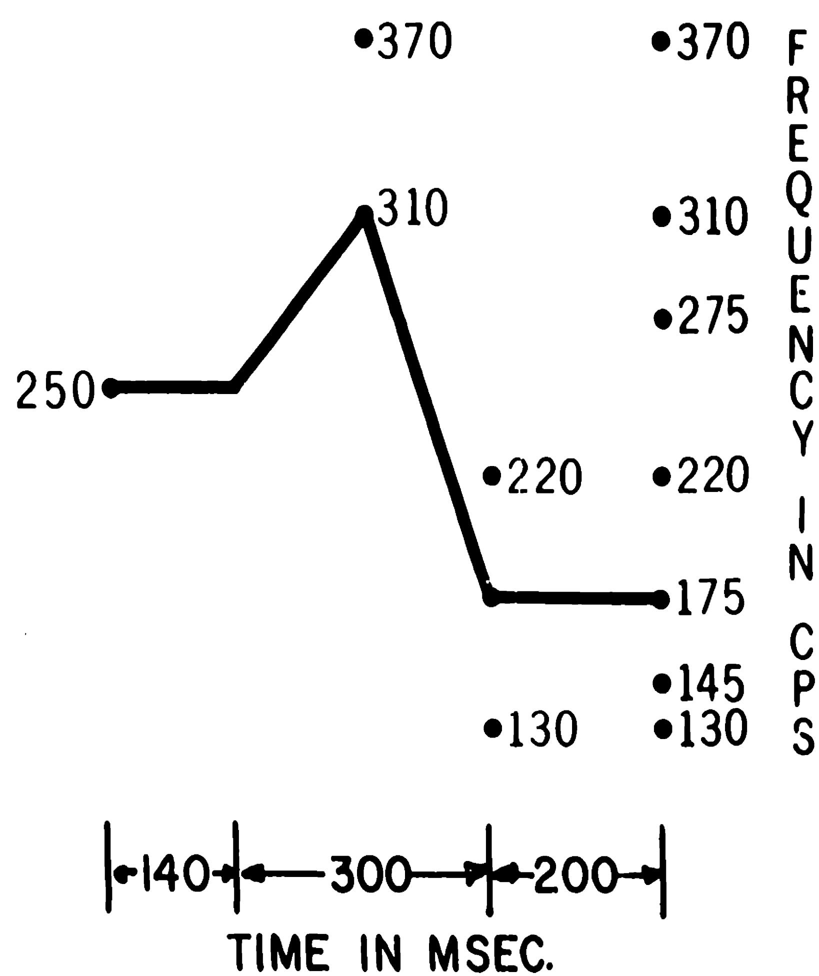


Fig. 1

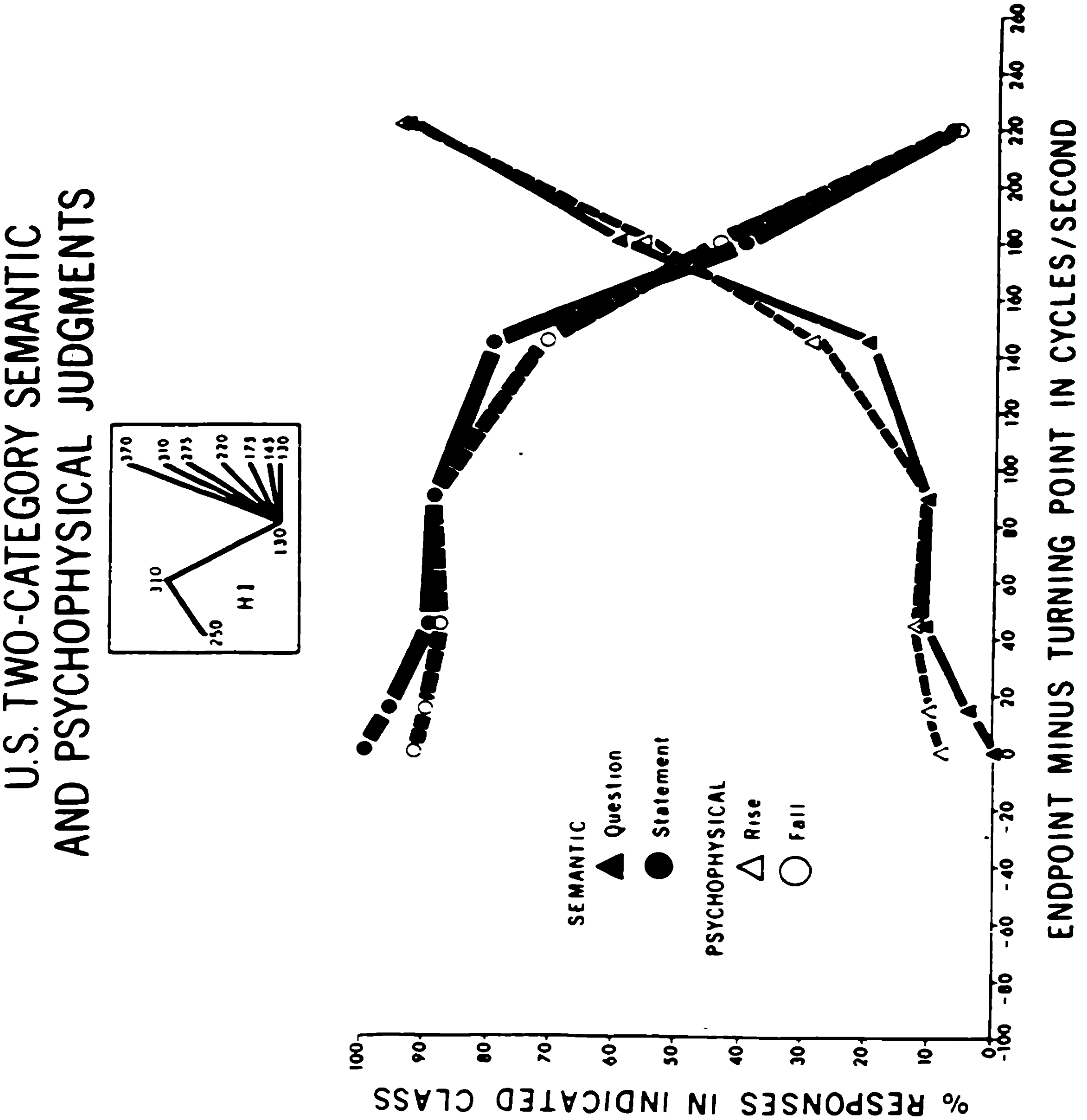

U.S. TWO-CATEGORY SEMANTIC
AND PSYCHOPHYSICAL JUDGMENTS
SEMANTIC
Question
Statement
PSYCHOPHYSICAL
Rise
Fall
% RESPONSES IN INDICATED CLASS
ENDPOINT MINUS TURNING POINT IN CYCLES/SECOND

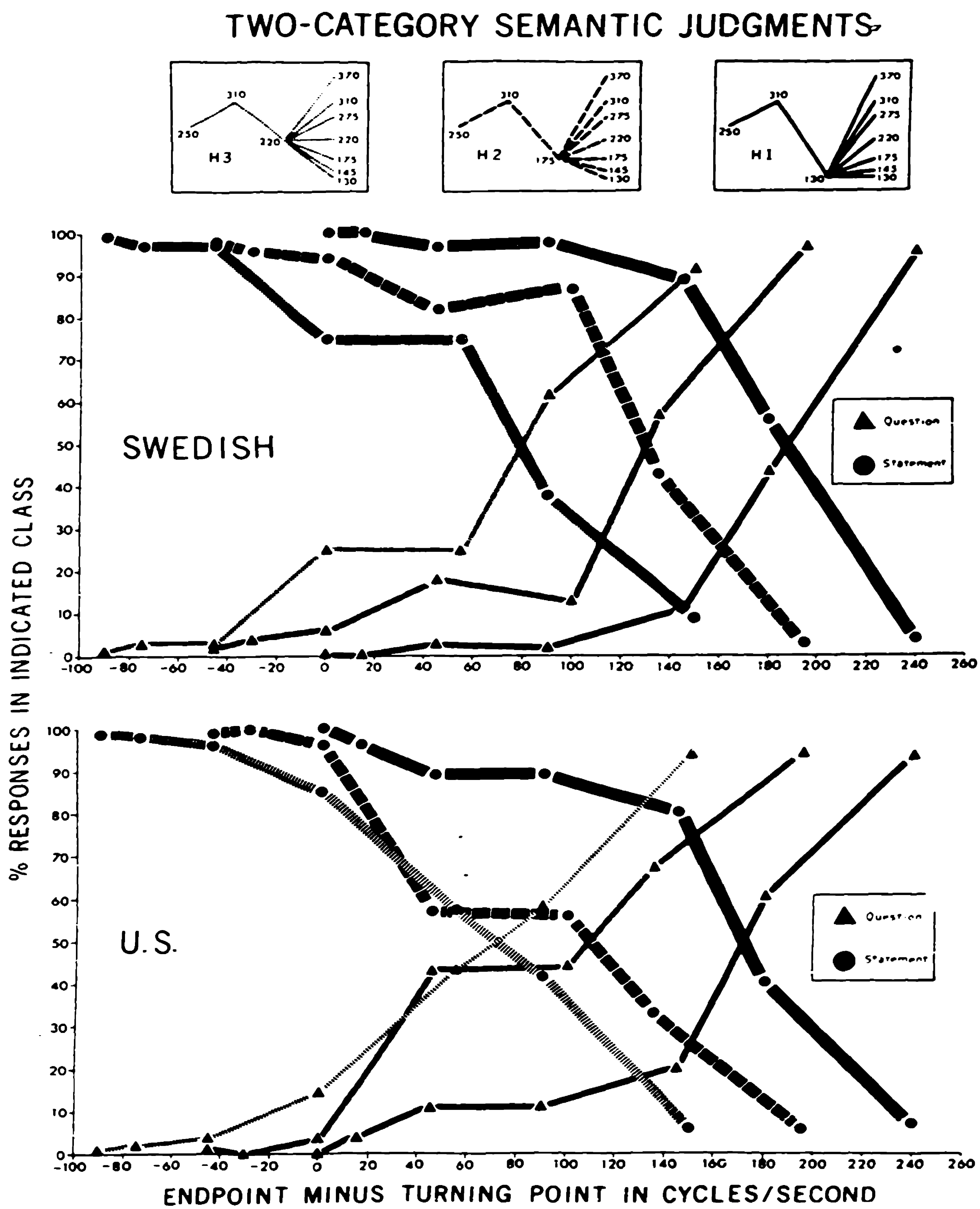
Fig. 2

abscissa while the percent
falling terminal pitch cont
Hadding-Koch and Studdert-K
physical" judgments agreed
They stated that, "Insofar
agree, it would seem that l
direction of the terminal g
direction to make their sem

In Figs. 3 and 4 the "
listeners are presented. T
"...that listeners may make
questions and statements.
preceding peak and turning p
interact in a manner that c
for a given f_o at the other
point leads to an increase i

We have presented the
responses seem to indicate t
signals in terms of an arche
interactions between the se
are otherwise rather complex
hypothesis. Let us first co

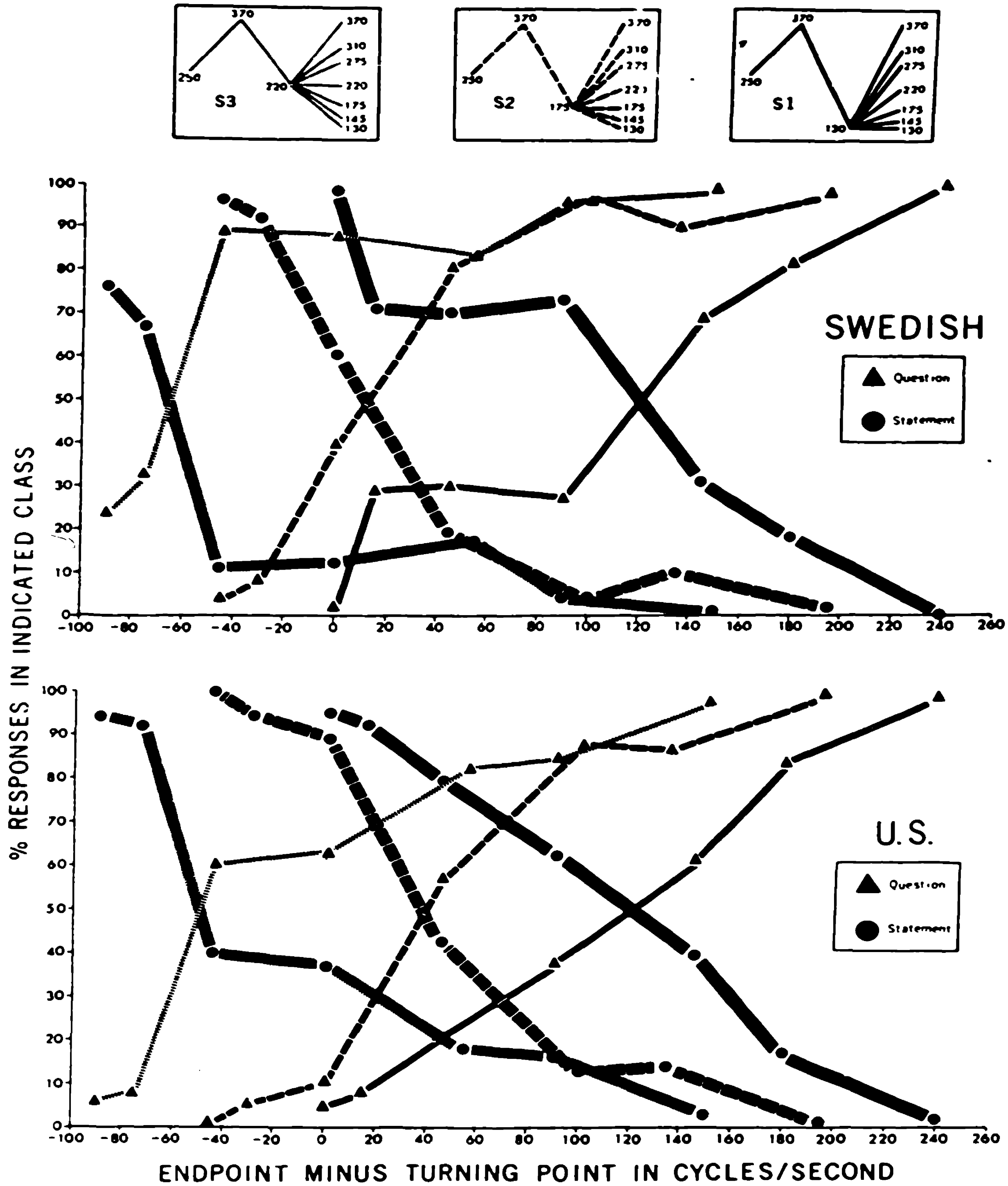
We will begin by repeat
in chapter two. Let us supp
archetype or basis of the n



(AFTER HADDING-KOCH AND STUDDERT-KENNEDY, 1964)

Fig. 3

TWO-CATEGORY SEMANTIC JUDGMENTS



(AFTER HADDING-KOCH AND STUDDERT-KENNEDY, 1964)

Fig. 4

English and that it is the phonetic output of a complete declarative sentence. The tension of the laryngeal muscles is constant during the production of the normal breath-group and the fundamental frequency contour is a function of the subglottal air pressure. The fundamental frequency will therefore fall at the end (the last 150-200 msec of phonation) of the breath-group as the subglottal air pressure decreases.

Let us suppose that a permitted modification of the normal breath-group is an increase in the tension of the laryngeal muscles at the end of the breath-group where the air pressure falls. One of the principal acoustic effects of an increase in the tension of the laryngeal muscles, in particular the crico-arytenoid muscle, is an increase in the fundamental frequency of phonation. We will use the notation [+BG] to represent the marked breath-group whose archetypal articulatory correlate is this increase in tension of the laryngeal muscles at the end of the breath-group. If the subglottal air pressure were constant the acoustic correlate of the marked breath-group would always be a rising fundamental frequency contour. However, the subglottal air pressure generally falls at the end of the normal unmarked breath-group, which tends to counteract the rising fundamental frequency contour that would occur with a constant subglottal air pressure. The two effects interact and the acoustic correlate of [+BG] may be a level terminal fundamental frequency contour, a rising fundamental frequency contour, or a falling fundamental frequency contour that however falls less than it would have in the absence of the terminal increase in laryngeal tension.

We will use the notation $[+P_s]$ to represent the segmental phonologic feature prominence. The archetypal articulatory correlate of $[+P_s]$ is a momentary increase in the subglottal air pressure that is superimposed on the breath-group by the activity of the respiratory muscles. This momentary increase in subglottal air pressure can occur at any part of the breath-group except at the very end of the breath-group. Let us for the moment also suppose that the presence of this momentary overpressure in the early part of the breath-group results in a lower air pressure at the end of the breath-group. This constraint could have a reasonable physiologic basis if we assumed that the main force involved in the production of the archetypal normal breath-group was provided by the elastic recoil of the lungs while the segmental feature $[+P_s]$ was executed by the added activity of some expiratory muscle or group of expiratory muscles. In any event let us suppose that this constraint on $[+P_s]$ exists, whatever it causes may be[1].

Let us now re-examine the data of the Hadding-Koch and Studdert-Kennedy experiment in the light of these hypotheses. In Fig. 5 six pairs of intonation contours are sketched. The American listeners categorized one member of each pair as a question 80 percent of the time and one member of each pair as a statement 80 percent of the time. Note that the end-points of all the question contours that had a high-point of 310 cps are all approximately 350 cps while the end points of

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1. This effect might be a compensatory reaction to offset a greater volume flow early in the breath-group if volume flow is considered primary and $[+P_s]$ secondary. We will present quantitative physiologic data that indicates that this effect exists whatever its causes may be.

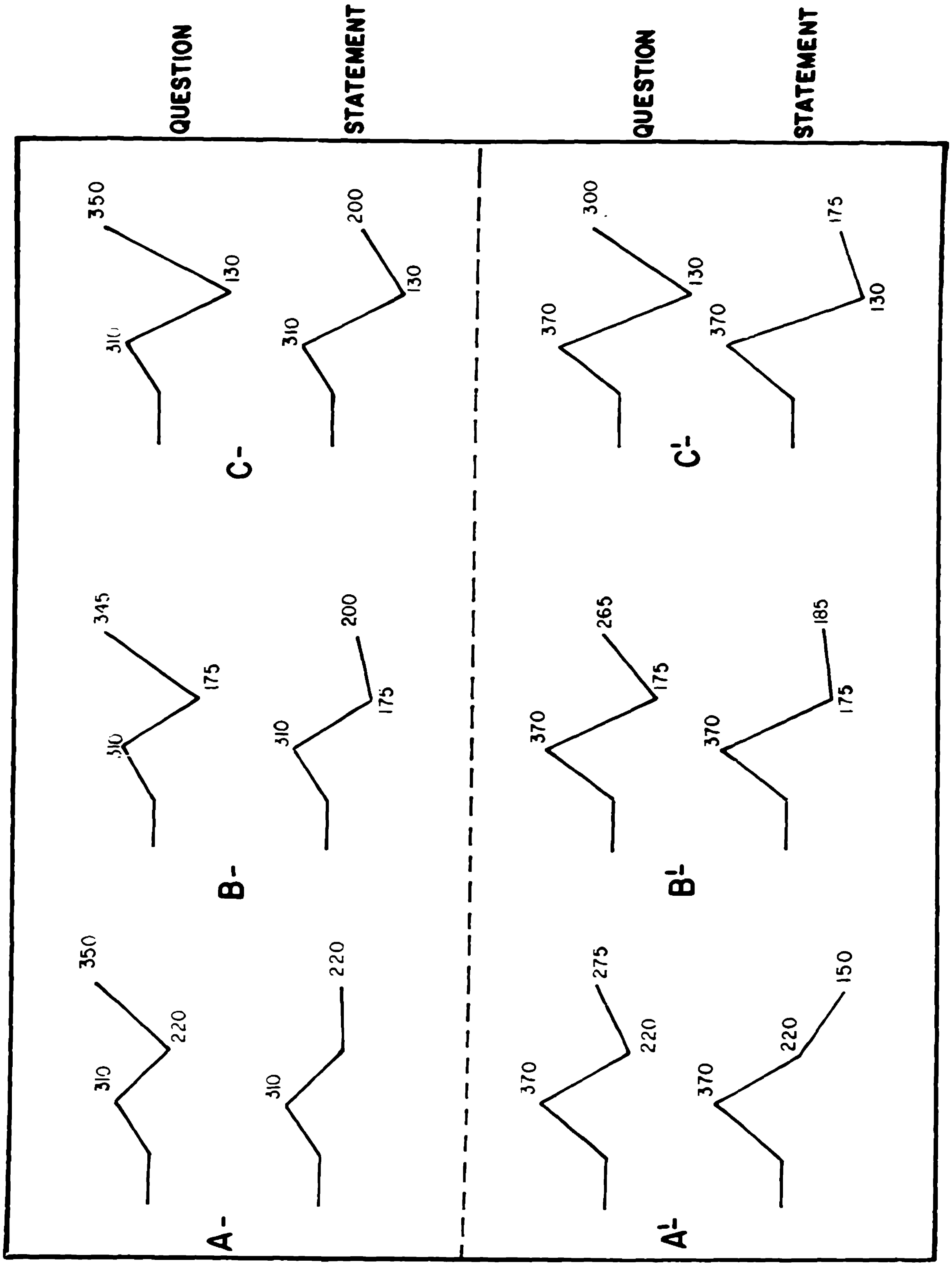

FIGURE 5

Fig. 5

all the contours that had a high-point of 370 cps range from 265 to 305 cps. Also note that the statement end points of all the 310 cps high-point contours range from 200 - 220 cps. The statement end points of the 370 cps high-point contours range from 150 - 185 cps. The question contours that had <u>lower</u> high points all had higher end points. The statement contours that had <u>lower</u> high-points also had higher end points.

In Fig. 6 we have presented two of these contours to make our point clearer. The two contours were identified as questions 80 percent of the time by the American listeners. Note that the end point of the 370 cps high-point contour is only 265 cps while the end point of the 310 cps high-point contour is 335 cps. Why do the listeners perceive the two contours as though they had identical terminal rises?[1] The actual physical rise is obviously not the factor to which the listeners are responding. The terminal rise of the 370 cps high-point contour is 90 cps while the 310 cps high-point contour's terminal rise is 160 cps. The listeners do not seem to be making their judgments in terms of the relative frequency range of the contours. The contour that had the smaller initial fundamental frequency excursion (the 310 cps contour) has the greater terminal rise.

Let us consider our breath-group hypotheses. We would expect to find the constraints imposed by the speech production apparatus to be the

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1. These two contours are ones where the "psychophysical" and "semantic" judgments were in very good agreement.

TWO FUNDAMENTAL FREQUENCY CONTOURS

— DIFFERENT "END POINTS"

— SAME "PSYCHOACOUSTIC" AND "SEMANTI
RESPONSES (AMERICAN LISTENERS), I.E
"ENDING WITH RISING PITCH" AND "QUESTIO

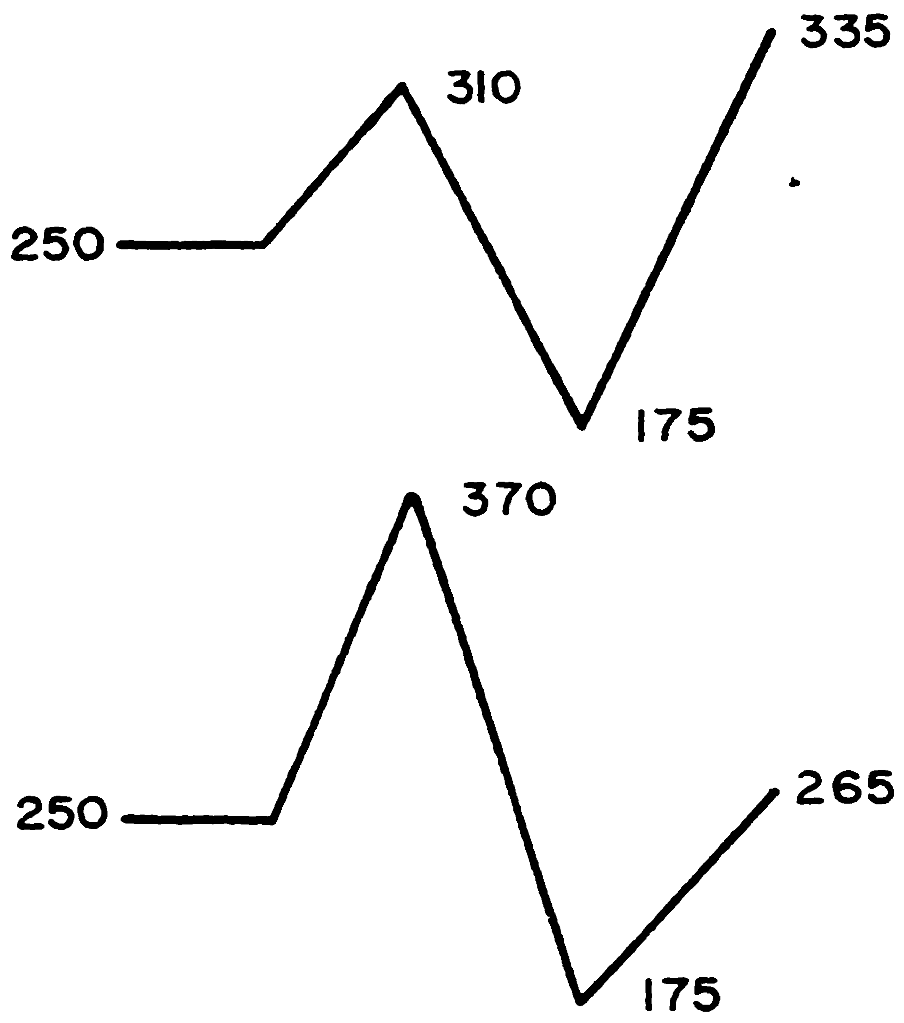

Fig. 6

factors that the listeners consider as they perceive the intonation contours by a process of "analysis by synthesis". The entire contour must be considered as an entity in this process because the listener "knows" that increases in the subglottal air pressure in the early part of the breath-group result in a lower air pressure at the end[1]. The listeners also "know" that not-falling terminal contours in English are due to increases in the tension of the laryngeal muscles which tend to raise the fundamental frequency.

The listeners deduce that the subglottal air pressure was higher at the midpoint of the 370 cps high point contour because f_o is a function of the subglottal air pressure in the non-terminal part of the archetypal breath-group. The listeners therefore deduce that the air pressure at the end of the 370 cps high-point contour is lower than the air pressure at the end of the 310 cps high-point contour because a higher air pressure occurred early in the breath-group[2]. If the two contours were both produced with equivalent degrees of increased laryngeal muscle tension the fundamental frequency at the end of the 310 cps high-point contour would therefore be greater than the fundamental frequency at the end of the 370 cps high-point contour.

The data in Figs. 3 - 6 for the American listeners indicates that the

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1. The listener "knows" this only if our premises are indeed correct. We are trying to state formally the linguistic competence of the listener with regard to the perception and production of intonation, and we are using this example, in effect, as a test of our hypotheses.

2. Some additional constraints must be placed on the two intonation contours that the listener is analyzing. Both contours must have the same duration and the same average subglottal air pressure. We will discuss these constraints in section C-3 in this chapter. The synthesized contours in this psychoacoustic experiment all had the same duration. They all started at the same fundamental frequency so the listeners would have inferred that the same "average" subglottal air pressure was being used for each contour.

listeners apparently make their decision regarding the terminal contour in this way. All the contours that have greater high points are interpreted as questions when they have lower terminal rises, irrespective of the "turning point". In Fig. 7 we have plotted the hypothetical air pressure and laryngeal tension functions for the 310 cps and 370 cps high-point contours. Note that the same laryngeal tension results in a higher f_o at the end of the 310 cps high-point contour. The "high-points" of all the contours were interpreted as though they were produced by means of a momentary increase in the subglottal air pressure over the subglottal air pressure that is typical of the breath-group. The fundamental frequency at the end of the contour then was interpreted as though it was the result of the subglottal air pressure of the now modified breath-group and of increases in the tension of the laryngeal muscles.

The perception of the listeners was keyed to their decisions regarding the possible articulatory gestures that could have produced these stimuli. They heard terminal rises only when they inferred the presence of an increase in the tension of the laryngeal muscles. The confidence of the listeners' responses reflected the calculated magnitude of the increased laryngeal tension. A greater degree of calculated laryngeal tension would be interpreted as a terminal rise more often than would a lower degree of increased tension.

In Fig. 8 we have presented two contours abstracted from the Hadding-Koch and Studdert-Kennedy data that rather strikingly illustrate our point. The same terminal contour is interpreted as a rising contour 80 percent of the time when it is preceded by a 370 cps high-point and as a

HYPOTHETICAL SUBGLOTTAL AIR PRESSURE AND LARYNGEAL TENSION FUNCTIONS

(MARKED BREATH-GROUP)

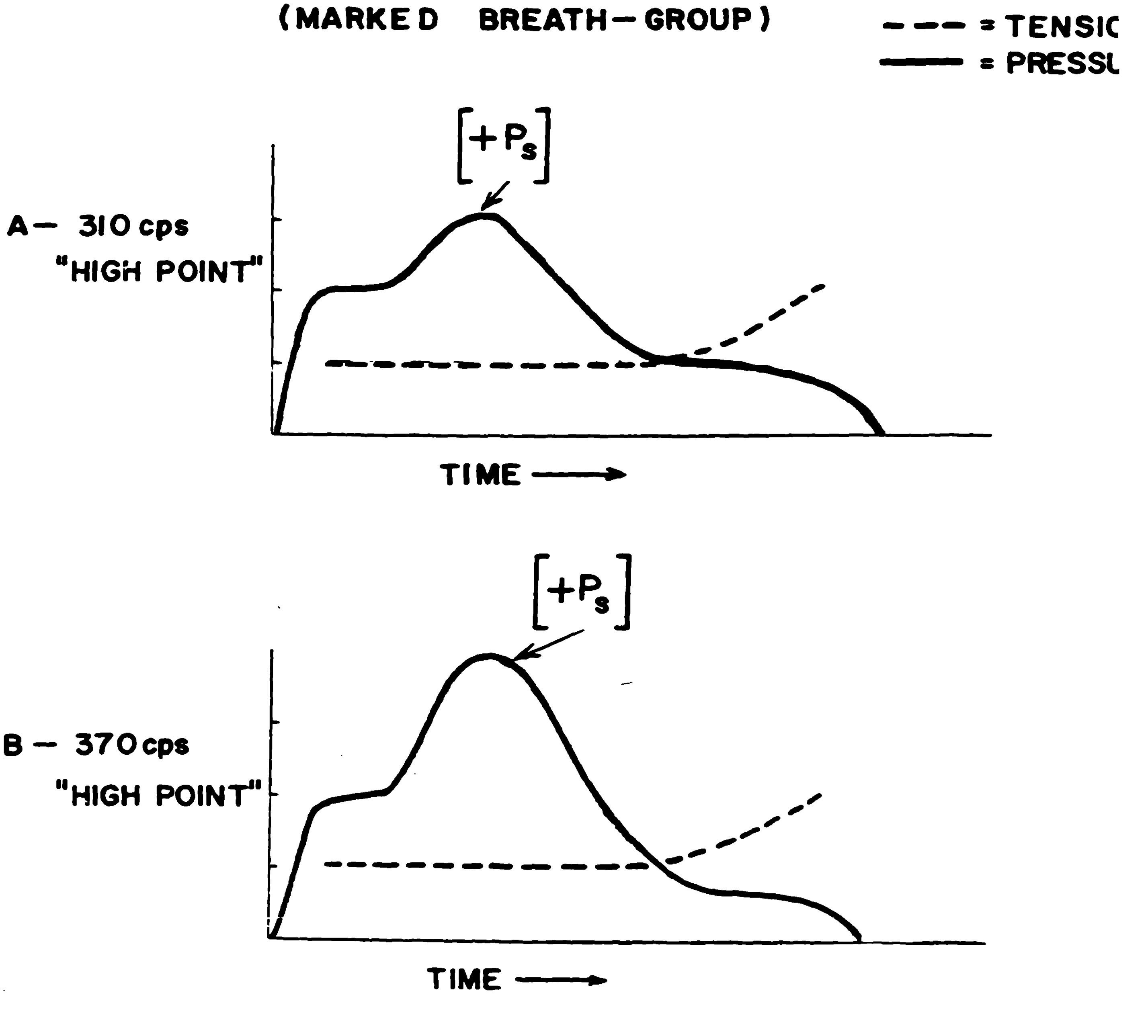

Fig. 7

TWO FUNDAMENTAL FREQUENCY CONTOURS
— IDENTICAL "END POINTS"
— OPPOSITE "SEMANTIC INTERPRETATIONS" (SWEDISH LISTENERS)

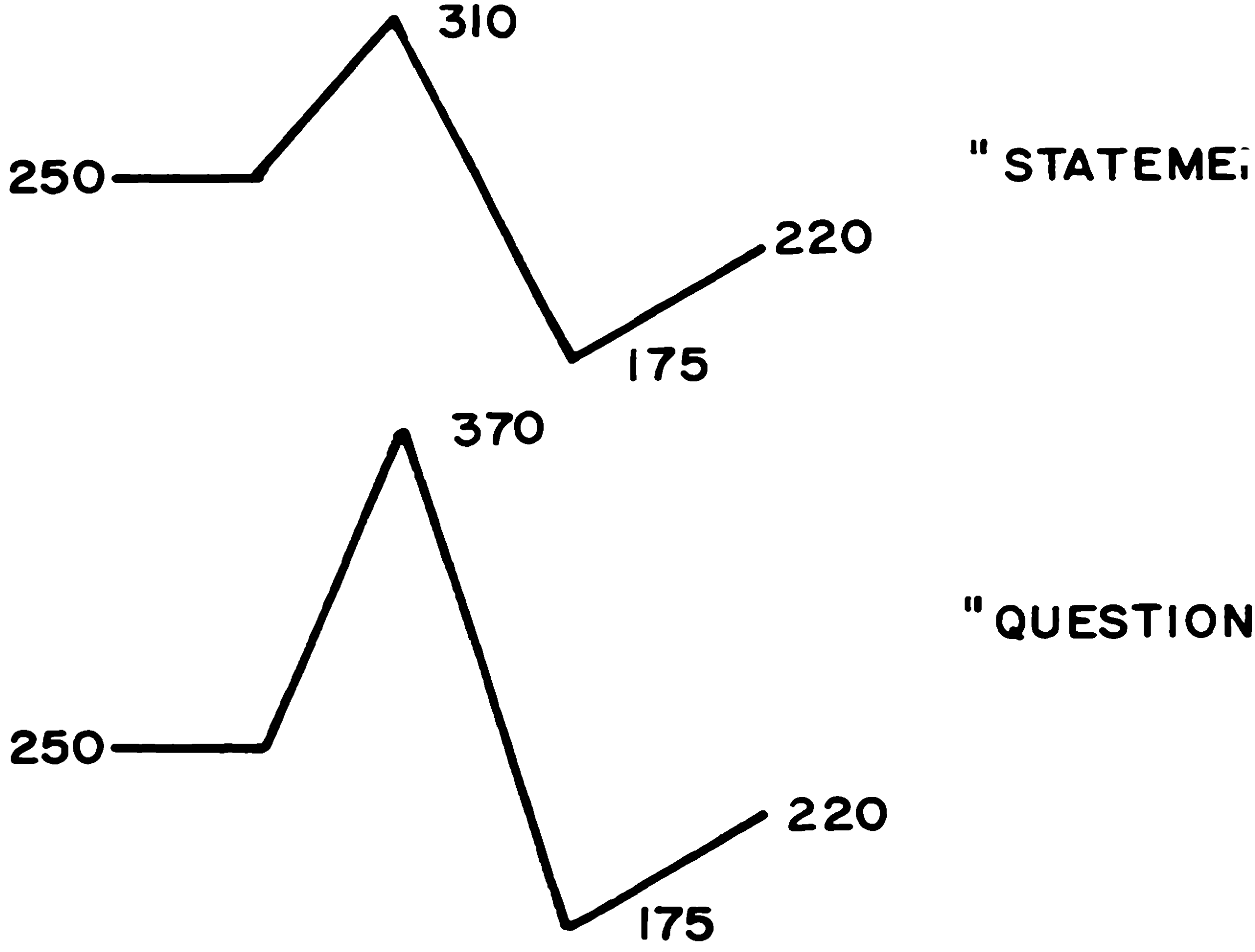

Fig. 8

falling contour 80 percent of the time when it is preceded by a 310 cps high-point. These judgments were made by the Swedish listeners. Similar effects occurred for the American listeners. The Swedish listeners, in general, responded differently to the same contours. In Fig. 9 we have abstracted a set of contours for the Swedish listeners from the data of Figs. 3 and 4. Note that the Swedish listeners also behave in the same way as the American listeners for contours b-b', and c-c'. The terminal rise of the contour does not need to be as high for the utterance to be judged a question when the high-point is higher. For both the Swedish responses to these contours and the American responses to the contours in Fig. 5, a 60 cps high-point difference is approximately equivalent to a 75 to 40 cps end point differences. 370 cps high-point contours having an end point 40 to 75 cps lower than the end point of the corresponding 310 cps high-point contour are categorized as questions at the same level of confidence. The response of the Swedish listeners to contours a and a' is however rather different from the response of the American listeners to these same stimuli.

Now Hadding-Koch points out that traditional phonetic analyses say that Swedish yes-no "...questions may also be distinguished by a comparatively high f_0 throughout the utterance." (Hermann, 1942). The responses of the Swedish listeners to contours a and a' support this view. They indicate that yes-no questions may have two distinct phonetic outputs in Swedish. The speaker may modify the basic breath-group by increasing the tension of the laryngeal muscles at the end of the breath-group as is the case for English. The Swedish listeners, like the American listeners,

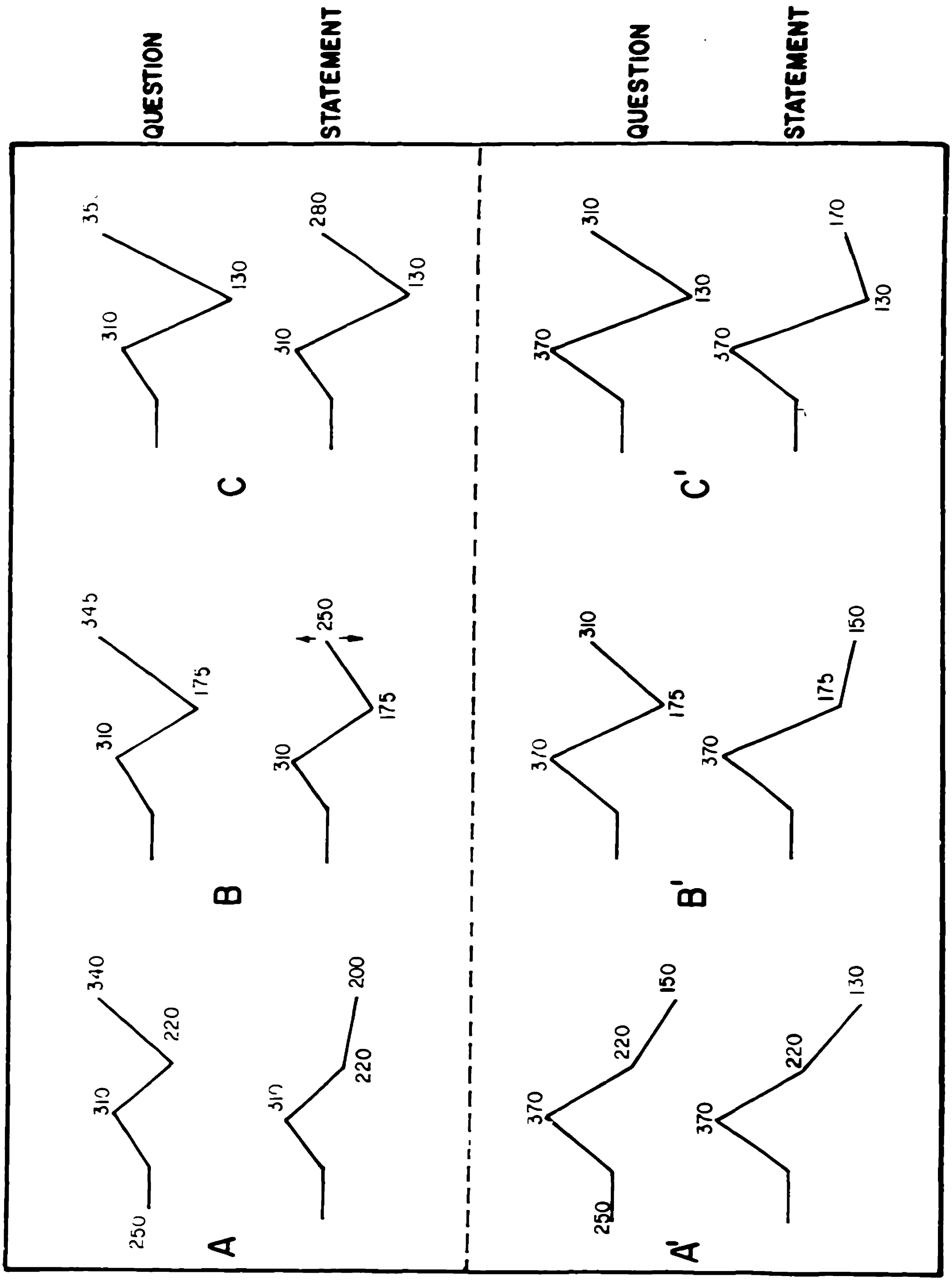

Fig. 9

seem to interpret contours b-b' and c-c', which have a fundamental frequency prominence at their midpoint, as contours modified by a subglottal pressure peak. The terminal rises are then apparently ascribed to the effect of an increased laryngeal tension. The fundamental frequency is a function of the interaction of the subglottal air pressure and the increased tension of the laryngeal muscles. The listeners apparently use a rather complex recognition routine in which they consider what degree of laryngeal tension would produce a particular terminal fundamental frequency, given the subglottal air pressure at the end of the contour. The subglottal air pressure at the end of the contour is a function of the subglottal air pressure peak at the midpoint of the contour. The key to the problem is the fundamental frequency at the midpoint of the contour, which is interpreted as though it were produced by means of an extra high subglottal air pressure superimposed upon the normal breath-group of the language.

In Swedish a yes-no question may also result in a phonetic output in which the laryngeal tension is raised throughout the entire breath-group. When a Swedish listener hears contour a' he interprets it as a breath-group in which the tension of the laryngeal muscles throughout the entire utterance is higher than is the case for the normal breath-group. The listener notes that the fundamental frequency does not fall at the "turning point". Contour a's turning point is 220 cps while the other contours' turning points are 175 and 130 cps. The fundamental frequency rise at the high-point is therefore interpreted as the acoustic output of a generally high laryngeal muscle tension rather than a transitory air pressure peak, as is the case for the other contours where the fundamental frequency abruptly falls after the high-point. Hadding-Koch and Studdert-Kennedy noted that the so-called "semantic" and "psycho-physical" judgments of the listeners did not agree as well for the Swedish listeners as they did for the American listeners. This anamoly is quite consistent with this reasoning.

In American English, yes-no questions are always produced with a marked breath-group. If listeners are asked to categorize signals according to whether they end with a rising fundamental frequency contour or whether they are questions, they will form the same categories. In Swedish a yes-no question can apparently be produced with either a marked breath-group or a breath-group that has generally a high laryngeal tension. The "psychoacoustic" responses where the listeners were asked to identify terminal rising fundamental frequency contours therefore sorted out the contours that were produced with a marked breath-group. The "question" responses sorted out both the contours that were produced with marked breath-groups and the contours which were produced by a generally high laryngeal tension throughout the breath-group.

Implications of the Perceptual Experiment

The responses of the listeners to the stimuli of this experiment could obviously be represented by means of a set of empirical functions that would fit the curves plotted in Figs. 2, 3, and 4. What we have instead proposed is that the listeners perceive these signals by means of a feedback mechanism of the analysis-by-synthesis type, in which they use their knowledge of the phonologic features that produce intonational signals. We hypothesized that the listeners used the archetypal or primary articulatory correlates of these features which we tried to motivate in terms of the physiologic and perceptual constraints of the speech production apparatus and the auditory system. These constraints obviously have an innate basis and in chapter two we showed that the archetypal unmarked breath-group was manifested in the first utterances of neonates. We are saying, in other words, that the intonational signal is perceived in terms of these archetypal patterns because they represent the most basic way in which intonational signals can be produced using the human vocal tract. The listeners respond to the intonation signals in this way precisely because the intonation contours are speech signals that are normally produced by the human vocal tract. The effects noted in the Hadding-Koch and Studdert-Kennedy experiment in fact tend to disappear when listeners hear non-speech stimuli like pure tones. The perception of terminal rising fundamental frequency contours is, for example, almost independent of the initial "high point" of the contour[1].

Our discussion of the articulatory activity that underlies Swedish intonation must, for the most, rest on these perceptual experiments which

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1. Personal communication from Michael Studdert-Kennedy.

obviously are not definitive[1]. However, we have direct physiologic evidence available for American English which quantitatively supports our hypotheses regarding both the nature and the primacy of the archetypal correlates of the breath-group and the feature $[P_s]$ as well as the alternative articulatory maneuvers that can produce equivalent acoustic or perceptual results.

B - Physiologic and Acoustic Data for American English

The following experiment was performed using special equipment, techniques and facilities devised by Dr. Jere Mead of the Harvard School of Public Health, Dr. Donald F. Proctor of the Johns Hopkins University, and Dr. Arend Bouhuys of the John B. Pierce Foundation. These investigators have been pursuing an investigation of the activity of the respiratory system during phonation. Much of their work has involved the respiratory physiology of singing, and the experiment that we will describe was conducted as part of a session in which singing was also studied.

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1. The amplitude of the speech signal remained fairly constant for all the stimuli generated by Hadding-Koch and Studdert-Kennedy, which may have prevented the listeners from responding precisely as they would have if they were listening to natural speech stimuli.

(1) - Procedure

Four native male speakers of American English each recorded a list of sentences and words under several different conditions. Each speaker was recorded in a separate session. Two speakers were medical students. The other two were medical faculty members. The speaker sat in a sealed body plethysmograph which allowed the volume events during phonation to be measured. The plethysomograph is essentially a sealed box in which the subject sits with his head projecting out through a rubber dam. Volume changes due to both the displacement of air from the respiratory system and the compression of gas can be accurately measured with this apparatus (Mead and Milic-Emili, 1964).

The esophageal air pressure was measured by means of a 10 cm long balloon which was attached through a flexible plastic tube to a manometer. The balloon was introduced through the subject's nose so that it did not interfere with normal phonation. The balloon was positioned by first bringing it up into the upper part of the esophagus until artifacts due to the motion of the neck were registered. The balloon was then lowered about one cm. Artifacts due to the motion of the neck are registered if the balloon is positioned too high.

The esophageal pressure was recorded with a Sanborn 268B transducer. The bandwidth of the pressure recording system was in excess of 50 cps. The pressure recorded by the balloon is the pleural pressure relative to atmospheric. The lungs are isolated from the chest walls and the esophagus by the pleural membranes. The balloon therefore does not record the pressure in the lungs. However, it is comparatively simple to calculate the subglottal air pressure since the pleural pressure equals the pressure in the terminal air sacs (alveoli) of the lungs minus the static recoil pressure of the lung tissue. The static recoil pressure of the lungs, P_{st}, is a function of the volume of the lungs. As the lungs distend the static recoil force increases. The static recoil pressure can be determined for any speaker as a function of the lung volume by instructing the speaker to hold his breath with his airways open for various lung volumes. P_{pl} will be equal to $-P_{st}$ under these conditions. The alveolar pressure can then be determined for other conditions when the speaker does not hold his breath if the volume of the speaker's lungs is known.

During phonation most of the pressure drop in the respiratory system takes place at the glottis so that alveolar pressure is approximately equal to the subglottal air pressure. The subglottal air pressure can thus be calculated from the esophageal balloon pressure for steady state conditions if stimultaneous recordings of the volume of the lungs and the balloon pressure are available. For transient conditions the calculated subglottal air pressure must be regarded as an approximation of the true subglottal air pressure. When we made quantitative measurements that involved the subglottal air pressure we therefore tried to use only the quasi-steady state portions of the calculated pressure functions where the subglottal pressure was relatively steady[1]. A detailed description of the techniques involved in the measurement of subglottal pressure may be found in Bouhuys, Proctor, and Mead, (1965).

The subjects each sang a series of sustained notes at low, medium and high intensities. They then read the list of sentences and words presented in Table I at a normal speaking level and at a loud speaking level. The subjects were unaware of the particular objectives of this experiment and they had no knowledge either of formal linguistic theories or of acoustic phonetics. They were instructed to read the sentences in a natural way and were cautioned to avoid "acting". The subjects first read the material at a normal speaking level. They were asked to read the number of each sentence or word and then read the sentence or word twice. The acoustic signal was recorded by means of a Shure Bros. type 98108 microphone that was placed 2-3 inches from the speaker's lips. The speech signal, balloon pressure, and lung volume were all recorded on a multichannel F. M. tape recorder. The speech signal was also simultaneously recorded on an Ampex type 300 audio tape recorder, at 7 1/2 inches per second.

The balloon pressure curves and volume data were then simultaneously plotted on a multichannel polygraph pen and ink recorder at a paper speed of 5 cm/sec. An additional channel was used to provide an approximate indication of the amplitude of the speech signal by driving one of the polygraph gavanometers with the speech signal. Normal sound spectrograms were made of some of the utterances on a Voiceprint Sound Spectrograph using the linear 3kc display. Quantized spectrograms were made using

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1. The quasi-steady state portions of the P_s function had variations of less than 0.2 cm H_2O over 100 msec.

TABLE I

SENTENCES

1. The life of a light house keeper formerly was very lonely.
2. The Pennsylvania Railroad still goes to New York City.
3. Did Joe eat his soup?
4. Our maid weighted 180 pounds but the Jones's had a light house keeper for more than twenty years.
5. Joe ate his soup, didn't he?
6. Did <u>Joe</u> eat his soup? (Joe doesn't usually eat soup.)
7. Grandfather was a rebel at heart because he was born in Alabama.
8. Joe ate his soup?
9. The peasants were induced to rebel from their masters.
10. Because so many electrical aids are available, the life of a light house keeper fortunately isn't very difficult these days.
11. Did Joe eat <u>his</u> soup? (He sometimes eats Bill's soup.)
12. Did Joe eat his <u>soup</u>? (He hardly ever eats soup.)
13. The number that you will hear is nine.
14. Joe ate his soup!
15. The number that you will hear is ten.
16. Joe ate his <u>soup</u>!
17. A stitch in time saves nine.
18. Joe ate his soup.
19. <u>Joe</u> ate his soup!
20. A stitch in time saves ten.
21. Joe didn't eat soup, did he?
22. You're going to drive down that rutted road?

WORDS

1. Pennsylvania Railroad
2. rebel (noun as in grandfather was a rebel)
3. rebel (verb to rebel)
4. light house keeper (someone who tends a light house)
5. light house keeper (a not-heavy house keeper)
6. light house keeper (a woman who dusts her house)
7. nine
8. ten

the 7.5 kc logarithmic display. Both narrow band (50 cps) and wide band (300 cps) sound spectrograms were made.

The subglottal air pressure was derived by graphically subtracting the elastic recoil force from the pleural pressure recorded by the esophageal balloon. A pantograph was then used to retrace the calculated subglottal air pressure and the measured volume plots to the same time scale as the sound spectrograms. Synchronizing signals had been added to an earlier stage of the processing to both the sound spectrograms and the volumetric and pressure data so it was possible to line up the spectrograms and the volume and pressure tracings with an accuracy of approximately ± 40 msec.

(2) - General Observations

The subjects, in general, followed their instructions. One speaker did not repeat each sentence or word when he read at his normal speaking level. Another speaker read the number of the sentence before he repeated the sentence. One of the speakers also tended to dramatize his readings. In all the speakers read 462 sentences and 91 words. Each sentence in Table I was read 21 times and each word was read at least 11 times[1]. The numbers that identified the words or sentences were read a total of 402 times.

It was, of course, possible to determine the expiratory and inspiratory portions of the speakers' respiratory cycles by looking at the lung volume tracings. We found that 456 of the sentences and 85 of

---

1. One of the speakers found it impossible to distinguish between word 6 and words 4 and 5 and refused to read it.

the words were produced on a single expiration regardless of the duration of the utterance. The speaker ended the expiration when he finished the sentence or word. The duration of these expirations ranged from 300 msec to 9 seconds. Two of the longer sentences were twice uttered using two expirations separated by a short inspiration. In two instances the two repetitions of the same sentence were uttered on one expiration. In three instances the two repetitions of the same word were uttered on one expiration. Thus 99.2 percent of the sentences or words were uttered on a single expiration. The length of the expiration was determined by the time that it took to utter the words that were part of the complete sentence. The length of the expiration was apparently linguistically conditioned.

Now it might be argued that each sentence or word was uttered on a single expiration because the utterances were in a list which caused the subjects to pause between each utterance. This argument however does not explain why the subjects used separate expirations when they repeated each utterance. The treatment of the introductory numbers is also significant. The introductory numbers must be treated formally as one word sentences[1]. The number that precedes each utterance is semantically and syntactically independent of the word or utterance that follows. Three of the subjects used a separate expiration for the introductory number 84 percent of the time. The fourth speaker used a separate expiration only 57 percent of the time. The striking fact

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1. The single isolated words may be regarded as limiting cases or deleted metalinguistic sentences of the form, "The word you will hear is ________."

about the subglottal air pressure plots for all the introductory numbers is that they all have the same "shape" whether or not the speaker ended the expiration after he uttered the introductory number. The speaker manipulated his respiratory muscles to produce a sterotyped subglottal air pressure curve whether he paused for an inspiration or not. The air pressure curves of the two sentences that were produced on the same expiration[1] also looked as though the speaker had paused for an inspiration, though in fact he did not. This data seems to indicate that the speakers in these cases used the air pressure contour that would have resulted from a single bounded expiration to segment the speech signal into complete sentences. The combined statistics for all of the introductory numbers and the test words and sentences show that a single expiration was used for each "sentence" 87 percent of the time. The air pressure contour that resulted from the activity of the respiratory muscles during a single expiration was used to segment the speech signal. In the other instances the speakers used alternate patterns of muscular activity to produce air pressure contours that were indistinguishable from the contours that occurred when expiration actually ended. The subglottal air pressure contour that occurred during a single expiration thus seemed to serve as an archetypal pattern for segmenting the speech signal into sentences.

The data that follows will be used to illustrate more precisely the articulatory and acoustic correlates of the marked and the unmarked

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1. The long sentences that were produced with two breath-groups represent another phenomenon. The speaker used a marked breath-group, [+BG], to indicate that the sentence was not yet over (c.f. chapter four).

breath-groups of American English and the segmental feature $[+P_s]$. We will also present data which shows that speakers sometimes use alternate articulatory maneuvers that produce a speech signal that is acoustically or perceptually equivalent to the signal that is produced with the archetypal maneuver.

The speaker can obviously raise the fundamental frequency at the end of the sentence by means of a subglottal overpressure. He can also raise the fundamental frequency in the middle of the breath-group by increasing the tension of his laryngeal muscles. The acoustic correlates of increased subglottal air pressure and laryngeal tension tend to overlap as we have seen in chapter one. However, the speaker "knows" that the listener will always perceive the acoustic signal as though it had been produced by the preferred archetypal pattern. The speaker can thus use equivalent articulatory gestures.

We will examine representative utterances of three of our four speakers. The utterances of speaker four, who produced exaggerated effects, will be omitted from this discussion. Speaker four's air pressure data also shows strong interference from his heartbeat, which makes it difficult to use his data.

(3) - Data on Individual Sentences - Speaker One

In Fig. 10 the subglottal air pressure, fundamental frequency and the volume of air in the speaker's lungs are plotted as functions of time for speaker one when he read sentence 18, "Joe ate his soup," at a normal speaking level. A quantized wide band (300 cps analyzing filter bandwidth) sound spectrogram is also presented. Time is plotted with

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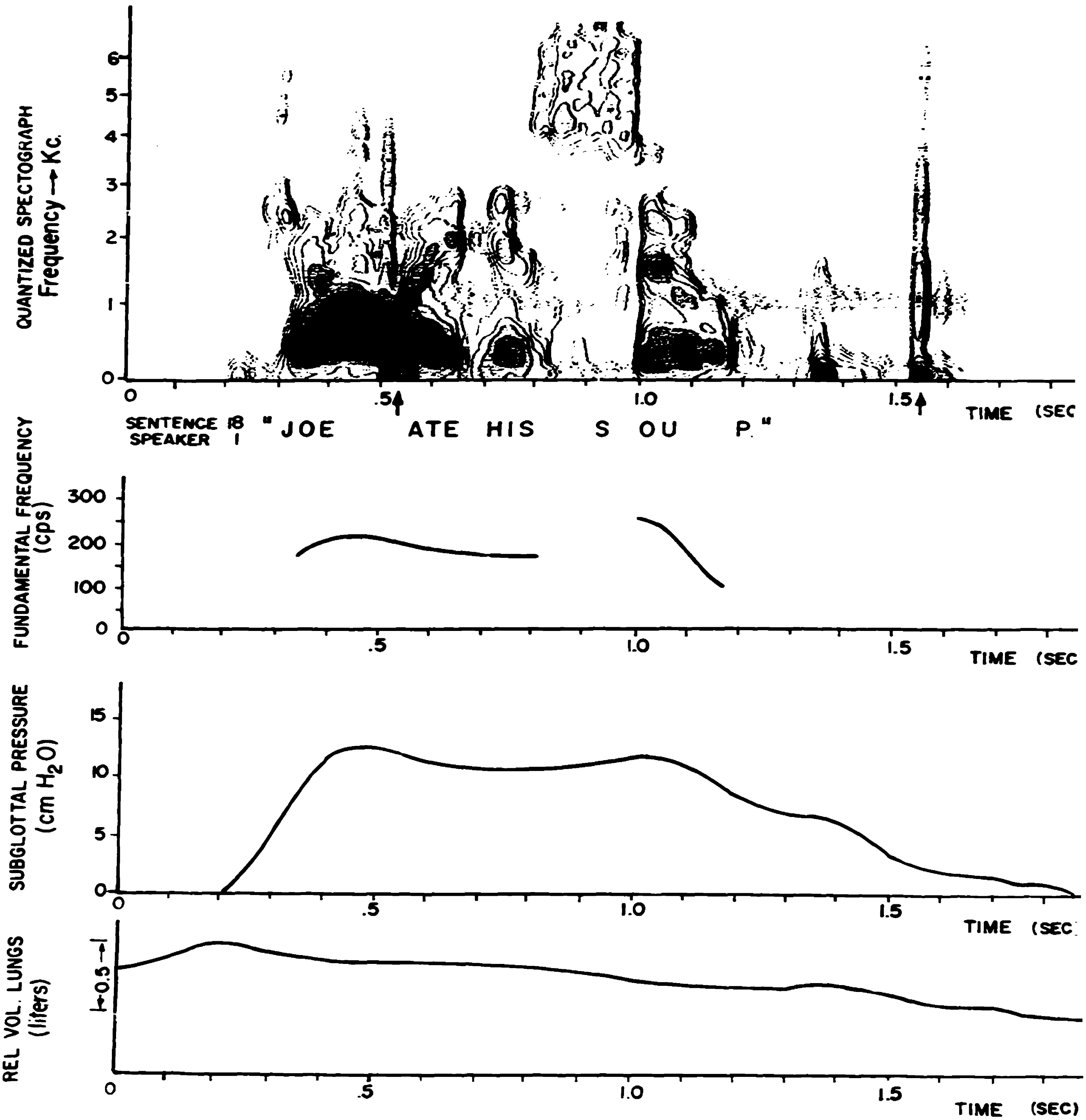
1. The sound spectrogram is quantized in 6 db steps. The plot is similar to a topographic map. Each contour represents a 6 db increment in amplitude.



QUANTIZED SPECTOGRAPH
Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME (SEC
SENTENCE 18
SPEAKER 1
"JOE ATE HIS S OU P."
FUNDAMENTAL FREQUENCY
(cps)
300
200
100
0
0
.5
1.0
1.5
TIME (SEC
SUBGLOTTAL PRESSURE
(cm H2O)
15
10
5
0
0
.5
1.0
1.5
TIME (SEC
REL VOL. LUNGS
(liters)
0.5
0
.5
1.0
1.5
TIME (SEC)

Fig. 10

respect to the abscissa. A logarithmic frequency scale that extends from 50 cps to 7.0 kc is plotted on the ordinate of the sound spectrograph. The synchronizing signals which were introduced to facilitate lining up the sound spectrogram. with the other plots are all marked by means of vertical arrows placed below the abscissa of the sound spectrogram. In Fig. 10 synchronizing signals are marked immediately after 0.5 sec and 1.5 sec. The fundamental frequency[1] is plotted in cps in the graph below the spectrogram. The subglottal air pressure is plotted in cm of water and the relative volume of air in the speaker's lungs is plotted in liters.

The speaker was uttering a short unemphatic declarative sentence. If our hypotheses are correct he should have been using an unmarked breath-group. If he were using the archetypal articulatory pattern he should therefore have used one expiration to produce the sentence and the tension of his laryngeal muscles should have been unchanged throughout the sentence. Note that the speaker approximated the archetypal pattern of articulatory gestures to produce an unmarked breath-group. The fundamental frequency curve follows the subglottal air pressure curve except for the vicinity of 1.0 sec, where it is higher. At the start of the sentence both the subglottal air pressure and fundamental frequency gradually rise and then fall. At the end of the sentence both the subglottal air pressure and the fundamental frequency fall. The subglottal air pressure, p_s, is 12.8 cm of water when the

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1. The fundamental frequency was derived by plotting the 5th harmonic of the fundamental frequency on a narrow band spectrograph that was made using the linear 3.0 kc frequency display.

contour is at its highest f_o, (230 cps); p_s is 10.5 cm when f_o falls to 170 cps and p_s is 7.8 cm at the end of the contour when f_o is 110 cps. At the start of the sentence p_s is 8.5 cm and f_o is 170 cps. If we were to assume that the tension of the laryngeal muscles was constant over the entire breath-group than we should expect to find that the fundamental frequency was a linearly increasing function of the subglottal air pressure. This is approximately the case. At the start of the sentence the subglottal air pressure seems to have less of an effect on the fundamental frequency but this discrepancy may reflect the uncertainty (± 40 msec) of the synchronization between the acoustic signal recorded by the microphone and the balloon pressure transducer. The air pressure varies quite rapidly at the start of the sentence and a small time error can result in a large pressure discrepancy. In Fig. 17 we have plotted the fundamental frequency versus the subglottal pressure for the points measured on the quasi-steady state portions of the air pressure and fundamental frequency functions of Figs. 10-12.

Note that there is a time delay of approximately 130 msec[1] from the beginning of expiration when the subglottal pressure starts to rise (0 cm of water) to the point where phonation starts. In chapter one we noted that it takes approximately 100 msec for the vocal cords to move from their open inspiratory configuration into the proper configuration for phonation. The data presented in Fig. 10 shows that a similar delay occurs between the initiation of the expiratory air

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1. We measured all time relationships on the unquantized wide band spectrograms where it was easier to see the onset and end of speech.

flow and the start of phonation. We have plotted this delay, which we will call the "phonation delay", and the initial subglottal air pressure in Fig. 34. We will plot on this figure all the phonation delays and initial subglottal air pressure for all of the data that will follow.

In Fig. 11 we have presented the data that was obtained when speaker one read sentence 19, "Joe ate his soup." All the data that follows will be for the sentences that were read at a normal speaking level. Note that there is a 180 msec delay between the start or the gradual rise of the subglottal pressure and the start of phonation. Note that in a qualitative sense, the fundamental frequency again seems to be an increasing function of the subglottal air pressure.

The subglottal pressure is 9.0 cm at the beginning of the word soup in Fig. 10. The subglottal air pressure is of course higher on the word Joe in Fig. 11, where it is 17.5 cm. In Fig. 10 the subglottal pressure is 12.5 cm for the word Joe. The speaker has emphasized the word Joe in Fig. 11 by means of a momentary increase in the subglottal air pressure. When we discussed the results of the Hadding-Koch and Studdert-Kennedy psychoacoustic data we hypothesized that a subglottal overpressure in one part of the breath-group would lower the subglottal air pressure elsewhere. We also said that the listeners would ascribe fundamental frequency prominences in the non-terminal portion of the breath-group to momentary increases in the subglottal air pressure.

The fundamental frequency contour of the sentence in Fig. 11 has a high peak fundamental frequency early in its breath-group on the word Joe. We can see that the articulatory gesture that is responsible for

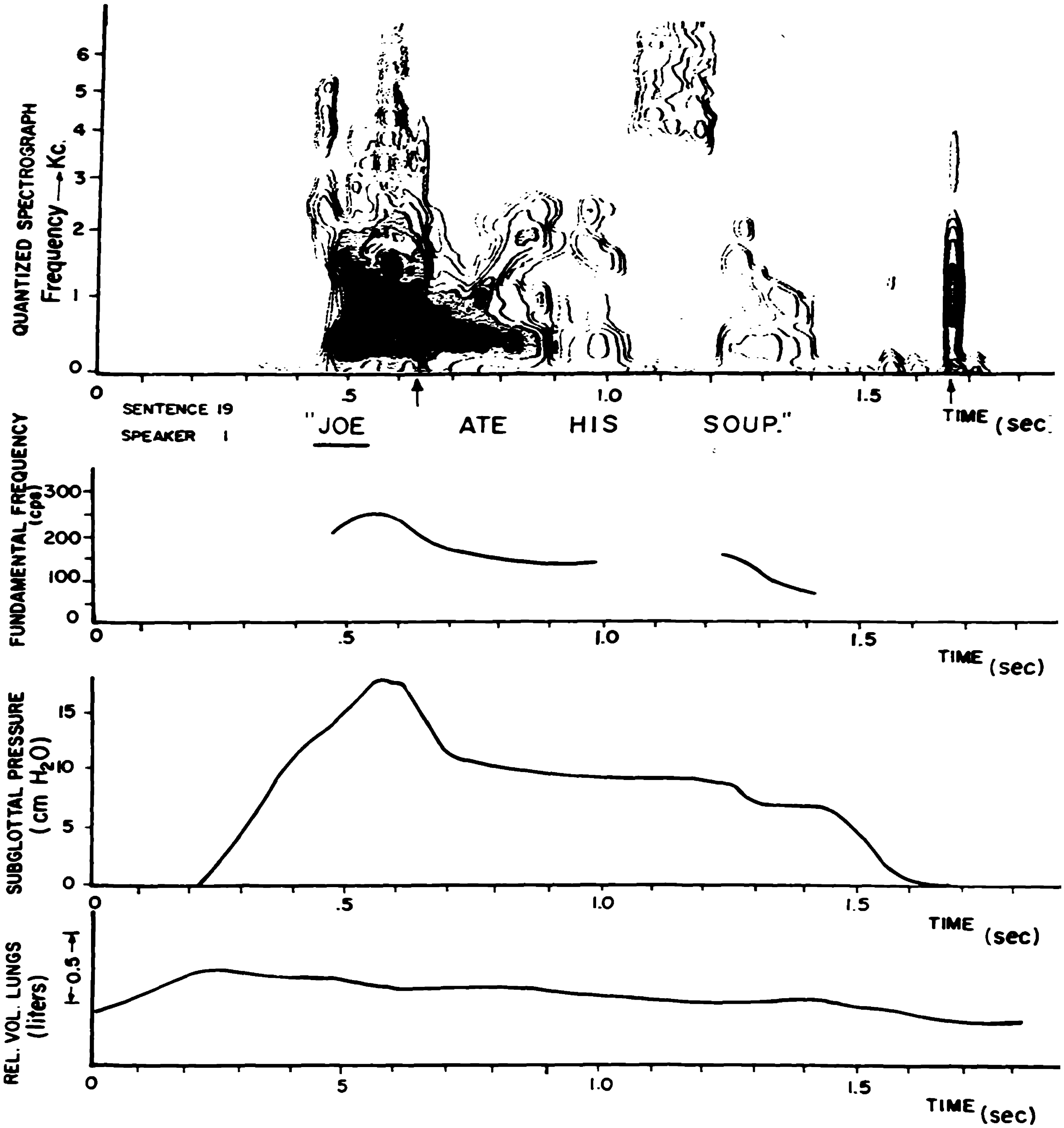
QUANTIZED SPECTROGRAPH
Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
SENTENCE 19
SPEAKER 1
"JOE ATE HIS SOUP."
TIME (sec)
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME (sec)
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
0
.5
1.0
1.5
TIME (sec)
REL. VOL. LUNGS (liters)
0.5
0
5
1.0
1.5
TIME (sec)

Fig. 11

this peak is, in fact, a momentary increase in the subglottal air pressure. The subglottal air pressure at the end of this breath-group is 2.7 cm lower than it is at the corresponding point in the breath-group of sentence 18 in Fig. 10.

The physiologic evidence therefore supports our "air pressure perturbation" hypothesis since the presence of the subglottal air pressure prominence early in the breath-group lowers the air pressure at the end of the breath-group 2.7 cm. In Fig. 17, where the fundamental frequency has been plotted with respect to subglottal air pressure for these sentences, we can see that the fundamental frequency varies at the rate of 16-20 cps per cm of water. If the tension of the laryngeal muscles followed the same pattern in both breath-groups the fundamental frequency would thus be approximately 50 cps lower at the end of the contour that had the higher initial subglottal pressure peak.

In the psychoacoustic experiment which we discussed earlier, the American listeners needed a lower terminal fundamental frequency to "hear" a terminal rise when the contour had a higher initial fundamental frequency prominence. An intonation contour, for example, would be heard as a "question" 80 percent of the time when its terminal fundamental frequency was 40 - 80 cps lower than the terminal fundamental frequency of a similar contour that had a lower initial fundamental frequency prominence (c.f. Fig. 5). The 50 cps "terminal fundamental frequency adjustment" that we would expect from the subglottal air pressure contour of Fig. 11 is thus within the range of the perceived fundamental frequency compensations that occurred in the independent psychoacoustic experiment. Note that the breath-groups in Figs. 10 and 11 both have similar durations and similar "average" subglottal air pressures. We will return to the constraints that must be placed upon the role of the "air pressure perturbation" hypothesis in section C-3.

In Fig. 12 we have plotted the data for sentence 16. The phonation delay and the initial subglottal pressure, and the fundamental frequency versus subglottal pressure data, have been entered in Figs. 34 and 17. The subglottal air pressure and fundamental frequency data fall into line with the data from Figs. 10 and 11 on Fig. 17. The phonation delay is again 130 msec. Note that the terminal fundamental frequency and subglottal pressure contours fall though the speaker has raised the subglottal air pressure at the start of the word soup.

The acoustic correlates of the subglottal pressure peaks in Fig. 11 and Fig. 12 were higher fundamental frequencies and greater envelope amplitudes. The duration of the words that received the peak subglottal air pressures were also longer in the utterances plotted in Figs. 11 and 12 than they were in the unemphatic utterance plotted in Fig. 10. The diphthong in soup has a duration of 220 msec in Fig. 12 where it received the peak subglottal air pressure. It had a duration of 180 msec in Figs. 10 and 11 where it did not receive the peak subglottal air pressure. The diphthong in Joe had a duration of 220 msec in Fig. 10 where it was not emphasized. It had a duration of 270 msec. in Fig. 11 where it received the peak subglottal pressure and 2. It had, however, a duration of 260 msec in Fig. 12 where it did not receive the peak subglottal air pressure. The total duration of the utterance in Fig. 10 was 900 msec. The total duration of the utterance plotted in Fig. 11 was 980 msec while the duration of the utterance in Fig. 12 was 1000 msec. Longer durations thus seem to be associated with the words that received the peak subglottal

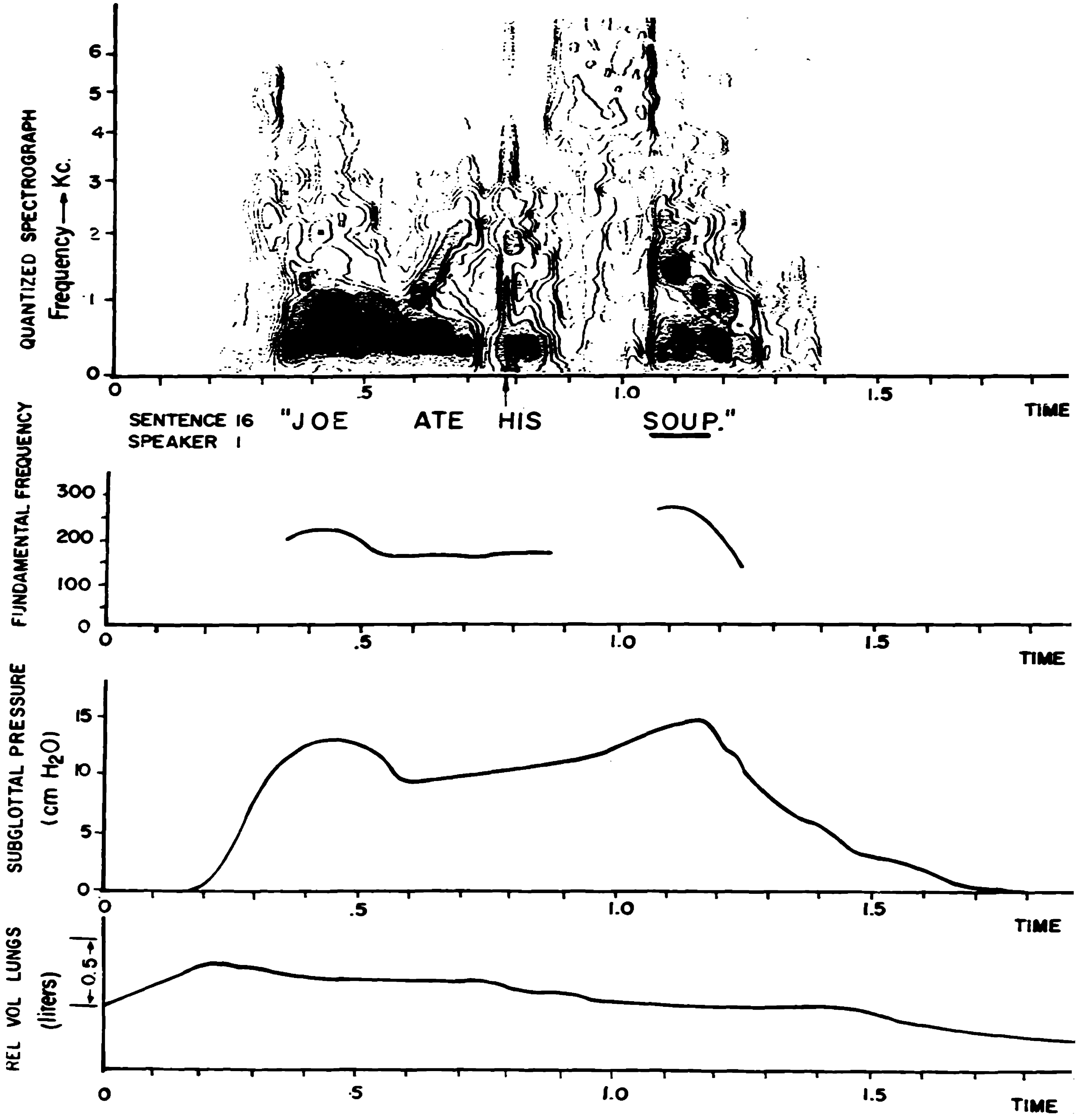
QUANTIZED SPECTROGRAPH
Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
SENTENCE 16
SPEAKER 1
"JOE ATE HIS SOUP."
FUNDAMENTAL FREQUENCY
300
200
100
0
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE
(cm H2O)
15
10
5
0
0
.5
1.0
1.5
TIME
REL VOL LUNGS
(liters)
0.5
0
.5
1.0
1.5
TIME

Fig. 12

air pressure. However, there may not be any causal relationship between the peak subglottal air pressure and the longer duration. The speaker may independently increase duration when he wants to emphasize a word. We will present other data that indicates that this seems to be what happens. The speaker can increase the duration of the vowel of an emphasized word without placing a momentary increase in subglottal air pressure on the vowel.

In Fig. 13 data derived from speaker one reading sentence three, "Did Joe eat his soup?" is presented. The plot of the volume of air in his lungs is not presented in this figure. Note that the shape of the air pressure plot is quite similar to that of Fig. 10 for the unemphasized declarative sentence, "Joe ate his soup." However, the fundamental frequency rises at the end of sentence three, though the subglottal air pressure is falling. The subglottal air pressure at the beginning of the vocalic portion of the word soup is 6.8 cm. It falls at 4.6 cm at the end of phonation.

If the tension of the laryngeal muscles were held constant at the end of this utterance we would expect the fundamental frequency to fall approximately 45 cps. The fundamental frequency instead rises 50 cps at the end of the breath-group. The speaker must therefore be tensioning his laryngeal muscles to produce a 100 cps rise in the fundamental

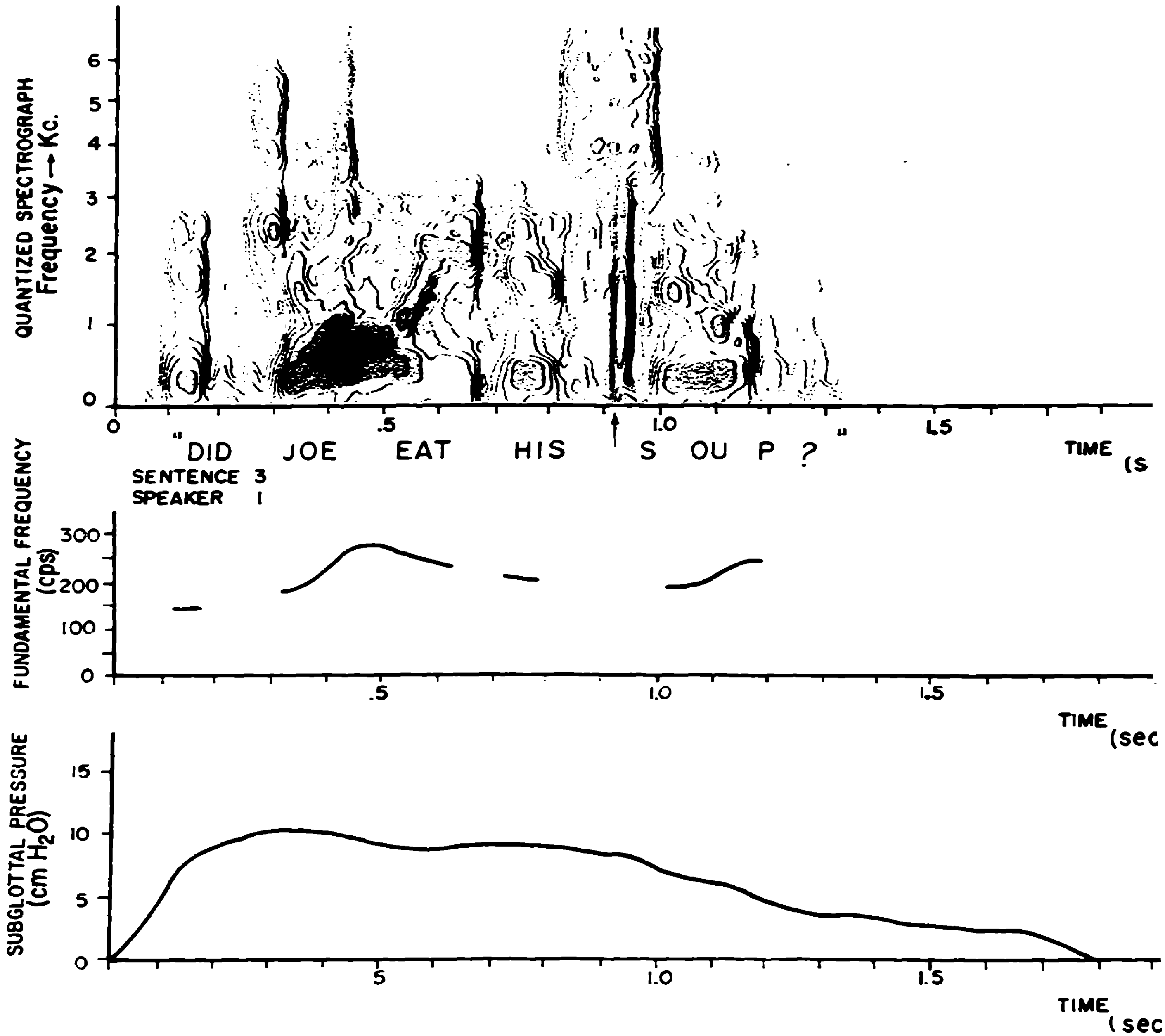
QUANTIZED SPECTROGRAPH
Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
"DID JOE EAT HIS S OU P ?"
TIME (s
SENTENCE 3
SPEAKER 1
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
.5
1.0
1.5
TIME (sec
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
5
1.0
1.5
TIME (sec

Fig. 13

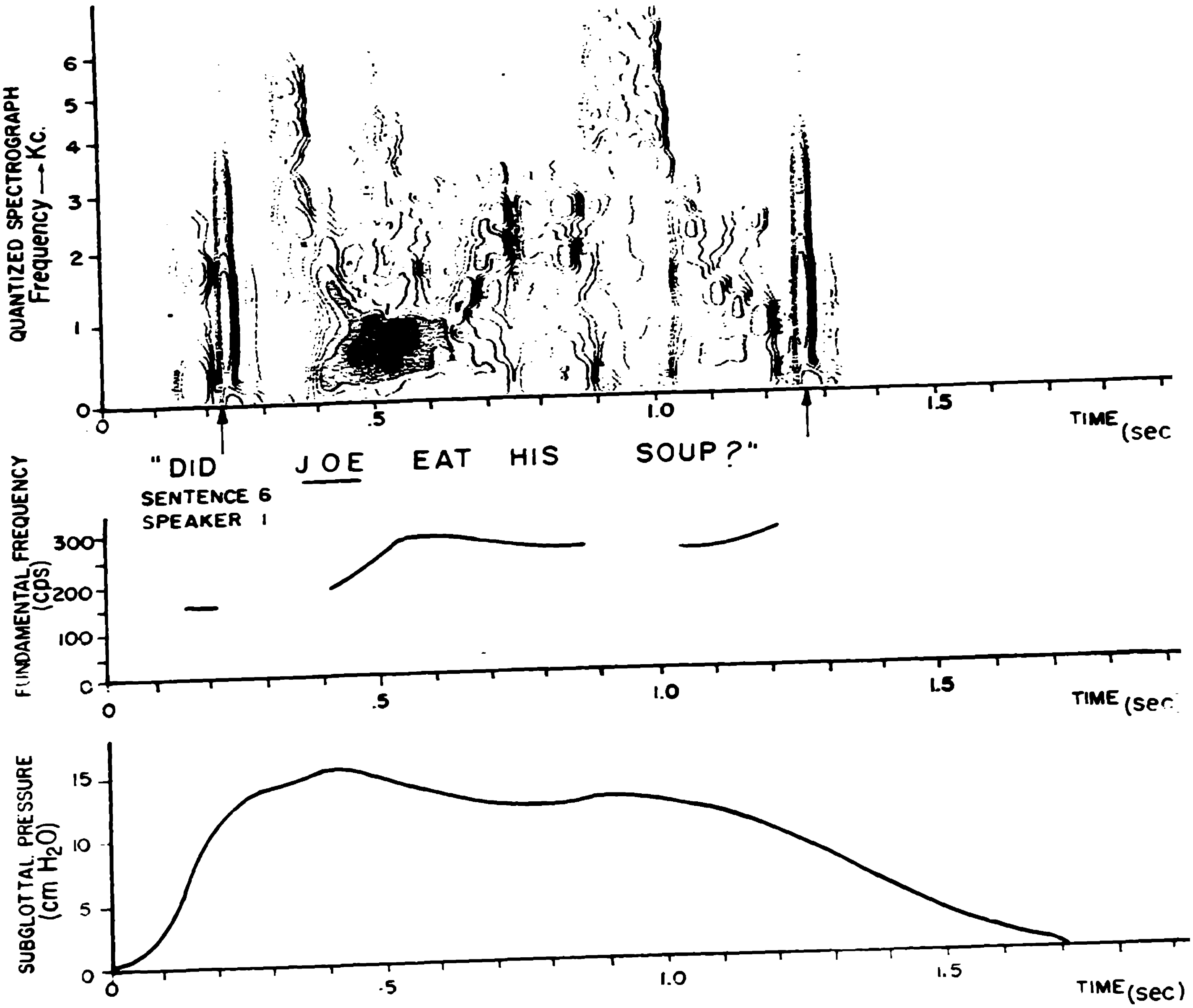
QUANTIZED SPECTROGRAPH Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME (sec
"DID JOE EAT HIS SOUP?"
SENTENCE 6
SPEAKER 1
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME (sec
SUBGLOTTAL PRESSURE (cm H2O)
15
10
5
0
0
.5
1.0
1.5
TIME (sec)

Fig. 14

frequency at the end of the breath-group to counteract the effects of the falling subglottal air pressure. The data in Fig. 13 is therefore consistent with our hypothesis concerning the marked breath-group [+BG]. The increase in the tension of the laryngeal muscles occurs at the end of the breath-group where the subglottal pressure falls. The acoustic correlate of this is a not-falling terminal fundamental frequency contour.

In Fig. 14 data for sentence 6, "Did Joe eat his soup?" is presented. The speaker placed extra prominence on Joe by placing the peak subglottal pressure on it. The subglottal pressure on Joe is 15.4 cm. In Fig. 13 the subglottal pressure on Joe was 10.0 cm. The fundamental frequency and duration of the diphthong of Joe in Fig. 14 are 290 cps and 240 msec respectively. The fundamental frequency of Joe is 280 cps in Fig. 13, where it was not supposed to be emphasized. However, the duration of the diphthong of Joe is 180 msec in Fig. 13. The peak amplitude of the first formant of /o/ in Joe relative to the rest of the sentence is the same (to the nearest 6 db) in Figs. 13 and 14. Perceptually, Joe is much more prominent[1] in Fig. 14 than it is in Fig. 13. Note that the fundamental frequency at the end of this sentence again rises though the subglottal air pressure falls.

In Fig. 15 the data for sentence 12, "Did Joe eat his soup?" is

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1. We will define the terms "prominence" and "emphasis" in chpater six. Briefly speaking, prominence is one of the perceptual manifestations of emphasis. Emphasis has sometimes been called "contrastive stress".

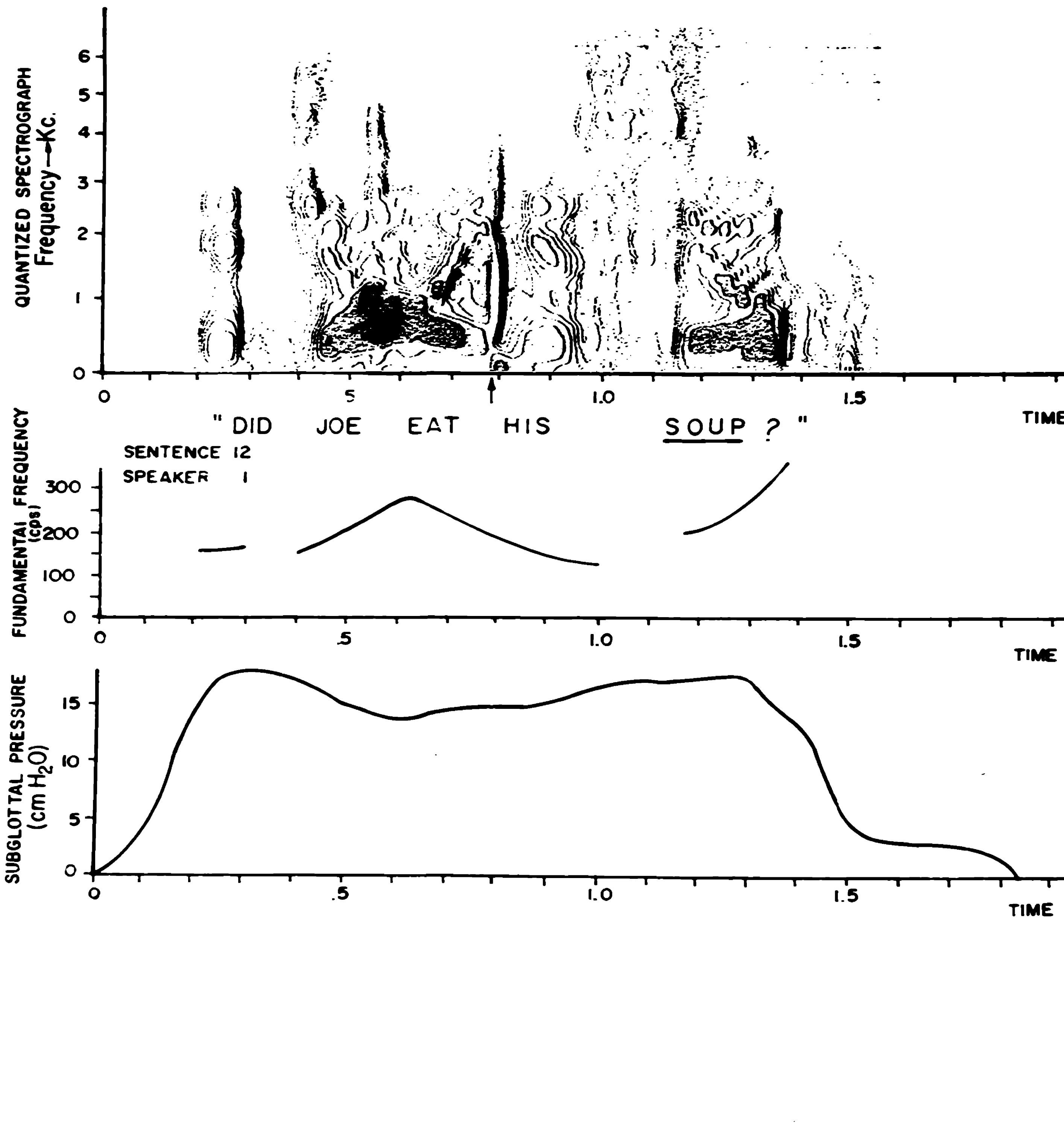

QUANTIZED SPECTROGRAPH
Frequency→Kc.
0
1
2
3
4
5
6
0
.5
1.0
1.5
TIME
"DID JOE EAT HIS SOUP ? "
SENTENCE 12
SPEAKER 1
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
0
.5
1.0
1.5
TIME

Fig. 15

presented. The speaker has again emphasized soup by means of increased subglottal air pressure. In Fig. 13, where the unemphasized question is displayed, the peak amplitude of the first formant of the vowel /u/ in soup was 6 db less than the peak amplitude of the first formant of the vowel /I/ in his. In Fig. 15 where soup is emphasized the peak amplitude of the first formant of /u/ is 6 db greater than the first formant of /I/. Amplitude is thus a reasonably consistent acoustic correlate of [$+P_s$] for speaker one though, in general, increases in the fundamental frequency and duration of the emphasized vowels are more consistent acoustic correlates of [$+P_s$].

The pressure function of Fig. 15 resembles that of Fig. 12 (the sentence "Joe ate his soup."). The overall magnitude of the pressure function is greater in Fig. 15, but the shape is the same. Note, however, that Fig. 15 ends with a rising fundamental frequency contour in contrast to Fig. 12. In both utterances emphasis has been placed on soup by means of increased subglottal air pressures. The speaker, however, does not place the peak pressure at the end of phonation for the declarative sentence in Fig. 12. If the peak air pressure were placed at the end of phonation the declarative sentence would end with a not-falling fundamental frequency contour unless he compensated by reducing the tension of his laryngeal muscles. The interrogative sentence in Fig. 15, of course, ends with a rising fundamental frequency contour. The fundamental frequency rises 170 cps though the subglottal air pressure is falling during the last 70 msec of phonation. The fundamental frequency rise is actually steeper during the last 70 msec of phonation. The speaker again tensions his laryngeal mucles at the end of the breath-group.

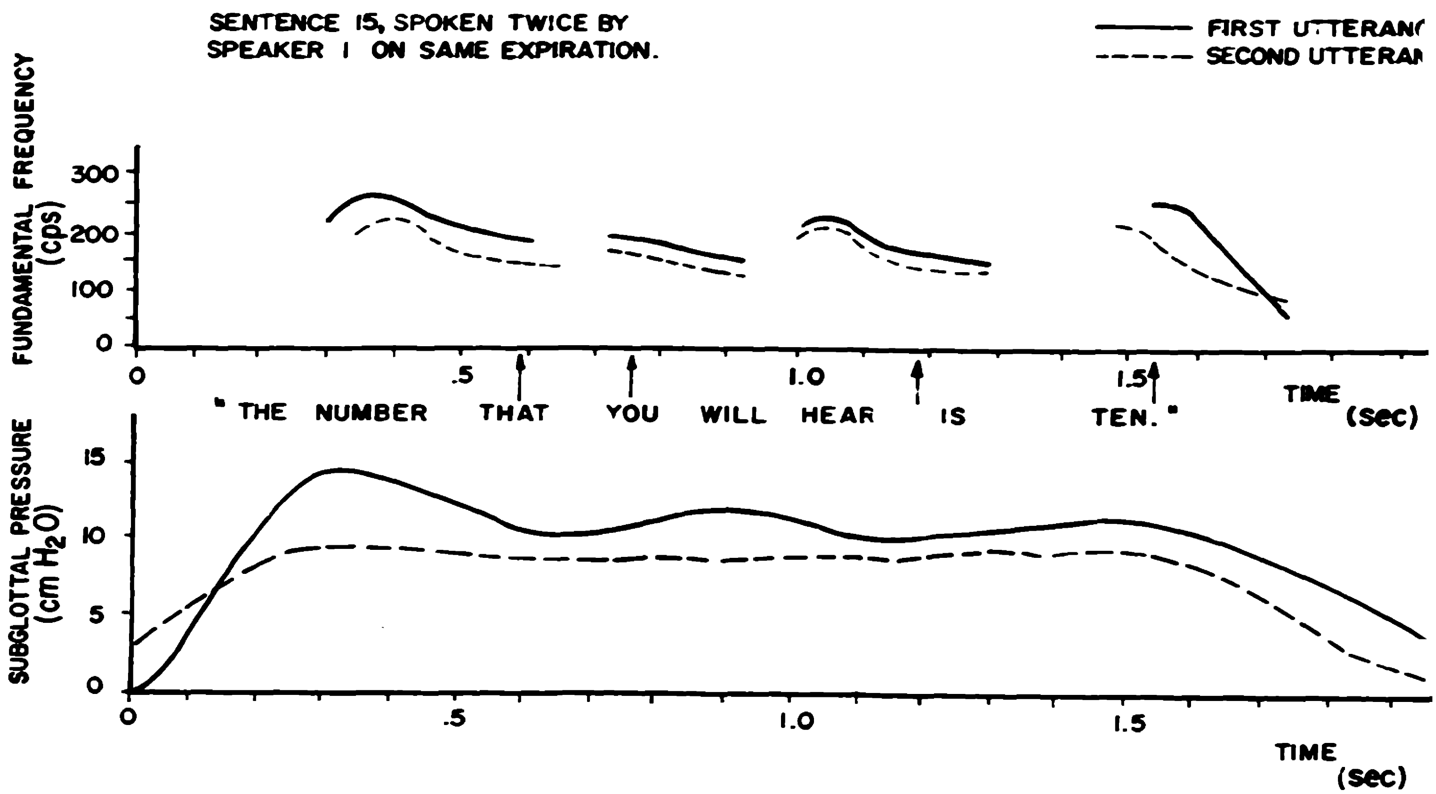
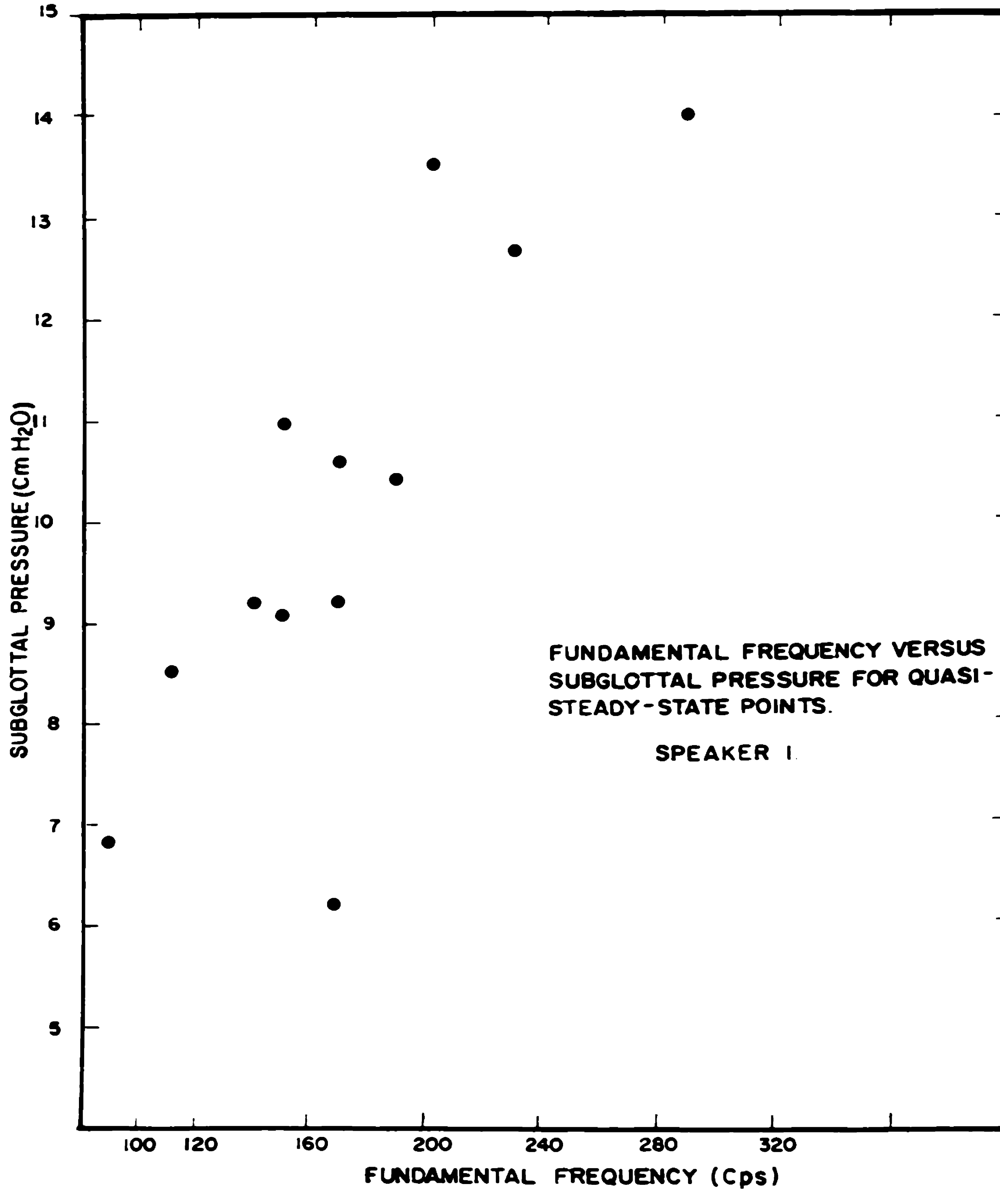

SENTENCE 15, SPOKEN TWICE BY SPEAKER 1 ON SAME EXPIRATION.
FIRST UTTERANC
SECOND UTTERAN
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME (sec)
"THE NUMBER THAT YOU WILL HEAR IS TEN."
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
0
.5
1.0
1.5
TIME (sec)

Fig. 16



15
14
13
12
11
10
9
8
7
6
5
SUBGLOTTAL PRESSURE (Cm H_2O)
100
120
160
200
240
280
320
FUNDAMENTAL FREQUENCY (Cps)
FUNDAMENTAL FREQUENCY VERSUS SUBGLOTTAL PRESSURE FOR QUASI-STEADY-STATE POINTS.
SPEAKER I

Fig. 17

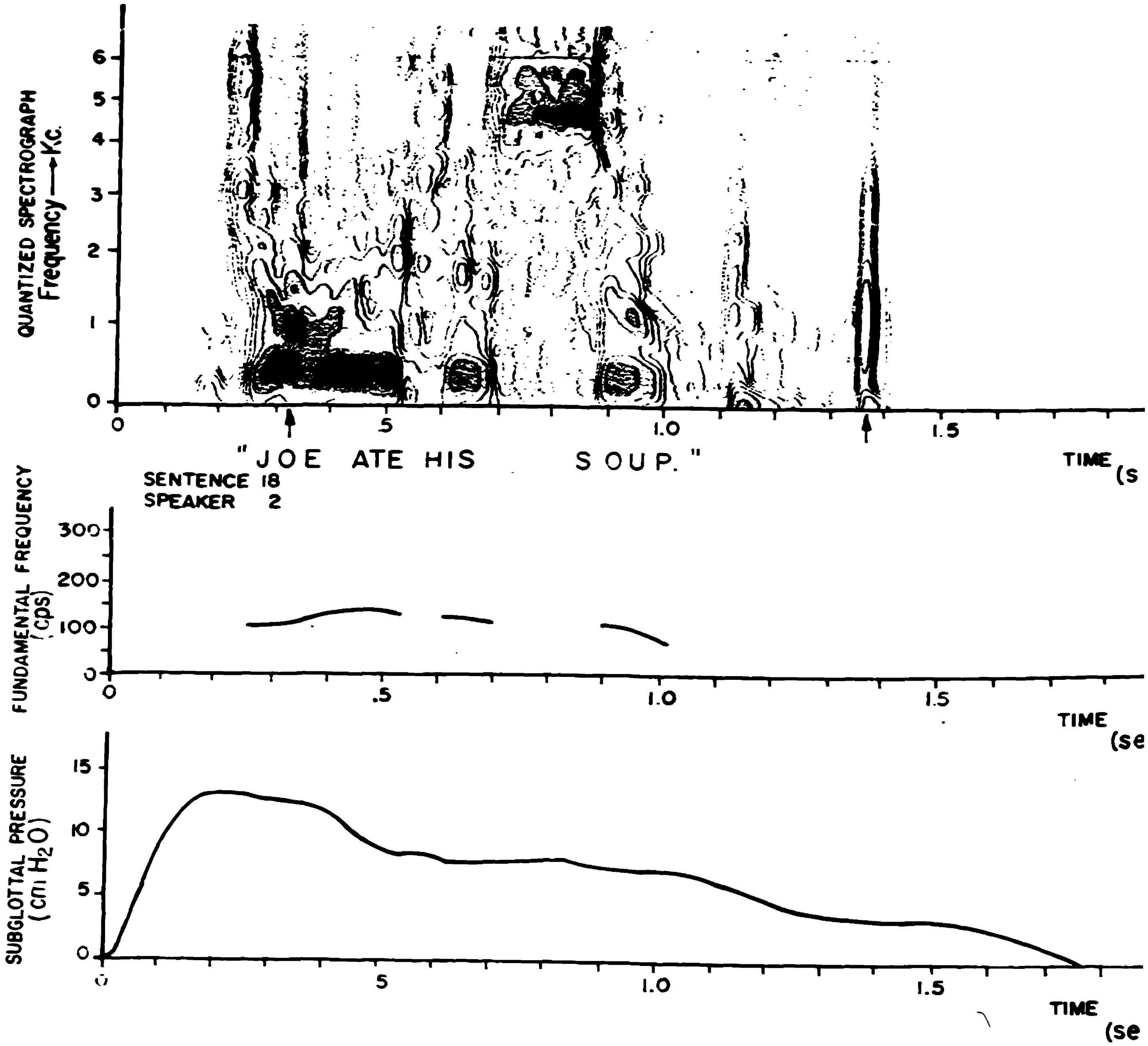

QUANTIZED SPECTROGRAPH
Frequency ——→ Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
"JOE ATE HIS SOUP."
TIME (s
SENTENCE 18
SPEAKER 2
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME (se
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
0
5
1.0
1.5
TIME (se

Fig. 18

The two articulatory gestures (a) - the momentary increase in the subglottal air pressure associated with $[+P_s]$, and (b) - the tensioning of the laryngeal muscles for the marked breath-group, are clearly independent for this data.

In two instances a speaker uttered the two repetitions of the same sentence on one expiration. In Fig. 16 the subglottal pressure plots and fundamental frequency contours are presented for speaker one when he uttered sentence 15 twice on the same breath-group. The solid lines are the plots for the utterance, 15A, and the dashed lines are the plots for the second utterance 15B. Note that the general shape of the subglottal air pressure function is similar for both utterances. The speaker controlled his respiratory muscles and produced two similar pressure contours that are both similar to the pressure function of the normal breath-group that he used for his unemphatic sentences, e.g., the pressure function in Figs. 10 and 13. The magnitude of the pressure function of 15B is somewhat smaller than that of 15A.

The two fundamental frequency contours in this figure also have the same shape. The fundamental frequency contour for 15B again has a smaller magnitude than that of 15A. It seems evident that the speaker manipulated his laryngeal muscles in the same manner for both utterances. The lower fundamental frequency contour of utterance B would then follow from the lower subglottal air pressure of utterance B. This hypothesis was tested by determining the average fundamental frequency and subglottal air pressure of the slowly varying portions of both contours where we could be sure of lining up the corresponding points on the

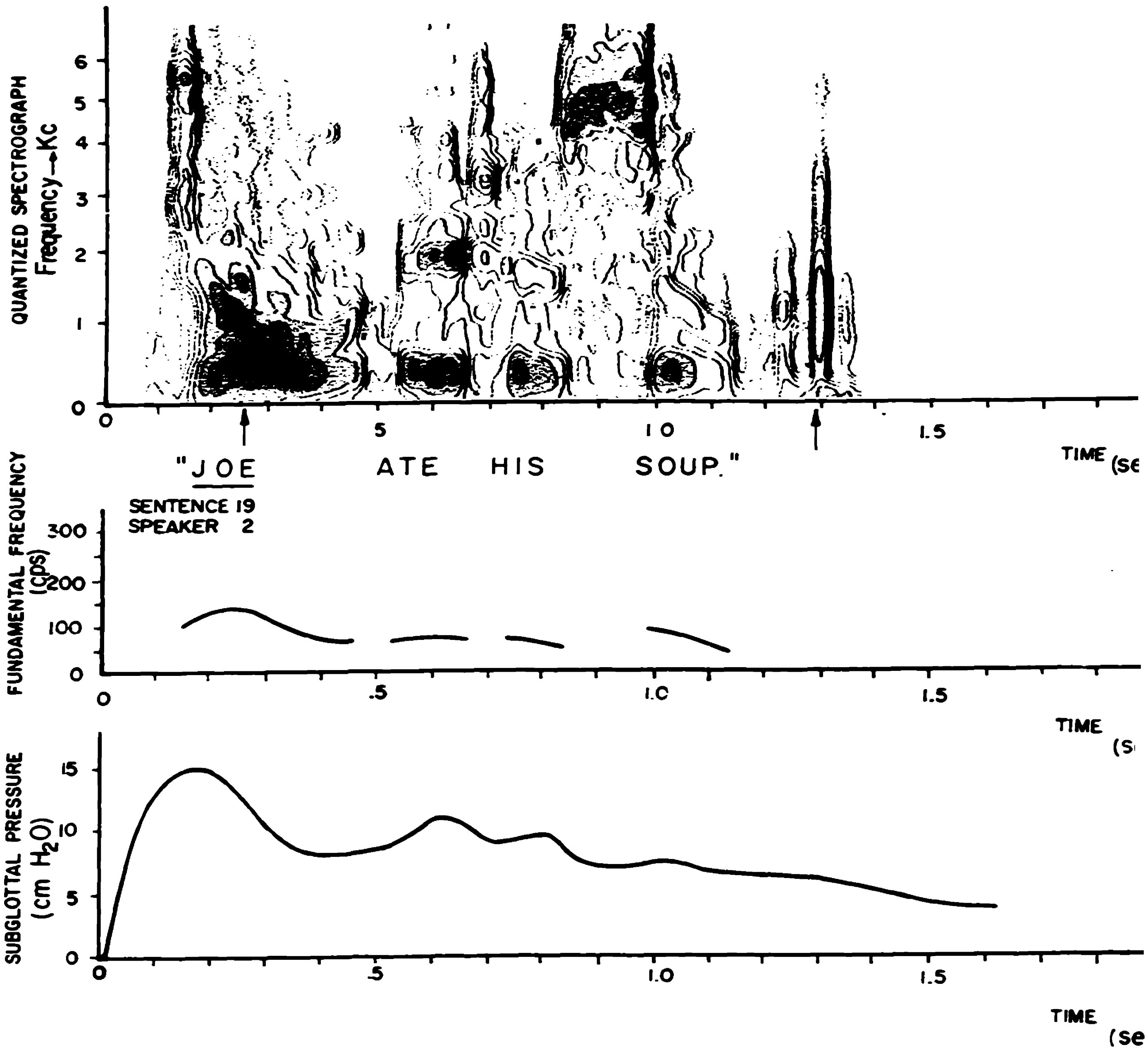

QUANTIZED SPECTROGRAPH
Frequency → Kc
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME (se
"JOE ATE HIS SOUP."
SENTENCE 19
SPEAKER 2
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME (s
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
0
.5
1.0
1.5
TIME (se

Fig. 19

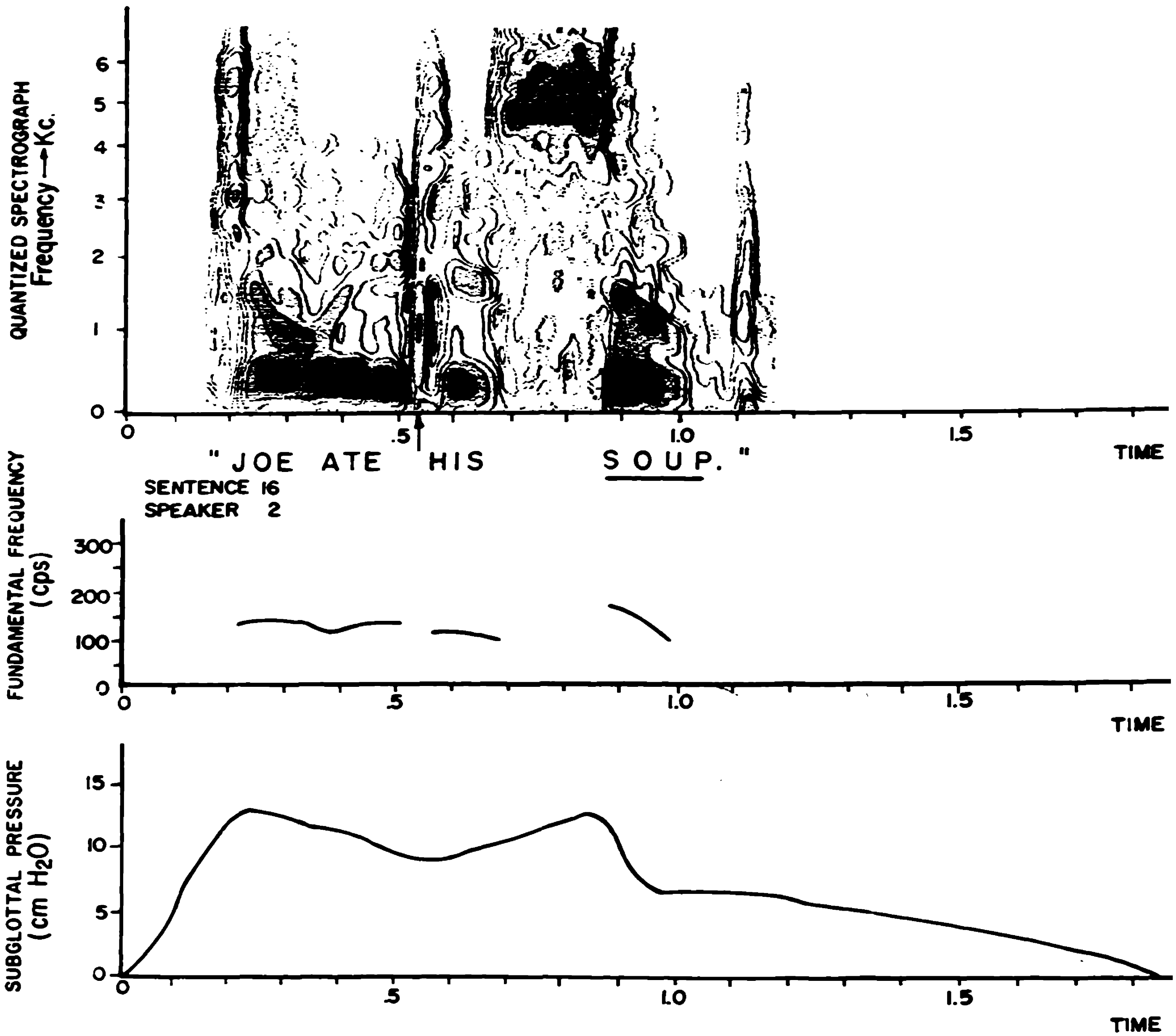

QUANTIZED SPECTROGRAPH
Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
"JOE ATE HIS SOUP."
SENTENCE 16
SPEAKER 2
FUNDAMENTAL FREQUENCY
(cps)
300
200
100
0
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE
(cm H_2O)
15
10
5
0
0
.5
1.0
1.5
TIME

Fig. 20

subglottal pressure and the fundamental frequency plots. The average fundamental frequency and subglottal pressure of the four points marked by arrows in Fig. 16 was 213 cps 10.7 cm H_2O for utterance A and 175 cps and 8.9 cm H_2O for utterance B. If the control of the laryngeal muscles was similar for both utterances then the rate of change of f_o with subglottal air pressure is 21 cps/cm H_2O. The rate of change of f_o with subglottal air pressure is 16-20 cps/cm H_2O in Fig. 17 where we plotted fo with respect to the subglottal air pressure for Figs. 10, 11, and 12. We assumed that speaker one used unmarked breath-groups or unmarked breaths modified only by momentary increases in the subglottal air pressure to produce the utterances plotted in these figures.

(4) - Data on Individual Sentences - Speakers two and three

In Figs. 18, 19 and 20 we have presented the fundamental frequency and subglottal air pressure plots for speaker two reading sentences 18, 19 and 16 in a normal speaking voice. Sound spectrograms of the utterances are presented, as was done for the previous data from speaker one's utterances. The phonation delay and initial subglottal pressure is still plotted in Fig. 34. If Fig. 18 is compared to Fig. 10 it is obvious that though speaker two starts his normal breath-group with a fairly large subglottal pressure peak (5.6 cm above the rest of the air pressure contour), he nonetheless starts phonation with a fundamental frequency that is lower than the fundamental frequency that occurs later in the breath-group where the subglottal pressure is lower. Speaker two must therefore start his normal breath-group with a lower

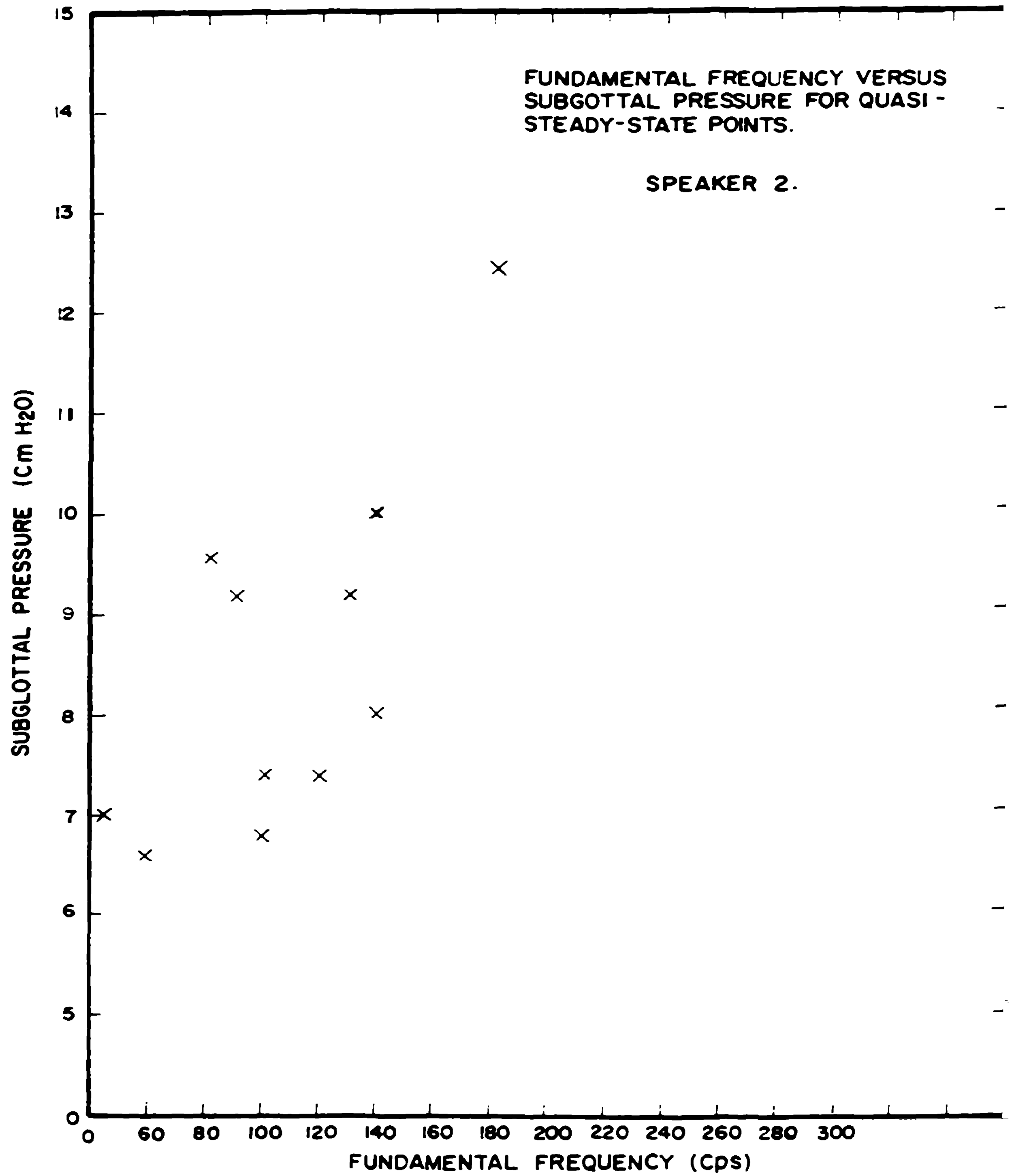

FUNDAMENTAL FREQUENCY VERSUS SUBGOTTAL PRESSURE FOR QUASI - STEADY-STATE POINTS.
SPEAKER 2.
SUBGLOTTAL PRESSURE (Cm H2O)
15
14
13
12
11
10
9
8
7
6
5
0
0
60
80
100
120
140
160
180
200
220
240
260
280
300
FUNDAMENTAL FREQUENCY (Cps)

Fig. 21

tension on his laryngeal muscles. The lower tension tends to lower the fundamental frequency and it thus counteracts the high initial subglottal air pressure that is typical for speaker two's breath-groups. The fundamental frequency at the end of phonation also seems to drop faster (60 cps for 0.6 cm) than it should if the tension of his laryngeal muscles were not also relaxed. He produces a fundamental frequency contour whose gross characteristics are not very different than speaker one's but he uses a different pattern of articulatory activity.

In Fig. 19 we see the presence of a momentary peak in the subglottal air pressure which has been placed on Joe. In Fig. 20 a subglottal overpressure has been placed on soup. The fundamental frequency still falls at the end of the declarative sentence on Fig. 20. However, the falling fundamental frequency in this case seems to be due to the falling subglottal air pressure. The terminal fall is 100 cps and the subglottal air pressure falls 4.8 cm. In Fig. 21 the fundamental frequency has been plotted with respect to the subglottal air pressure for quasi-steady state intervals drived from the plots in Figs. 18-20. The rate of change of f_o with respect to subglottal pressure is about 18 cps/cm H_2O for the data on Fig. 21. The data points in this plot are scattered more than the data points in Fig. 17 where similar data was plotted for speaker one. This undoubtedly is the case because speaker two tends to vary the tension of his laryngeal muscles during his normal breath-group.

In Figs. 22 and 23 we have presented data derived from speaker two's utterances of sentences 3 and 8, "Did Joe eat his soup?" and

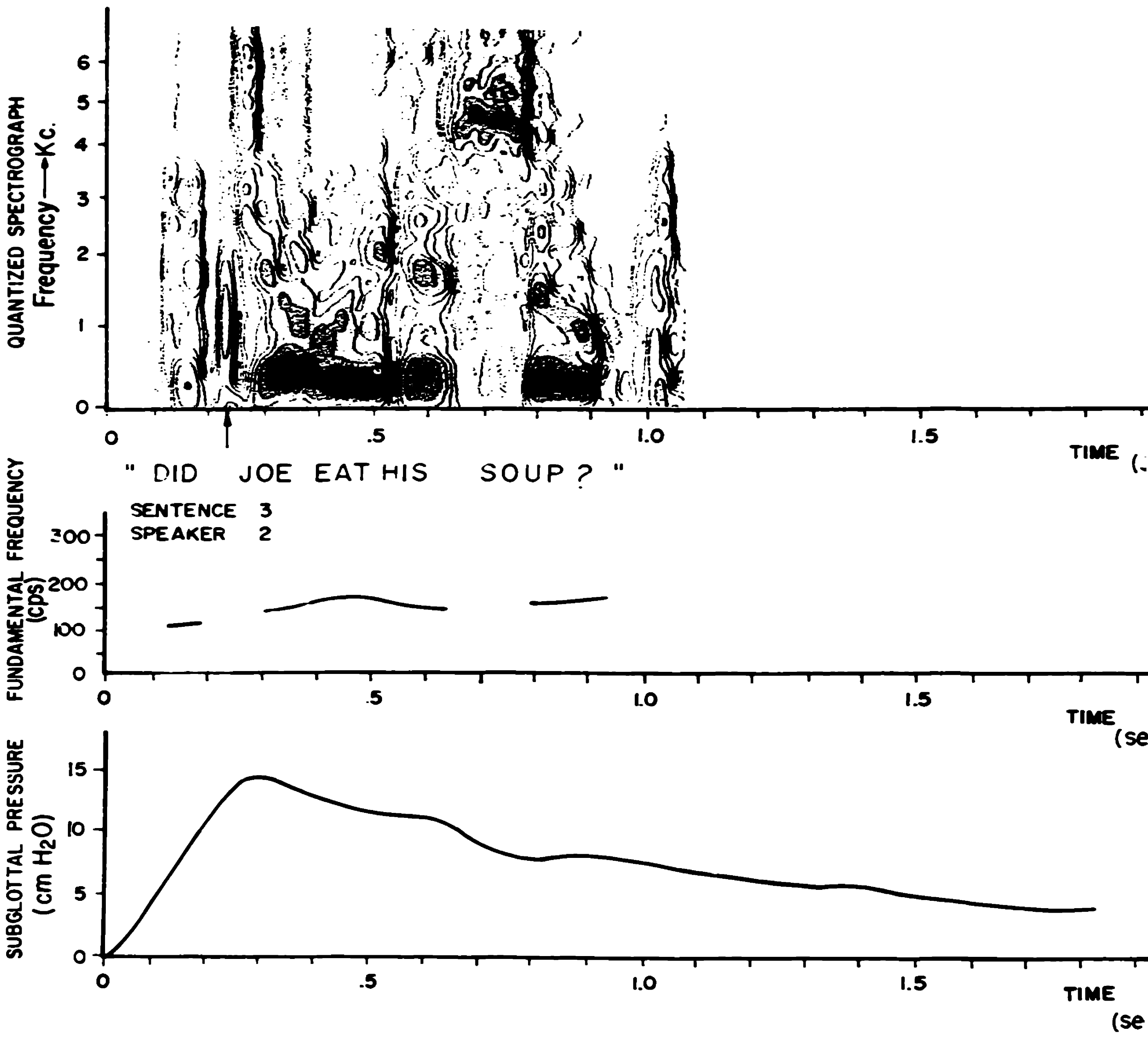

QUANTIZED SPECTROGRAPH
Frequency ——►Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
" DID JOE EAT HIS SOUP ? "
FUNDAMENTAL FREQUENCY (cps)
SENTENCE 3
SPEAKER 2
300
200
100
0
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE (cm H2O)
15
10
5
0
0
.5
1.0
1.5
TIME

Fig. 22

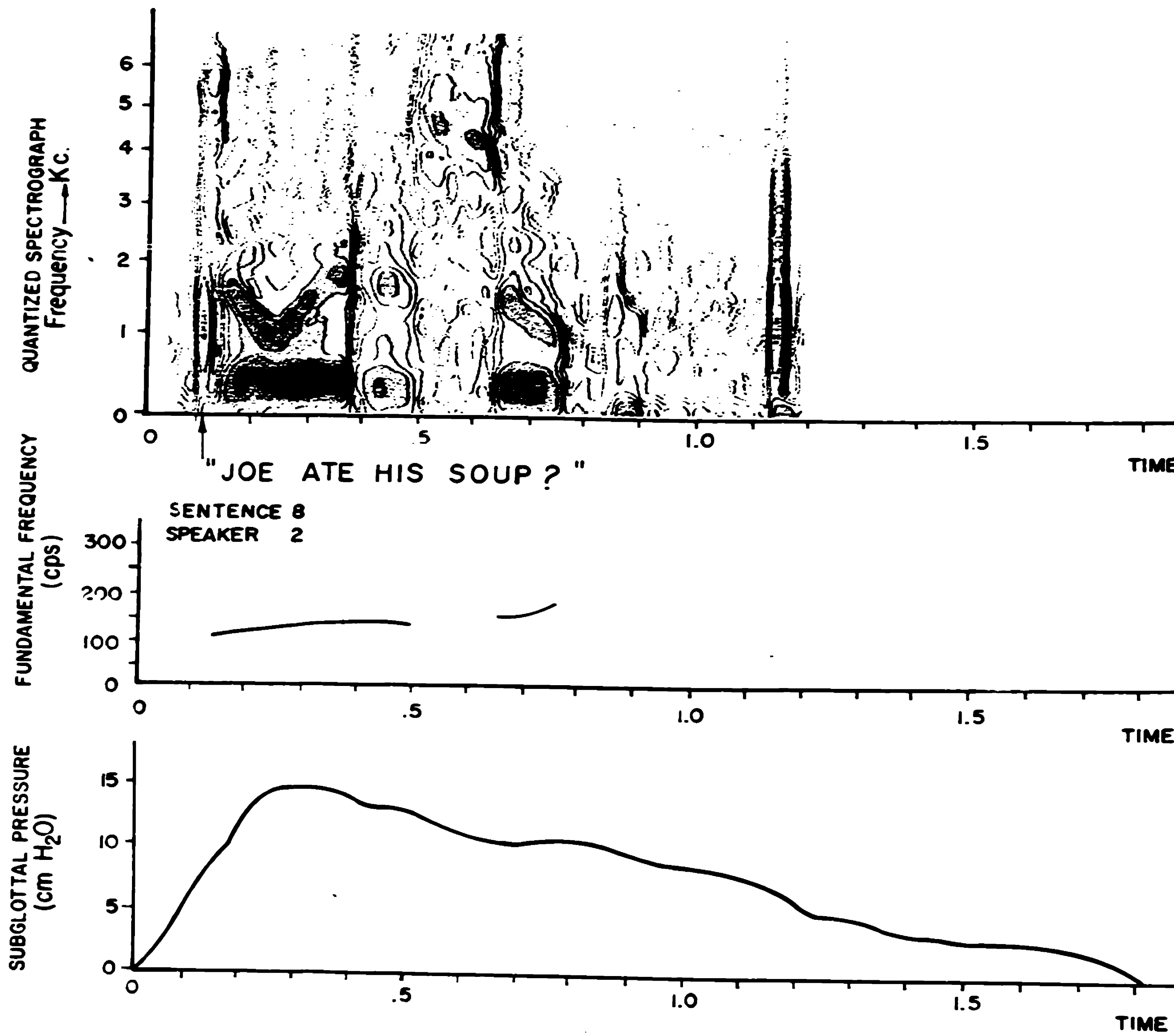

QUANTIZED SPECTROGRAPH
Frequency ⟶ Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
"JOE ATE HIS SOUP ?"
SENTENCE 8
SPEAKER 2
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE ($cm\ H_2O$)
15
10
5
0
0
.5
1.0
1.5
TIME

Fig. 23

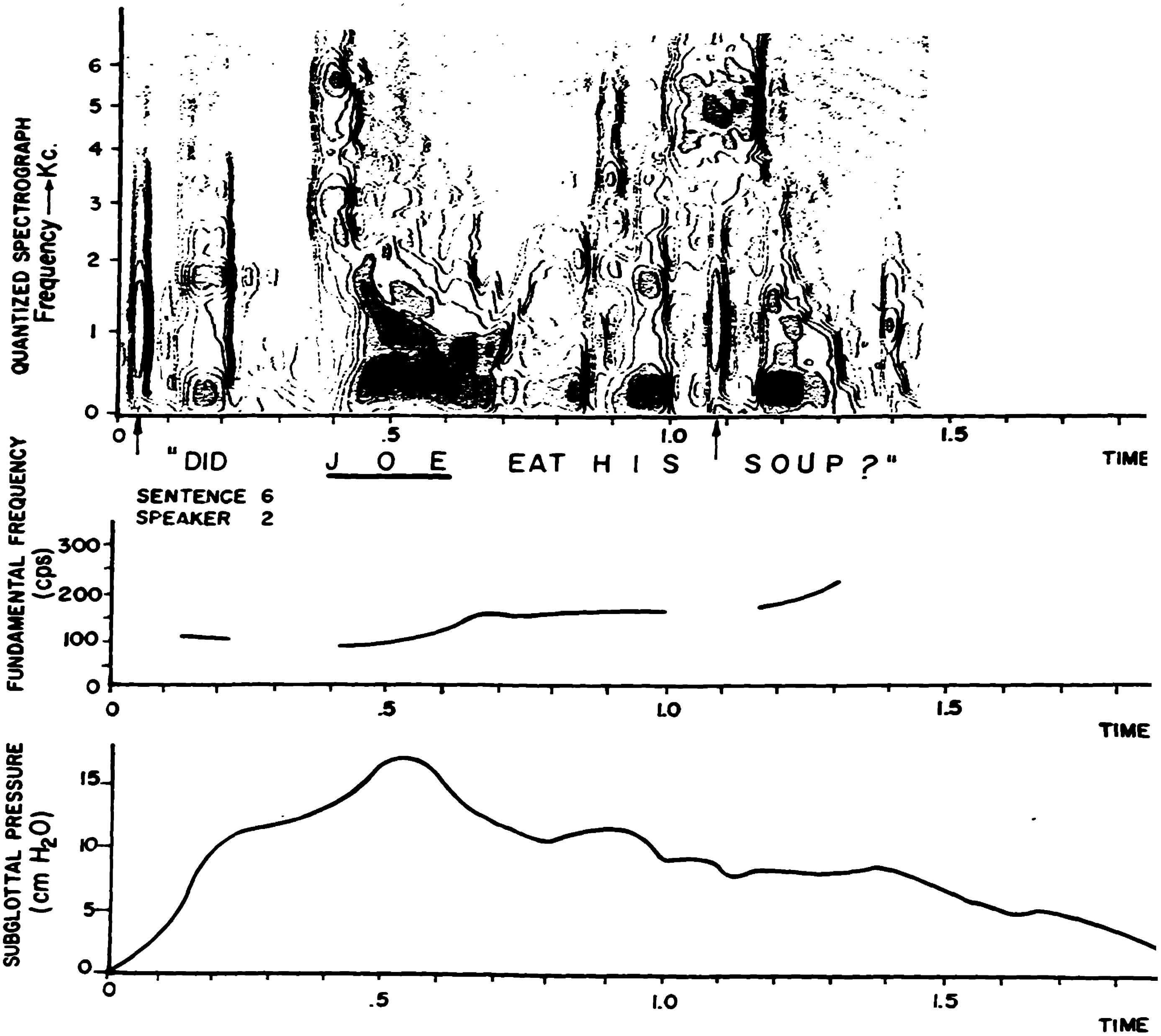

QUANTIZED SPECTROGRAPH
Frequency → Kc.
0
1
2
3
4
5
6
0
.5
1.0
1.5
TIME
"DID JOE EAT HIS SOUP?"
SENTENCE 6
SPEAKER 2
FUNDAMENTAL FREQUENCY (cps)
0
100
200
300
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE (cm H2O)
0
5
10
15
0
.5
1.0
1.5
TIME

Fig. 24

"Joe ate his soup?" The fundamental frequency at the end of the two interrogative sentencesof Figs. 22 and 23 rises through the action of the laryngeal muscles since the subglottal air pressure is relatively steady. Note that the subglottal air pressure contours are similar to that of Fig. 18 where the data for the unemphasized declarative sentence is presented. All of the contours start with a comparatively high subglottal air pressure. However, the initial fundamental frequency for all of these sentences is slightly lower than the fundamental frequency that occurs in the middle of the breath-group where the subglottal air pressure is lower.

In Fig. 24 the data for sentence 6, "Did Joe eat his soup?" is plotted. Emphasis is again placed on Joe by means of a momentary increase in the subglottal air pressure which perturbs the subglottal air pressure function that is usually associated with speaker two's normal breath-group. However, f_o does not rise on Joe, perhaps because speaker two characteristically starts his breath-group with a lower laryngeal tension. The fundamental frequency again rises at the end of the breath-group through the activity of the laryngeal muscles. Note that the duration of the diphthong of the emphasized Joe is 300 msec whereas its duration in Figs. 22, 23, 20 and 18,where it is not emphasized, are respectively 150, 150, 150 and 130 msec. Its duration in Fig. 19, where it was also emphasized,is 250 msec. Thd duration of the diphthong in soup is likewise 150 msec in Fig. 20 where it receives emphasis. Its durations in Figs. 18, 19, 22, 23, and 24,where it does not receive emphasis,are respectively 120,130, 120, 110, and 130 msec. Duration thus

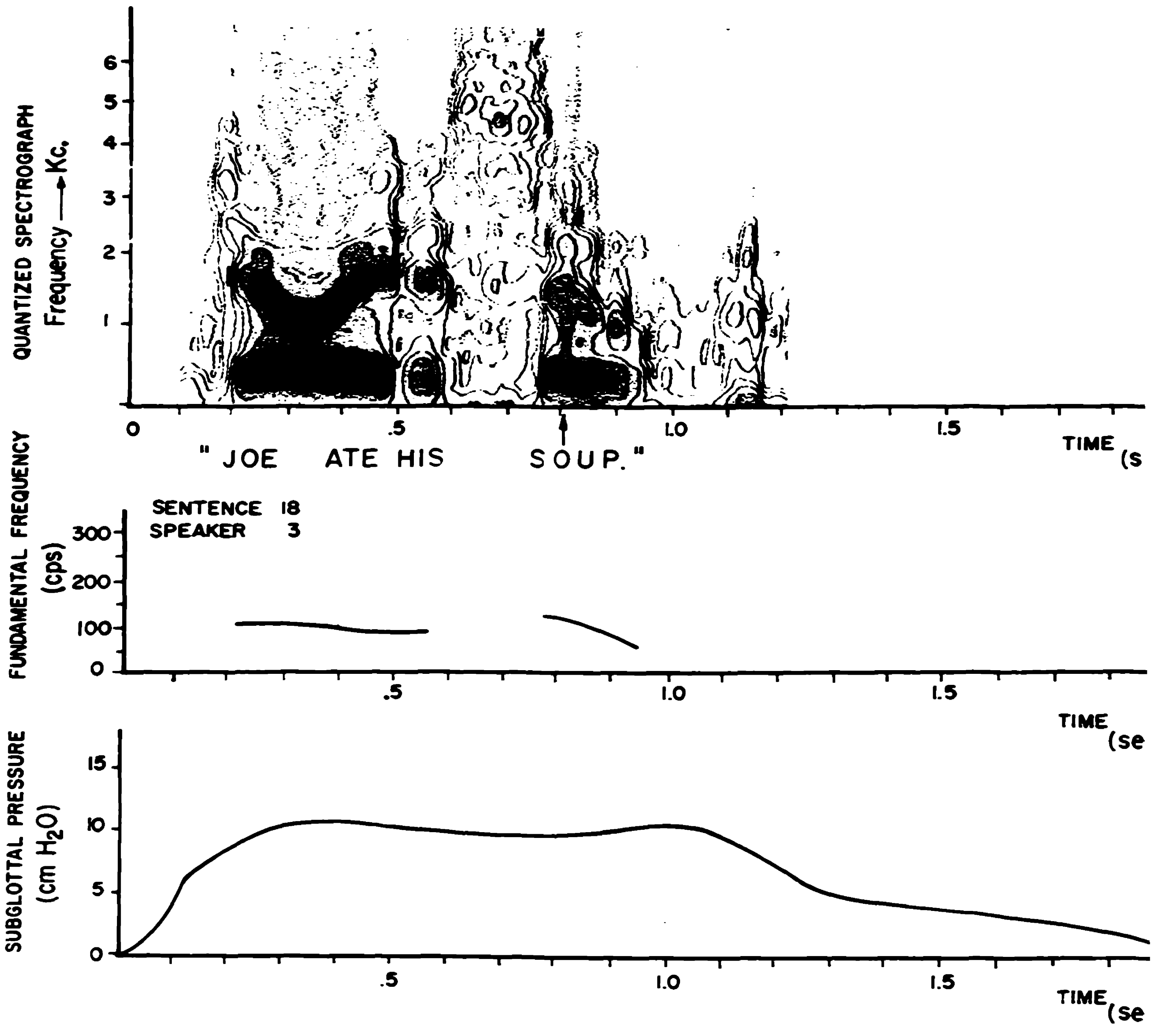

QUANTIZED SPECTROGRAPH
Frequency ——→ Kc.
6
5
4
3
2
1
0
.5
1.0
1.5
TIME (s
" JOE ATE HIS SOUP."
FUNDAMENTAL FREQUENCY (cps)
SENTENCE 18
SPEAKER 3
300
200
100
0
.5
1.0
1.5
TIME (se
SUBGLOTTAL PRESSURE ($cm\ H_2O$)
15
10
5
0
.5
1.0
1.5
TIME (se

Fig. 25

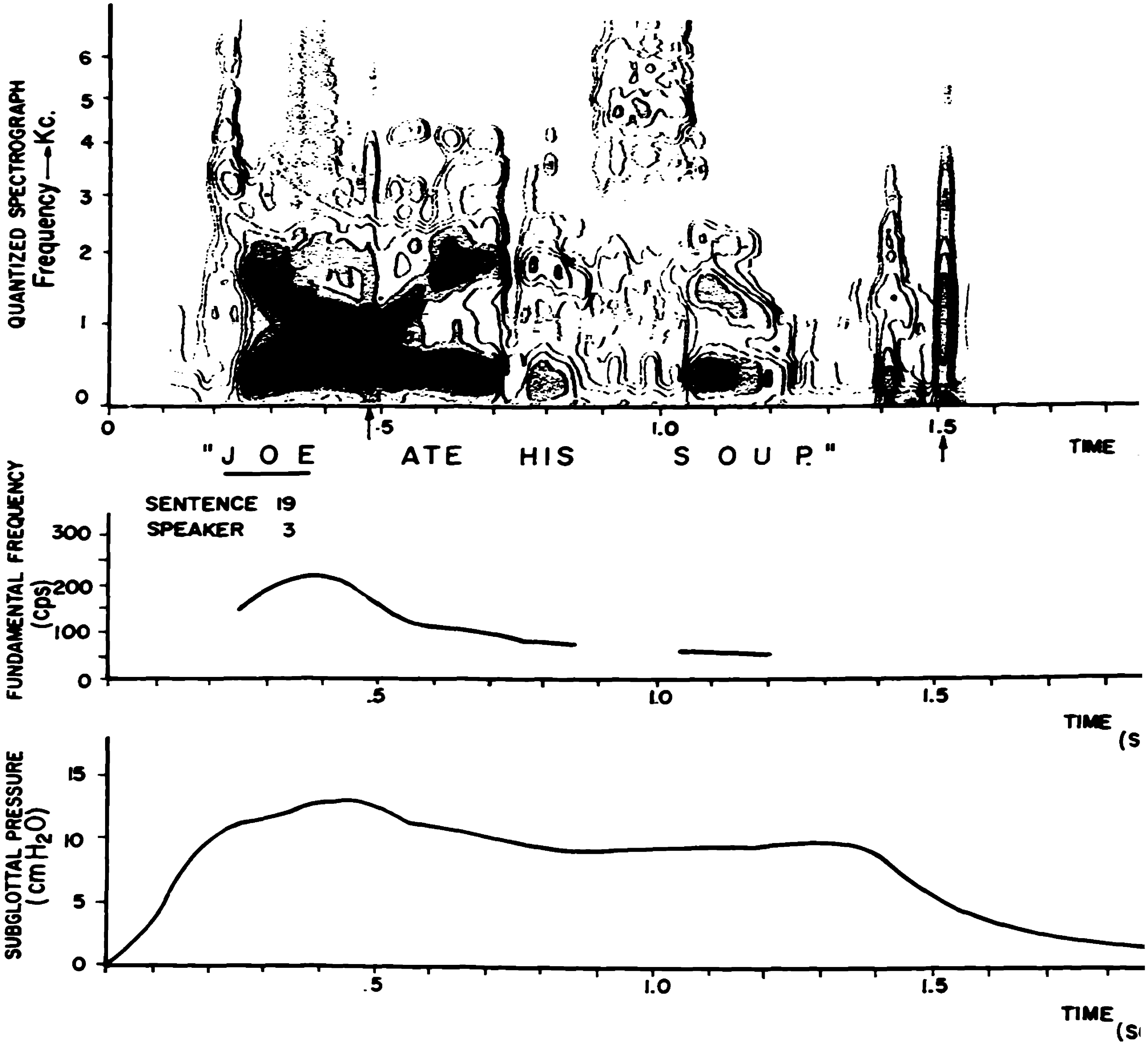
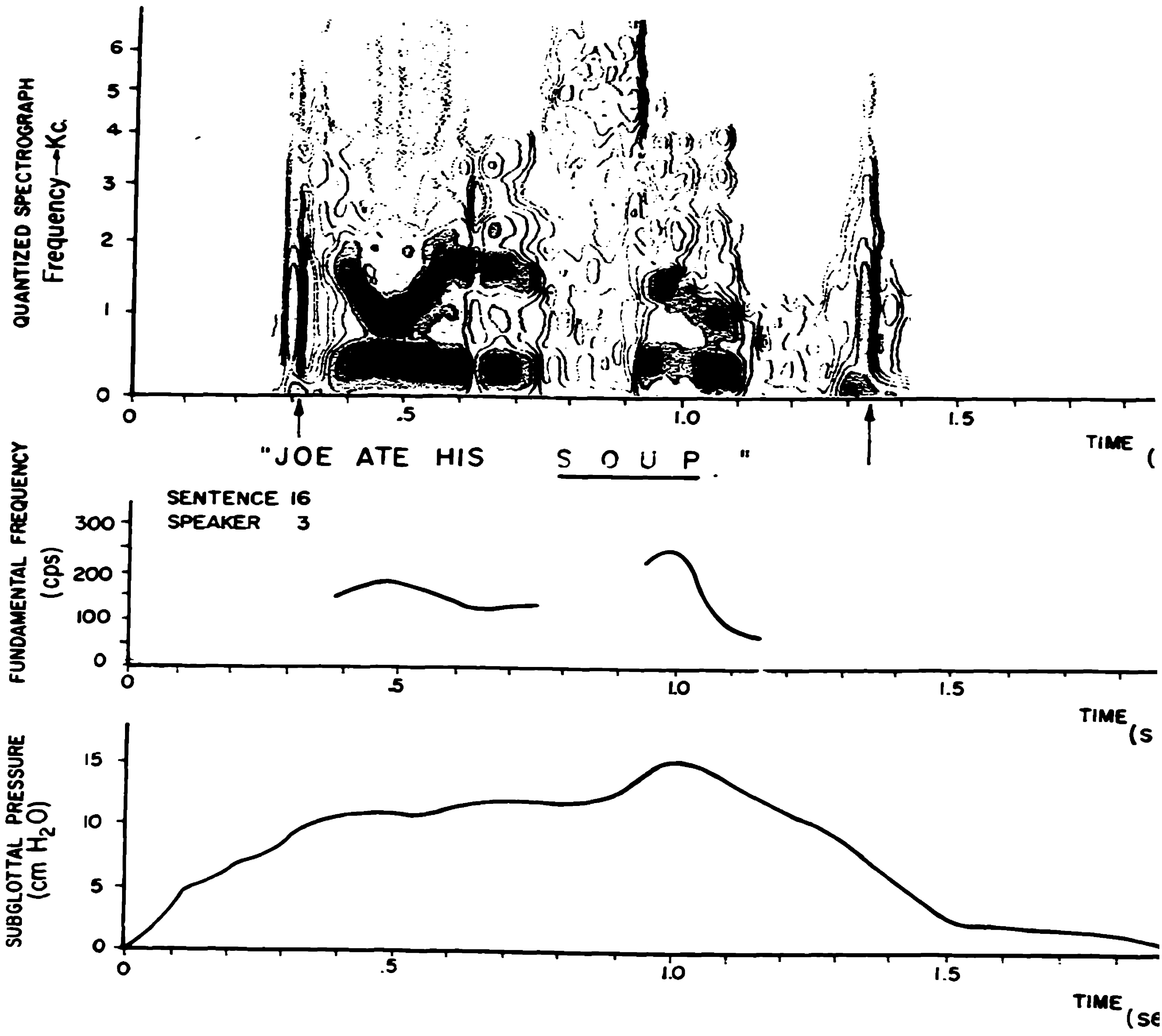

QUANTIZED SPECTROGRAPH
Frequency ⟶ Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
"J O E ATE HIS S O U P."
SENTENCE 19
SPEAKER 3
FUNDAMENTAL FREQUENCY
(cps)
300
200
100
0
.5
1.0
1.5
TIME (S
SUBGLOTTAL PRESSURE
(cm H2O)
15
10
5
0
.5
1.0
1.5
TIME (S

Fig. 26



QUANTIZED SPECTROGRAPH Frequency—Kc
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME (
"JOE ATE HIS SOUP."
FUNDAMENTAL FREQUENCY (cps)
SENTENCE 16
SPEAKER 3
300
200
100
0
0
.5
1.0
1.5
TIME (s
SUBGLOTTAL PRESSURE (cm H_2O)
15
10
5
0
0
.5
1.0
1.5
TIME (se

Fig. 27

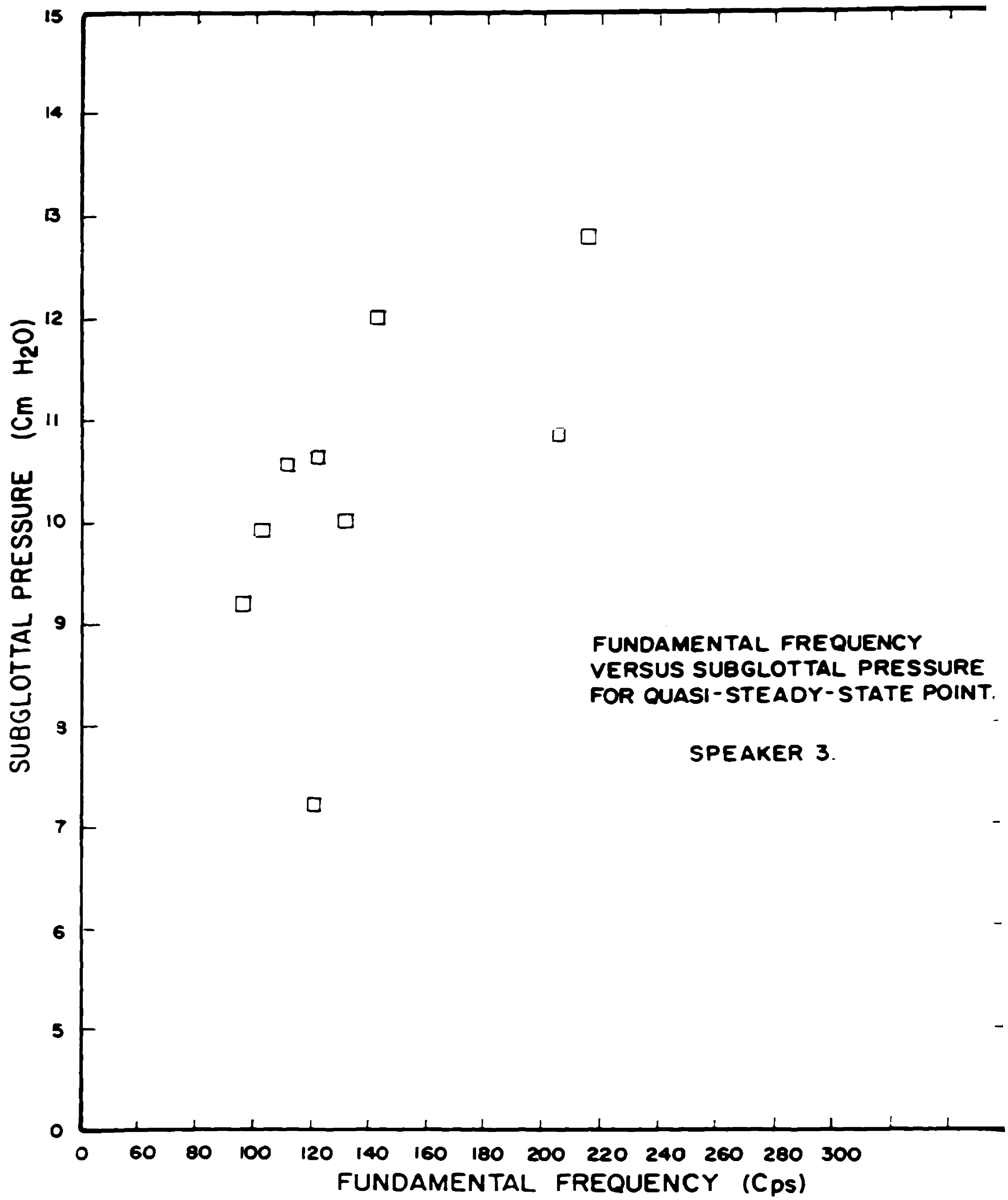

15
14
13
12
11
10
9
8
7
6
5
0
SUBGLOTTAL PRESSURE (Cm H_2O)
FUNDAMENTAL FREQUENCY
VERSUS SUBGLOTTAL PRESSURE
FOR QUASI-STEADY-STATE POINT.
SPEAKER 3.
0 60 80 100 120 140 160 180 200 220 240 260 280 300
FUNDAMENTAL FREQUENCY (Cps)

Fig. 28

seems to be an acoustic correlate of $[+P_s]$ for speaker two.

The peak amplitude of F_1 of /o/ in Joe is the same vis-a-vis the amplitude of the vowels of eat and his in both the sentences where speaker two emphasized Joe and the sentences where he did not emphasize Joe. In Fig. 25, where the peak subglottal air pressure occurred on /j/ of Joe, the amplitude of /j/ at 5.5 kc is 6 db greater than it was in Fig. 22, where Joe was not emphasized. The amplitude of F_1 and F_2 of /u/ in soup were 6db higher in Fig. 20 where soup was emphasized. Amplitude is thus not as consistent an acoustic correlate of $[+P_s]$ for speaker two as the fundamental frequency or the duration of the vowels.

In Figs. 25, 26, and 27 the data for three of speaker three's declarative sentences have been presented. In Fig. 28 the fundamental frequency is plotted with respect to the subglottal air pressure for quasi-steady state points derived from these figures. In Figs. 29-32 the data for several of his interrogative sentences is plotted. Note that the subglottal pressure functions in Figs. 25, 29 and 30 which are typical of this speaker's breath-groups when they are not perturbed by subglottal overpressures, are quite distinct from the corresponding curves for speakers one and two. The subglottal pressure function of each speaker has a characteristic "shape".

The declarative sentences seem to make use of the archetypal articulatory gestures except that the fundamental frequency at the end of phonation in Figs. 25 and 26 seems to fall through some laryngeal adjustment. The speaker is preserving the acoustic correlates of the normal breath-group though he does not produce the terminal fundamental

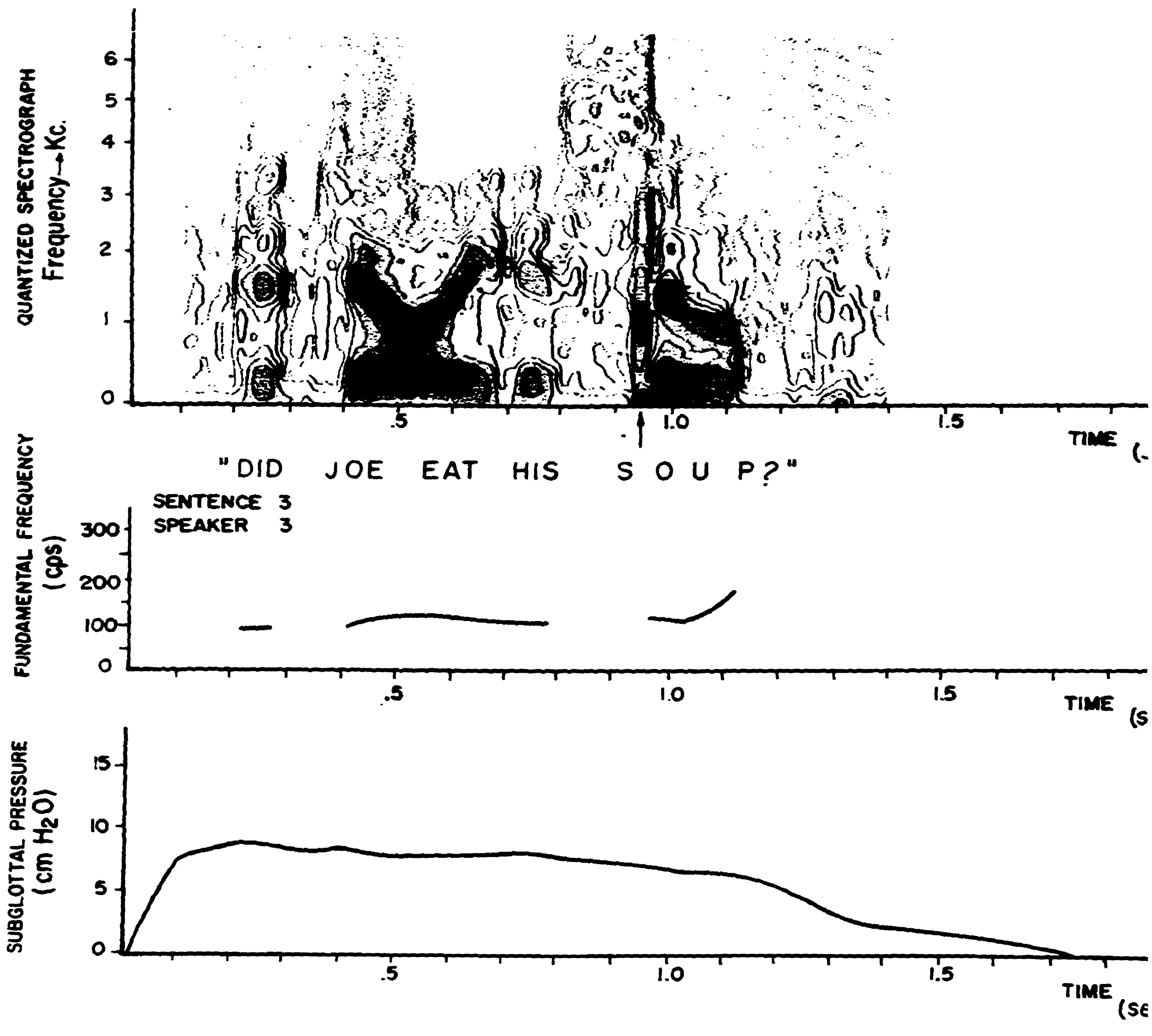

QUANTIZED SPECTROGRAPH
Frequency → Kc.
6
5
4
3
2
1
0
.5
1.0
1.5
TIME
"DID JOE EAT HIS S O U P?"
SENTENCE 3
SPEAKER 3
FUNDAMENTAL FREQUENCY
(cps)
300
200
100
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE
(cm H_2O)
15
10
5
0
.5
1.0
1.5
TIME

Fig. 29

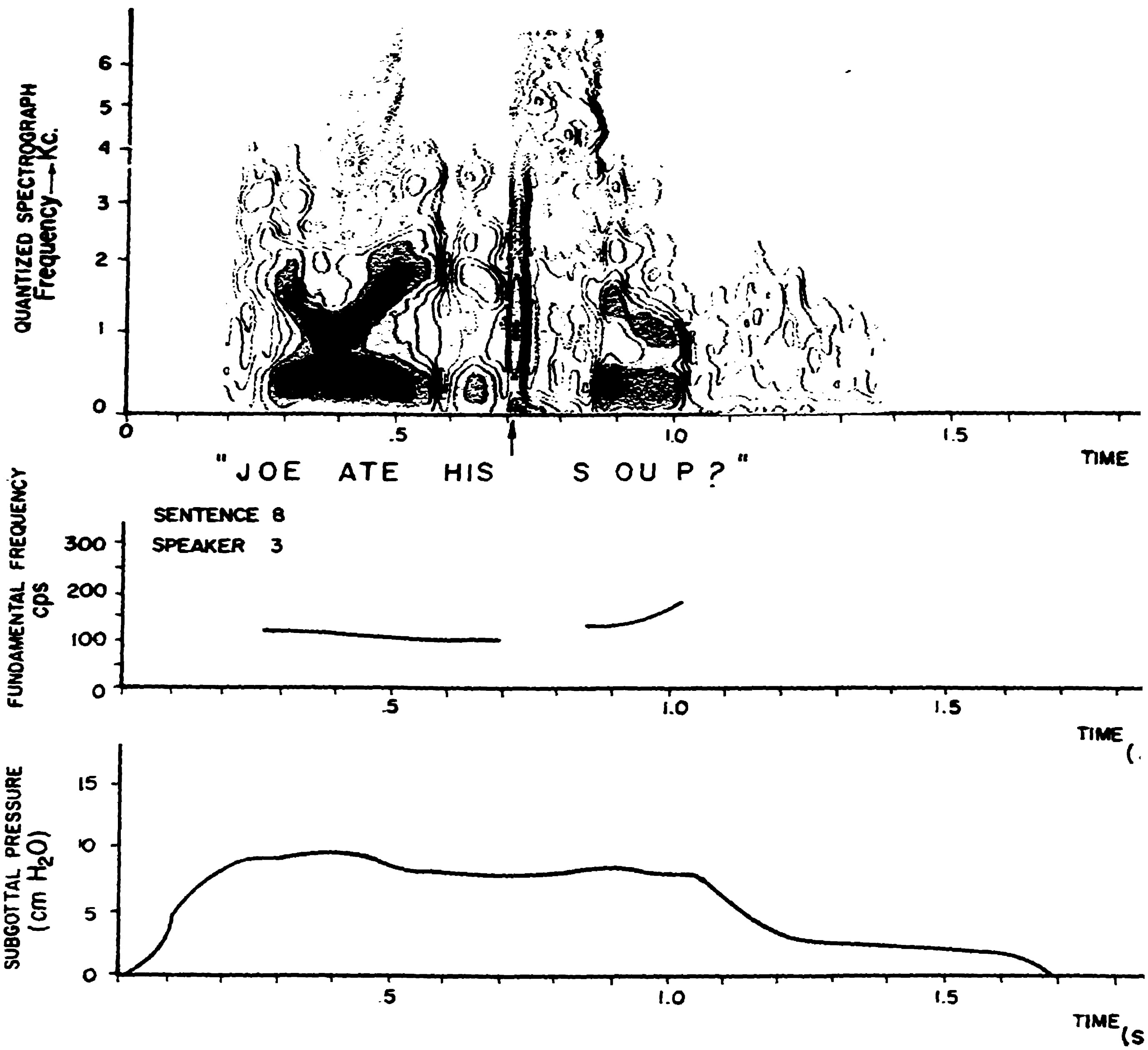

QUANTIZED SPECTROGRAPH Frequency → Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
"JOE ATE HIS S OU P ?"
SENTENCE 8
SPEAKER 3
FUNDAMENTAL FREQUENCY cps
300
200
100
0
.5
1.0
1.5
TIME
SUBGOTTAL PRESSURE (cm H2O)
15
10
5
0
.5
1.0
1.5
TIME

Fig. 30

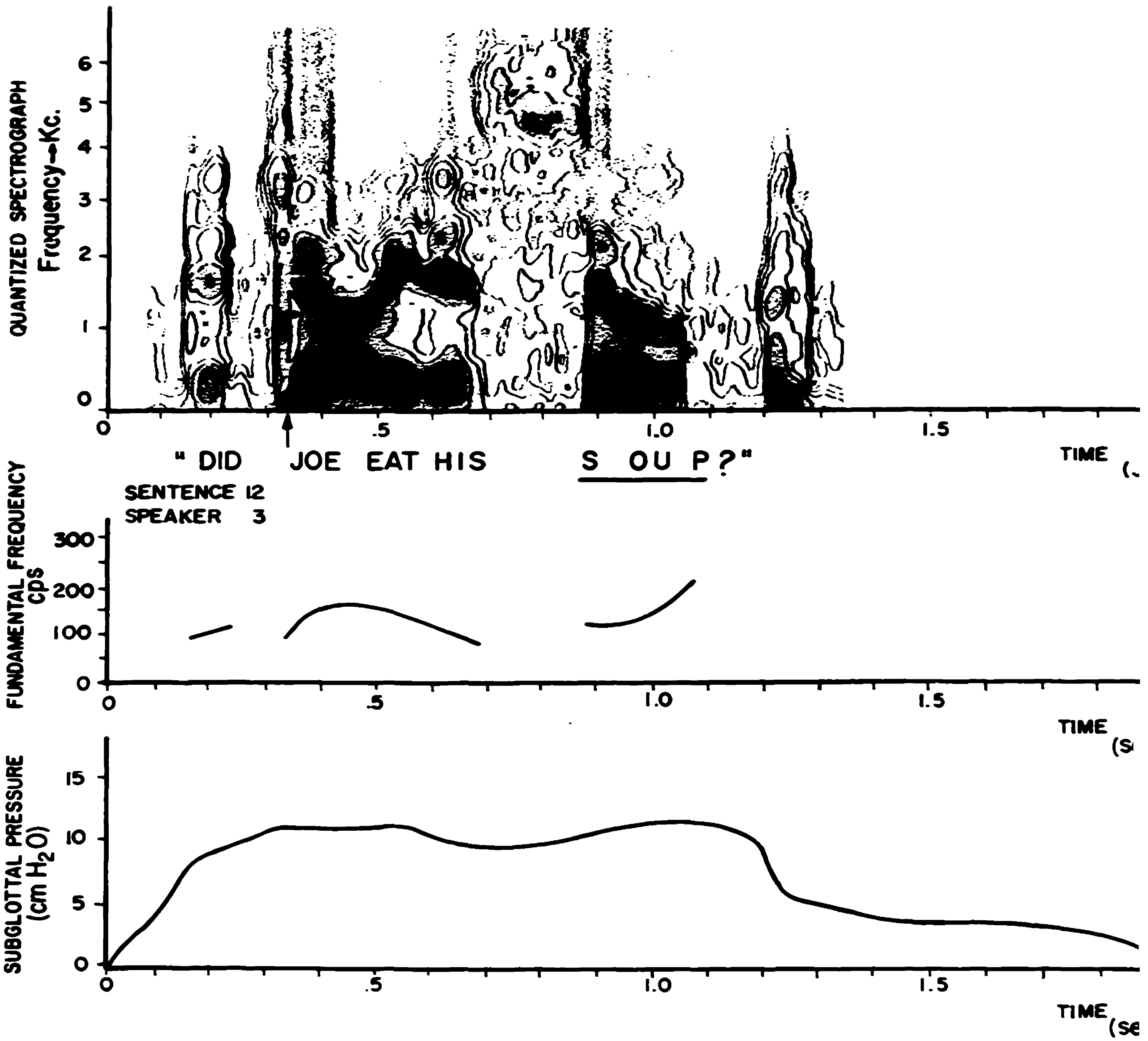
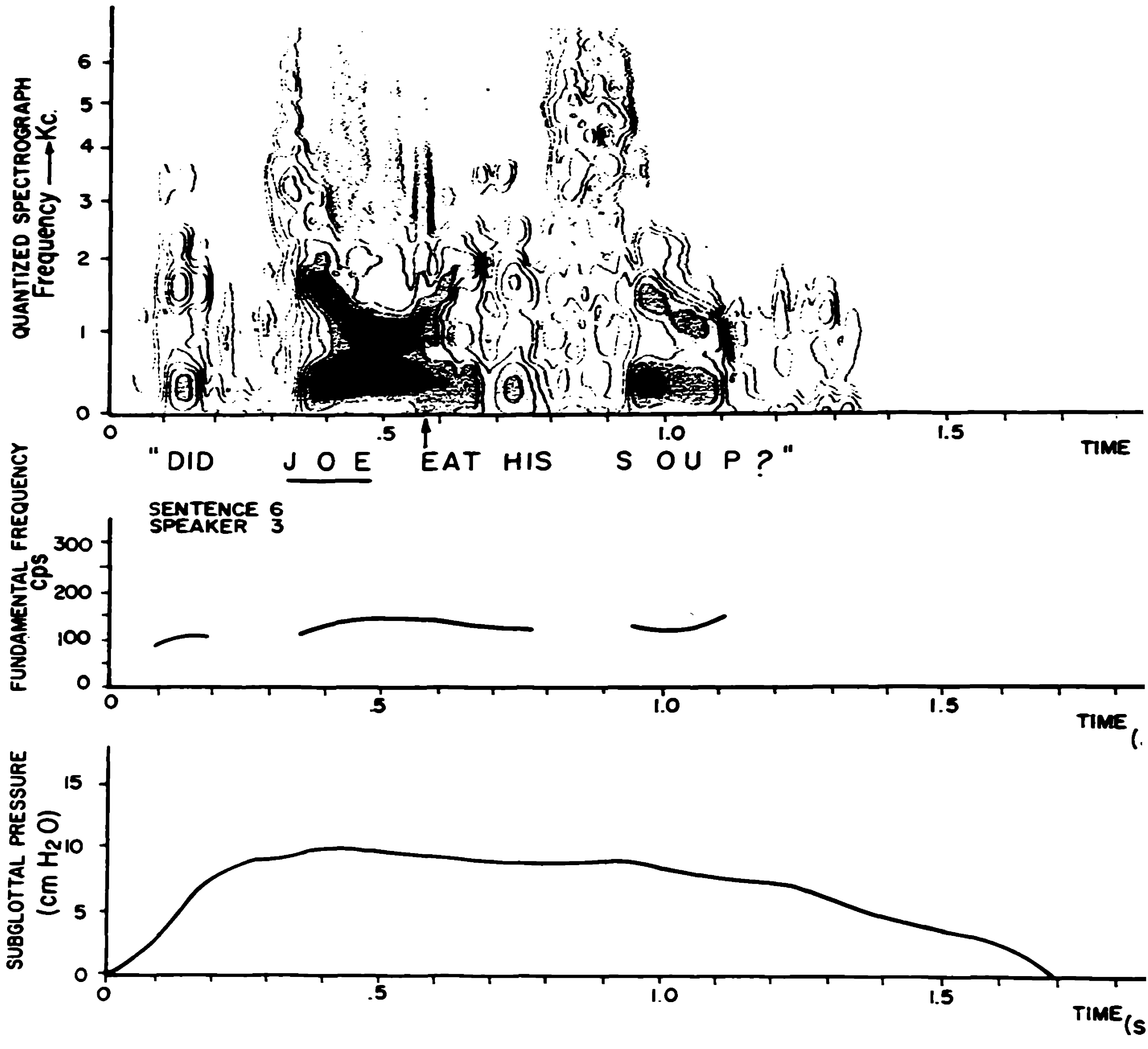

QUANTIZED SPECTROGRAPH
Frequency—Kc.
0
1
2
3
4
5
6
0
.5
1.0
1.5
TIME
" DID JOE EAT HIS S OU P?"
SENTENCE 12
SPEAKER 3
FUNDAMENTAL FREQUENCY
cps
0
100
200
300
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE
(cm H2O)
0
5
10
15
0
.5
1.0
1.5
TIME

Fig. 31



QUANTIZED SPECTROGRAPH
Frequency ⟶ Kc.
6
5
4
3
2
1
0
0
.5
1.0
1.5
TIME
"DID JOE EAT HIS SOUP?"
SENTENCE 6
SPEAKER 3
FUNDAMENTAL FREQUENCY
cps
300
200
100
0
0
.5
1.0
1.5
TIME
SUBGLOTTAL PRESSURE
(cm H2O)
15
10
5
0
0
.5
1.0
1.5
TIME

Fig. 32

frequency fall by reducing his subglottal air pressure.

In Figs. 29 and 30 the data for two interrogative sentences is displayed. Both breath-groups obviously involve an increase in the tension of the laryngeal muscles at the end of phonation, since the fundamental frequency rises though the subglottal air pressure is either falling slightly or is steady. In Fig. 31 emphasis has been placed on <u>soup</u> by means of a momentary increase in the subglottal air pressure. The archetypal articulatory correlate of the segmental feature [+P_s] has again been used by the speaker. The subglottal air pressure at the very end of phonation, however, is falling though the fundamental frequency rises 90 cps. The tension of the laryngeal muscles must therefore have been increased at the end of phonation.

In Fig. 32 the fundamental frequency again rises at the end of the sentence though the subglottal air pressure is falling. The marked breath-group has its usual articulatory correlates. Actually there was no instance in the entire data sample, including the sentences that are not plotted here, in which the rising fundamental frequency contour typical of the interrogative sentences was not generated by means of an increase in the tension of the laryngeal muscles. In some instances the subglottal air pressure also increased at the very end of phonation. However, in no instance was the increase in the subglottal air pressure, in itself, sufficient to account for the magnitude of the terminal fundamental frequency rise. The segmental feature [+P_s], however, often involved the use of articulatory gestures other than the archetypal increase in the subglottal air pressure. In Fig. 32, for example, the speaker emphasized Joe by increasing its duration. The duration of the diphthong of Joe is 250 msec in Fig. 32. Its average duration was 150 msec when speaker three did not emphasize Joe. It seems significant that its duration was also increased to 300 msec when it was emphasized in Fig. 26 and also received a momentary increase in subglottal air pressure. The increased duration that seems to be one of the articulatory correlates of [$+P_s$] therefore seems to be independent of the subglottal overpressure. Both the increased duration and the subglottal overpressure appear to be independent at the articulatory level. Perceptually the increased duration probably is interpreted in terms of loudness because of the integrating properties of the auditory system (c.f., chapter one.).

In Fig. 33 we have presented two fundamental frequency contours for sentence 22, "You're going to drive down that rutted road?". Speaker three first read the sentence as a statement. He suddenly noticed that he had made an error and said, "Drat it, I've made a mistake, I've read it as a statement instead of a question." He then immediately reread the sentence. Contour A is the fundamental frequency contour of the sentence when it was read as a statement. Contour B is the fundamental frequency contour of the sentence read as a question. Note that contour A ends with a falling fundamental frequency contour while contour B ends with a rising fundamental frequency contour. The subglottal pressure fell during the word road in both utterances. The minimal distinction between the question and the statement again is the presence of an increase in the tension of the laryngeal muscles at the end of phonation.

The quantized spectrograms show that the amplitude of the vowels

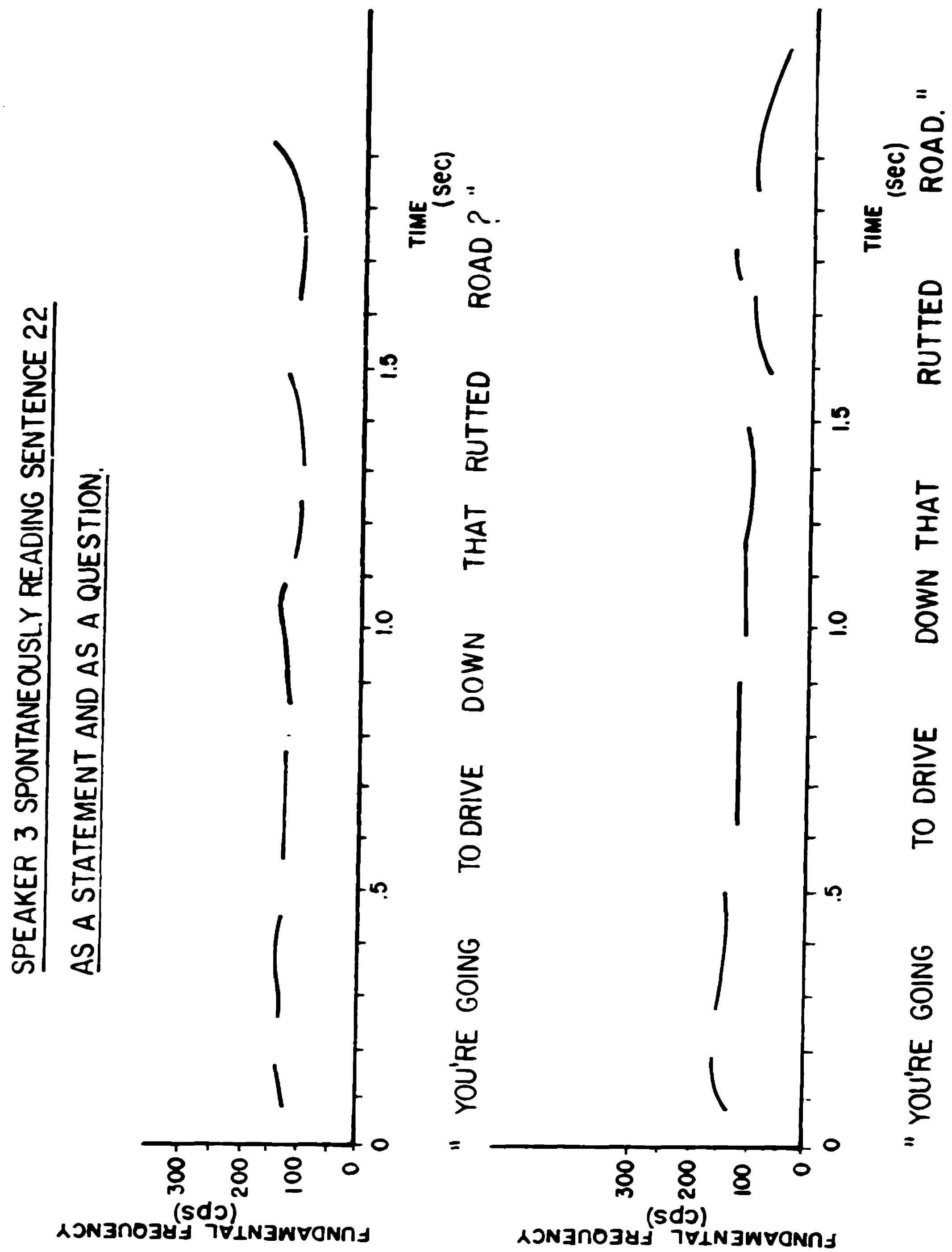

SPEAKER 3 SPONTANEOUSLY READING SENTENCE 22
AS A STATEMENT AND AS A QUESTION.
FUNDAMENTAL FREQUENCY (cps)
300
200
100
0
0
.5
1.0
1.5
TIME (sec)
" YOU'RE GOING TO DRIVE DOWN THAT RUTTED ROAD ? "
" YOU'RE GOING TO DRIVE DOWN THAT RUTTED ROAD. "

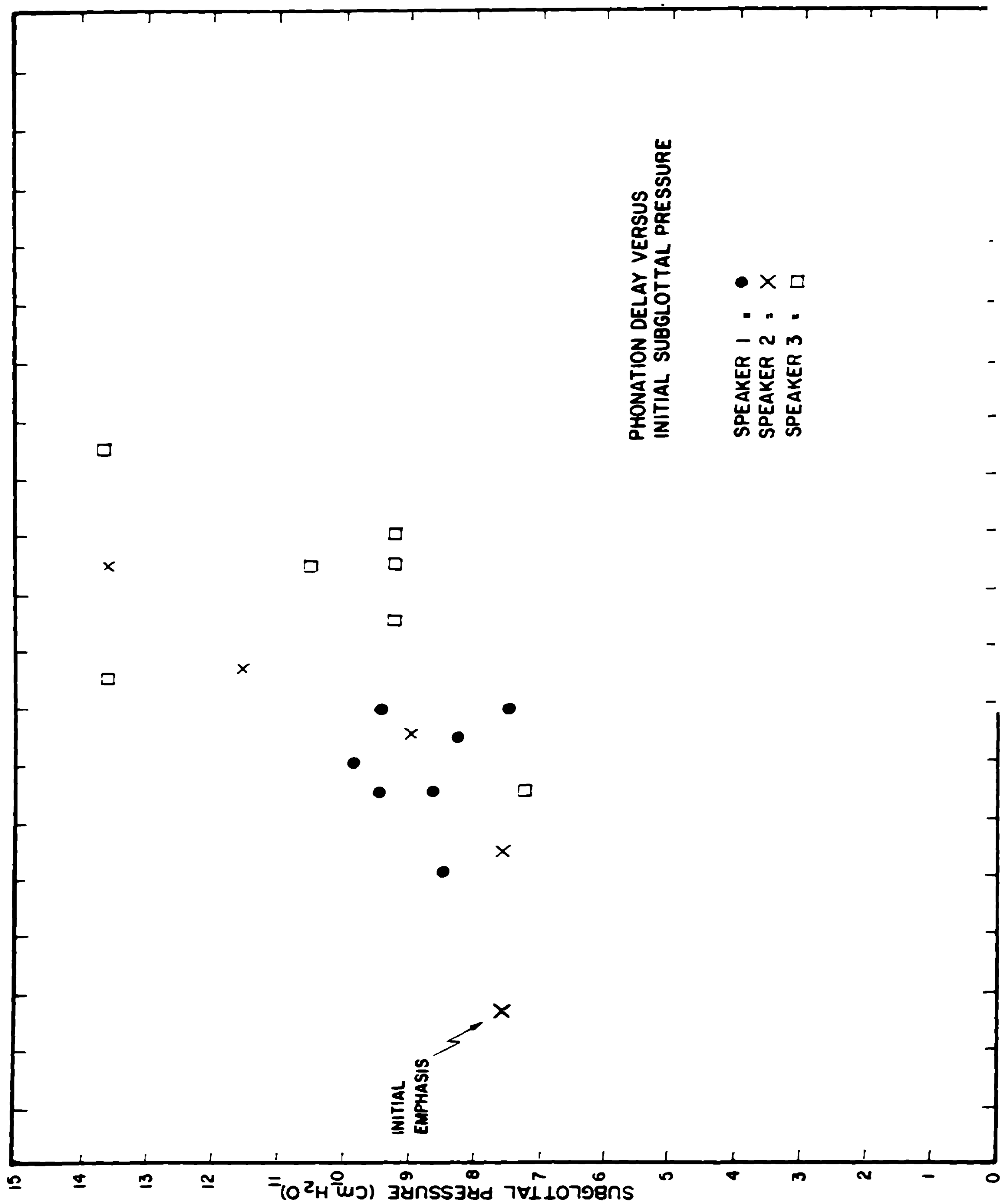
Fig. 33

that were emphasized were sometimes relatively greater than they were when they were not emphasized. In Fig. 26 the amplitude of F_1 of diphthong /ow/ of Joe is 6 db greater relative to the vowels of ate and soup than it is in Fig. 25 where it was not emphasized. In all the other examples the relative amplitude of the emphasized vowels was unchanged or smaller. Amplitude is thus not a consistent acoustic correlate of $[+P_s]$ for speaker three.

C - Discussion of Data

(1) - The Start and End of the Breath-Group

In Fig. 34 we have plotted the phonation delay versus the initial subglottal air pressure. The phonation delay is the interval between the beginning of expiration and the start of phonation. The data points have been measured from the fundamental frequency and subglottal pressure functions that we have been discussing in this chapter. The data shows that phonation starts most often at a pressure of approximately 8-9 cm of H_2O after a delay of 120-200 msec. Two conditions must be met in order to develop a subglottal pressure. The subglottal respiratory system must be building up a positive alveolar pressure and there must be some obstruction to the airflow at the glottis. We obviously would have zero subglottal pressure if there were no obstruction to the airflow and we obviously could have zero subglottal pressure even if the glottis were fully closed, if air was not forced out from the lungs. The data on Fig. 34 shows that the initial subglottal air pressure is due to the coordinated action of both the respiratory and the laryngeal muscles.



PHONATION DELAY VERSUS
INITIAL SUBGLOTTAL PRESSURE
SPEAKER 1 = ●
SPEAKER 2 = X
SPEAKER 3 = □
INITIAL
EMPHASIS
SUBGLOTTAL PRESSURE (CM. H2O)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

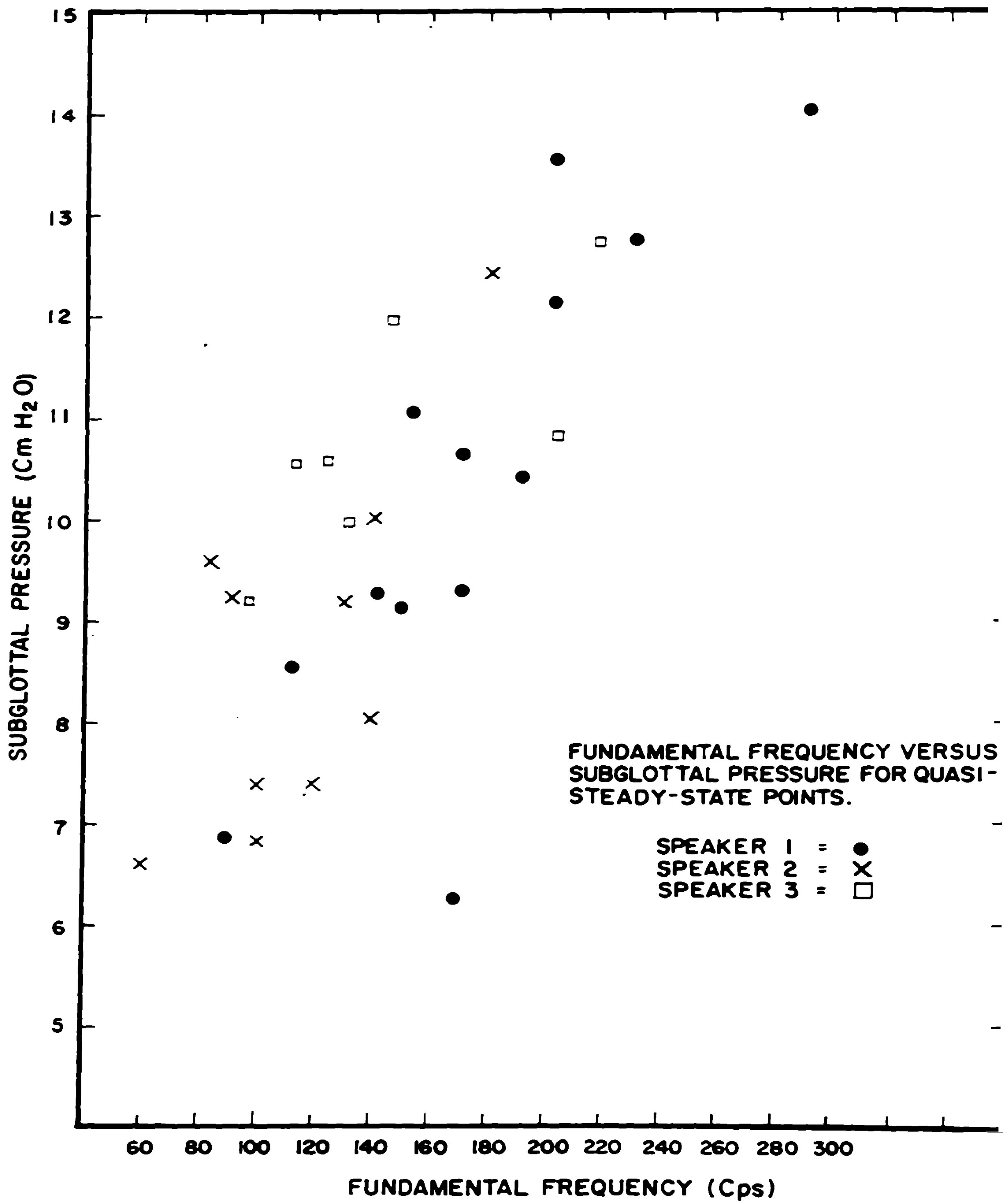
Fig. 34

As we noted earlier, observations of the activity of the vocal cords that were obtained by high speed cameras (c.f., chapter one) show that it takes about 100-150 msec for the vocal cords to get into position for phonation after they have been in their open respiratory position. Note that this duration approximately matches the average minimum phonation delay in Fig. 34.

Fig. 34 thus shows that expiration has already started as the vocal cords begin to close. The subglottal respiratory system must generate a positive alveolar pressure during expiration. The laryngeal muscles constrict the glottis and the subglottal pressure builds up. However, the respiratory mucles[1] also continue gradually to build up the subglottal pressure while the vocal cords move inwards, since the subglottal pressure increases as the phonation delay becomes longer. In most of the breath-groups plotted in this chapter the subglottal pressure continues to rise after the start of phonation, which clearly shows that the respiratory system continues gradually to build up the pressure.

---

1. Note that we are not stating that expiratory muscles build up the subglottal air pressure. The elastic recoil force provides most of the motive force for expelling air from the lungs. In order to maintain a low subglottal ari pressure at a large lung volume it is necessary to oppose the elastic recoil force by tensing the inspiratory muscles. A build-up in subglottal air pressure may therefore be effected by relaxing the inspiratory muscles.



SUBGLOTTAL PRESSURE (Cm H_2O)
15
14
13
12
11
10
9
8
7
6
5
60 80 100 120 140 160 180 200 220 240 260 280 300
FUNDAMENTAL FREQUENCY (Cps)
FUNDAMENTAL FREQUENCY VERSUS SUBGLOTTAL PRESSURE FOR QUASI-STEADY-STATE POINTS.
SPEAKER 1 = ●
SPEAKER 2 = X
SPEAKER 3 = □

Fig. 35

End of the Breath-Group

Our data also shows that the subglottal air pressure falls during the last 150-200 msec. of phonation for speaker one. This occurred even when a subglottal air pressure peak was used to emphasize the last word in the sentence (Figs. 12 and 15). The subglottal air pressure also fell during the last 150-200 msec of phonation for speakers two and three's breath-groups except for the instances where they departed from the archetypal pattern and maintained a high subglottal air pressure to the end of phonation. The increase in laryngeal tension of the marked breath-group, [+BG], always occurred during the last 150-200 msec of phonation.

These plots also show that the subglottal pressure either begins to fall at a faster rate or has fallen to a low pressure (3 cm H_2O or less), approximately 100-200 msec after the end of phonation (e.g., Figs. 15, 31, 32). This data seems to show that the subglottal pressure falls as the glottal obstruction is removed since the high speed motion pictures of the vocal cords also show that it takes about 100 msec for the vocal cords to open at the end of phonation. The subglottal respiratory muscles seem to operate more sluggishly than the laryngeal muscles. They often continue to maintain expiration after the end of phonation.

(2) - On Fundamental Frequency and Subglottal Air Pressure

In Fig. 35 we have combined all the data points that were plotted on Figs. 17, 21 and 28 for each speaker. Fundamental frequency has been plotted on the abscissa and subglottal air pressure on the ordinate. The calculated correlation coefficient is 0.85 and the correlation is significant at the 0.0001 level. All these data points were measured from the fundamental frequency and subglottal pressure contours of declarative sentences at points where we assumed that the tension of the laryngeal muscles was unchanged[1], so that the fundamental frequency was a function of the subglottal air pressure. We assumed, in short, that these sentences had archetypal unmarked breath-groups. This assumption thus seems to be reasonably valid.

The "linear" rate of increase of fundamental frequency with respect to subglottal air pressure is about 20 cps/cm H_2O. The calculated linear rate of change of f_o with respect to p_s for each individual speaker is: 16 cps/cm H_2O for speaker one, 18 cps/cm H_2O for speaker two, and 22 cps/cm H_2O for speaker three. Van den Berg (1959), in an experiment with an excised male larynx, measured f_o as a function of the subglottal pressure with tension as a paramter. Van den Berg applied tensions to the laryngeal muscles that he considered appropriate for phonation in the chest and falsetto registers. He excited the preparation with a mechanical source that supplied air at regulated pressures at the appropriate temperature and relative humidity. The rate of change of f_o with respect to air pressure varied from about 5 to 13 cps/cm H_2O for the chest register, depending on the tension of the laryngeal muscles and the average fundamental frequency. For the falsetto register the rate

1. It is important to note that we are not claiming that the normal breath-group always has a uniform laryngeal tension. Its <u>archetypal</u> articulatory correlate is a uniform laryngeal tension which results in an acoustic output where f_o is a function of the subglottal air pressure. The speaker may use alternate articulatory gestures to produce an acoustic output that is similar to the acoustic output of the archetypal articulatory correlate.

of change of f_o with respect to p_s varied from about 20 to 10 cps/cm H_2O. phonation occurred at either 100 or 130 cps in the chest register at a subglottal air pressure of 10 cm of water in this experiment. These values may vary for different speakers. As van den Berg (1959) points out "... every larynx sang after its own fashion."

The rate of change of f_o with respect to p_s that was obtained through our indirect technique for normal speech is somewhat greater than van den Berg's data. The range of air pressures over which phonation occurred according to our data is consistent with van den Berg's data as well as that reported by other studies in which the subglottal air pressure was measured during phonation in tracheotomized subjects (Strenger, 1958) or by a needle inserted into the trachea (Isshiki, 1964).

(3) Some Constraints on the "Air Pressure Perturbation" Hypothesis

The physiologic and acoustic data suggests that some obvious constraints must be placed on the "air pressure perturbation" hypothesis that we proposed to explain the data of the Hadding-Koch and Studdert-Kennedy psychoacoustic experiment. If two archetypal breath-groups have approximately the same durations and average subglottal air pressures then a momentary increase in the subglottal air pressure in the initial part of one breath-group will lower the air pressure at its end vis-a-vis the corresponding unperturbed breath-group. For example, the air pressure at the end of the breath-group in Fig. 11 is 2.7 cm H_2O lower than the air pressure at the end of the breath-group in Fig. 10. Both of these breath-groups were produced by means of the archetypal articulatory gestures and they both had similar durations and average subglottal air pressures. This effect was not apparent if the two breath-groups that were being compared had different average subglottal air pressures or different durations. For example, the air pressure is not lower at the end of the breath-group in Fig. 14 vis-a-vis the breath-group in Fig. 13. The average subglottal air pressure in Fig. 14 is approximately 4 cm H_2O higher than the average subglottal air prssure in Fig. 13. The durations of the breath-groups in Figs. 22 and 24 are not similar, expiration is prolonged approximately 350 msec longer in the breath-group in Fig. 22 and the air pressure perturbation effect is not present.

We examined our entire data sample and compared all the utterances of sentence 18, "Joe ate his soup." with all the utterances of sentence 19, "Joe <u>ate</u> his soup." for each speaker. We also compared sentence 3, "Did Joe eat his soup?" with sentence 6, "Did <u>Joe</u> eat his soup?. We found that the subglottal air pressure was lower at the end of the sentences where the speaker placed omentary peak pressure on <u>Joe</u> when we compared these sentences with utterances that were produced with breath-groups that had similar durations (within 100 msec) and similar average subglottal air pressures (within 1 cm H_2O).

Sixteen sentences were examined for speaker one. Two of these sentences were produced with different average subglottal air pressures (the sentences in Figs. 13 and 14). The other 14 sentences were produced with breath-groups that had similar durations and average air pressures. The average difference between the subglottal air pressure at the end of the perturbed breath-group and the "similar" unperturbed breath-group was 2.8 cm H_2O, with a standard deviation of 0.8 cm H_2O for the unmarked breath-groups. The average terminal air pressure difference for the similar marked breath-groups was 1.8 cm H_2O and the standard deviation was 0.75 cm H_2O. All the air pressures were measured at the end of phonation. Twelve sentences were examined for speaker two. Four sentences were produced on breath-groups that had dissimilar average air pressures. One sentence was produced on an extremely long breath-group. The perturbation effect did not occur in these four sentences. One other sentence also could not be examined since an artifact was present in the subglottal air pressure recording. We were able to compare 2 pairs of unmarked breath-groups and one pair of unmarked breath-groups. The terminal pressure differentials between the perturbed and unperturbed unmarked breath-groups were 2.5 and 3.0 cm H_2O while the terminal pressure differential for the pair of marked breath-groups was 2.0 cm H_2O. Twelve sentences were also examined for speaker three. In one of the marked breath-groups he emphasized Joe by simply increasing its duration so that no air pressure perturbation effects were noted. The average air pressures and the durations of four of the other breath-groups were also dissimilar and the perturbation effect could not be noted. The air pressure differential for two pairs of similar marked breath-groups was 1 cm H_2O. The air pressure differentials for two other pairs of marked breath-groups were 4.0 and 6.0 cm respectively but these utterances were produced with very high subglottal air pressures that are not typical of the rest of the data sample. (The speaker was reading at a "loud" level for these four sentences.)

This data therefore supports the "air pressure perturbation" hypothesis subject to these additional constraints. The average terminal pressure differential of the perturbed breath-groups was 2.3 cm H_2O [1]. Since the average rate of change of fundamental frequency with respect to subglottal air pressure is 20 cps/cm H_2O (Fig. 34) the momentary increase in subglottal air pressure on Joe would have resulted, on the average, in a 46 cps fall in the terminal fundamental frequency. This frequency fall is within the range of fundamental frequency deviations (40 - 80 cps) that we assumed the listeners in the psychoacoustic experiment compensated for, by means of the air pressure perturbation effect. However, we must point out that our air pressure calculations are only approximations since the uncertainty imposed by the time synchronization between the acoustic signal and the subglottal air pressure recording may have been as high as ± 40 msec for some of the sentences. The subglottal air pressure recording system has moreover been calibrated only for quasi-steady state conditions and the transient balloon pressure values may not be related to the subglottal air pressure in exactly the same way as the quasi-steady state values are.

In the psychoacoustic experiment all the intonation contours had the same duration and they all started from the same steady state fundamental frequency (250 cps) so that the listeners could reasonably infer that they had the same average air pressure. The additional constraints that we have composed on the air pressure perturbation hypothesis were therefore satisfied.

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1. If we exclude the two "loud" sentences.

As we noted earlier, the physiologic basis of this effect may perhaps be a consequence of the fact that the elastic recoil force of the lungs is the main force which acts to expel air out from the lungs during each breath-group. The elastic recoil force is a function of the instantaneous volume of the lungs. Now the average subglottal air pressure of each breath-group is determined by the extent to which the respiratory muscles oppose or aid the elastic recoil force. A speaker can maintain a given subglottal air pressure at virtually any lung volume by either opposing or supplementing the elastic recoil force by tensing the muscles of the chest and abdomen.

Let us suppose that the pattern of muscular activity that defines the breath-group is independent from the muscular activity that defines the segmental feature [$+P_s$]. The speaker, in other words, determines the pattern of muscular activity that complements the elastic recoil force without regard to whether any of the vowels in the breath-group's span are marked [$+P_s$]. This is a reasonable assumption since all distinctive features are essentially assumed to be independent at the articulatory level. (They constitute an "orthogonal" vector space.)

The presence of [$+P_s$] in the early part of the breath-group results in a greater airflow out from the lungs which, of course, lowers the volume of the lungs more than would have been the case if [$+P_s$] had not occurred. The elastic recoil force, which is a function of the volume of the lungs, therefore decreases. The air pressure in the breath-group is thus lower than it would have been in the absence of [$+P_s$] early in the breath-group. The air volume plots of our data unfortunately contain certain artifacts which make it impossible to verify quantitatively this hypothesis.

(4) - Other Segmental Intonational Features - Interactions Between Features

In many languages like Chinese, Thai, etc., additional segmental "tone" features exist. The primary acoustic correlates of these tones seem to be different functions of fundamental frequency (Chang, 1958; Abramson, 1962) and the question of interactions between these tonal features and the suprasegmental intonational features arises. Although these tonal features are clearly segmental (Chao, 1948) their acoustic correlates may still interact with the suprasegmental features just as $[P_s]$ does. Fortunately we do not have to speculate about this problem. Chang (op. cit.) in an acoustic and phonetic study of the tones and intonation of the Chengtu dialect (Szechuan, China) noted that this dialect had two sentence intonation patterns, a "falling tune" that is used for ordinary and emphatic statements, sentences expressing emphatic approval, awe, contempt, etc., and a "rising tune" that is used for questions. The rising pitch in the question occurs at the very end of the sentence on a special particle. Chang notes that,

> "These particles are meaningless by themselves, but they play an important part in bringing out the intonation of the sentence and thus denote whether the sentence is a question or a statement. If the particle is pronounced on a high pitch level or with a rising tone, then the sentence is a question. If on the other hand the particle is pronounced with a falling tone, than the sentence is a statement. It may be asked whether it is these particles that fix the intonation of the sentence or whether they merely bring out the intonation more clearly to the listener by indicating whether the sentence has a rising or a falling tune. The latter explanation seems a more plausible one since the same particle can be used in different types of sentences and it is then pronounced with different tones. (p. 78).

Chang notes that four tones exist in this dialect. I a high-rising, II a low-falling, III a high-falling and IV a low falling-rising. When these tones occur on the final syllable of a sentence that has a falling tune Tone I becomes mid-level, Tone II remains low-falling, Tone III remains high-falling, and Tone IV becomes low low-falling, checked by a glottal stop. When the tones occur on the final syllable of a sentence with a rising tune, Tone I remains high-rising and often ends higher than usual, Tone II becomes low-level, Tone III becomes high-level, and Tone IV becomes low-rising. Chang also discusses other perturbations of the tones that occur when they are concatenated in connected speech. Other perturbations occur when the speaker makes the syllable on which the tone occurs more prominent. Listeners apparently decode the fundamental frequency contour in terms of the suprasegmental intonation and the segmental tones[1].

Abramson (op. cit.) in his acoustic and phonetic study of Thai also notes that the sentence intonation and the segmental tones interact. He states that the rising intonation used for yes-no questions in Thai "...may so affect the lexical tone of the final syllable (of a sentence, PL) as to make it indistinguishable from /ˇ/ (a dynamic rising tone)."

Egerod (1956) in his study of the Lungtu dialect (of Chinese) also notes that,

> "The sentence intonation is superimposed on the individual tones and determines the absolute pitch and general inflection of the utterance, whereas the tones determine the relative difference in pitch and inflection among the syllables. The sentence intonation modifies the pitch and inflection on the tones. Only at the end of an utterance may the tone be modified beyond recognition by the intonation."

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1. Other tone interactions may have different causes. The "sandhi" may not arise from interactions on the articulatory level.

The fact that the tones are segmental features whereas the intonation is a suprasegmental feature may make the perception recognition routine feasible for these languages. Note that for these languages, which are unrelated to English, the rising intonation that differentiates a question is restricted to the last syllable of the utterance, as is the case for our English data. The phonemic tones of these languages are probably effected at the articulatory level by changes in muscle tension since promience by stress[1] is an independent factor in Chang's study.

Note that the fundamental frequency contours of the utterance plotted for the three speakers in Figs. 10-33 all show variations in the fundamental frequency within the breath-group. To a degree these variations follow from the variations of the subglottal pressure functions. However, they often seem to be the result of variations in the tension of the laryngeal muscles during the non-terminal portion of the breath-group. The points in Fig. 35, where fundamental frequency is plotted with respect to subglottal air pressure, have a fair amount of horizontal dispersion which indicates that the laryngeal tension is not always constant throughout the non-terminal portion of each breath-group. Our initial hypothesis regarding the complete absence of variations in the tension of the laryngeal muscles during the production of a declarative sentence in American-English must therefore be considered a first approximation.

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1. Stress is equivalent to force of utterance in Chang's study, which follows Daniel Jones' phonetic system, (c.f. chapter 7).

There is a great deal of variation from one speaker to the next regarding these non-terminal fundamental frequency variations. Speaker three tends to use less fundamental frequency variations than speaker one (compare Figs. 25 and 10). The three speakers do not even produce similar relative variations for the same sentence (compare Figs. 25, 18, and 10). These variations may represent chance variations in the tension of the laryngeal muscles which continually has to be set and reset as the vocal cords move in and out of the "phonation neutral position" to produce vowels and voiced consonants or unvoiced consonants. However, the data on Fig. 16 (where two fundamental frequency contours that had similar "shapes" were produced for two repetitions of the same sentence that had different average subglottal air pressures) indicate that the speaker may sometimes be controlling the fundamental frequency contour through deliberate modifications of laryngeal tension. Successive productions of the same sentence by the same talker often had similar fundamental frequency contours. All three of the speakers appear to be producing normal utterances. Some listeners occasionally said that speaker three's voice was "flat" compared to the other two speakers but no linguistically relevant contrasts betweeen the three speakers' utterances were noted.

Several studies of English speech (Berry, 1953; Lieberman, 1963) have suggested that fundamental frequency, amplitude, and duration are all functions of the relative importance of the word in an utterance. Obviously semantic and social factors as well as syntactic factors enter into the assessment of a word's relative "importance". These variations in fundamental frequency may manifest the importance or "functional load" of each word in the sentence. The mechanisms whereby these fundamental frequency variations are produced is at present a matter for conjecture. The mechanism might consist of "tone" features similar to those of Chinese, which may involve variations in laryngeal tension superimposed on the breath-group laryngeal tension contour. Variations in subglottal air pressure may also be involved. Further study is obviously necessary.

D - Summary and Discussion of Hypotheses and Observations

We will pause to review our hypotheses in the light of the data that we have alaready discussed before we turn to discuss some of the linguistic functions of the breath-group.

(1) We presented data that shows that the breath-group is a suprasegmental feature whose scope in the examples that we discussed was usually the constitutent sentence. In the examples that will follow in chapter four we will show that the scope of the breath-group may delimit any constituent in the derived phrase marker.

The breath-group at the articulatory level involves a coordinated pattern of muscular activity that includes the subglottal, laryngeal, and the supraglottal muscles during an entire expiration. The data shows that the subglottal respiratory muscles start to force air out from the lungs while the laryngeal muscles close the glottis to its "phonation neutral position" and adjust the tension of the vocal cords. The supraglottal vocal tract simultaneously begins to move into position and phonation commences at a specified fundamental frequency which the speaker can repeat at will. At the end of the sentence the subglottal respiratory muscles lower the subglottal air pressure during the last 150-200 msec. of phonation. The tension of the laryngeal muscles for the unmarked American English breath-group appears to remain relatively steady throughout the sentence. The fundamental frequency of phonation is thus a function of the subglottal air pressure function and it falls during the last 150-200 msec of phonation.

(2) - The falling terminal fundamental frequency contour that results from the absence of an increase in the laryngeal tension at the end of the unmarked breath-group apparently is a universal aspect of the unmarked breath-group. Data on the cries of newborn infants was reviewed in chapter two which showed that these initial vocalizations have the general form of the unmarked breath-group insofar as the fundamental frequency falls at the end of phonation because the subglottal pressure falls. This aspect of the breath-group, which is apparently innately determined, may be the result of a condition of minimum articulatory control The speaker does not bother to increase the tension of his laryngeal muscles to maintain the fundamental frequency as the subglottal air pressure falls. Phonetic data was briefly reviewed that indicated that many related and unrelated languages apparently have an unmarked breath-group that is characterized, in part, by a falling terminal fundamental frequency contour.

(3) Phonetic analyses were cited in chapter one that indicated that the breath-groups of individual languages might each be characterized by different patterns of laryngeal tension control in the non-terminal parts of the breath-group. In British English, for example, the

tension of the laryngeal muscles may initially be high and may gradually fall throughout the breath-group in contrast to American English where the laryngeal tension apparently remains relatively constant throughout the breath-group. The developmental data reviewed in chapter two indicated that children may acquire the idiosyncratic aspects of the breath-group of their native language during the first year of life. The scope of the breath-group in all of the languages reviewed can encompass the constitutent <u>sentence</u>.

(4) The existence of a marked breath-group [+BG] was hypothesized. The marked breath-group contrasts with the unmarked breath-group during the last 150-200 msec of phonation where the tension of the laryngeal muscles increases in the marked breath-group. The increased tension of the laryngeal muscles counters the falling subglottal air pressure and the marked breath-group thus has a terminal not-falling fundamental frequency contour. The marked breath-group is thus in a sense the "simplest" alternative to the unmarked breath-group since the laryngeal tension is increased at only one point in the breath-group - when the subglottal air pressure falls.

The relatively steady laryngeal tension function that chacterizes the non-terminal portions of the American English breath-group and the falling laryngeal tension function that probably characterizes the British English breath-groups (c.f. chapter one, section I), may perhaps be regarded as the "simplest" contrasts with the terminal fundamental frequency contour of the marked breath-group. They result in a level or a falling fundamental frequency contour that brings into relief the terminal not-falling fundamental frequency contour of the marked breath-group. The details of the non-terminal laryngeal tension functions of the breath-groups of other languages undoubtedly vary but it is unlikely that any language has a laryngeal tension function that rises before the terminal part breath-groups, since this could lead to confusions between the marked and the unmarked breath-groups. The breath-groups of different languages may perhaps also be characterized, in part, by specific non-terminal subglottal air pressure functions and by different coordinations between the muscles that generate the breath-group and the supraglottal muscles that articulate the segmental phonemes. These hypotheses on the language specific aspects of breath-groups are, of course, speculative in the absence of detailed physiologic data on many languages.

(5) A segmental phonologic feature [P_s] was hypothesized. The "archetypal" articulatory correlate of [$+P_s$] is a momentary increase in the subglottal air pressure that can occur in any part of the breath-group except the last 150-200 msec of phonation. More than one instance of [$+P_s$] can occur in a single breath-group although there probably are some constraints on how close momentary subglottal air pressure peaks can occur.

(6) The archetypal articulatory correlates of the unmarked and marked breath-groups and [$+P_s$] are the most basic articulatory maneuvers that can map out these features. The archetypal unmarked breath-group, for example, is produced on a single bounded expiration. The innately determined cries of neonates were produced on archetypal unmarked

breath-groups. The archetypal articulatory patterns perhaps may reflect the "optimal" use of the innate physiologic mechanism.

We noted that other alternate articulatory maneuvers could produce acoustic signals that were acoustically or perceptually equivalent to the signals that were produced by the archetypal maneuvers. A speaker can, for example, produce the subglottal air pressure function that is chacteristic of the breath-group without pausing for inspiration between two adjacent breath-groups. However, we hypothesized that the listener perceives intonational signals in terms of the archetypal articulatory correlates of the marked and the unmarked breath-groups and the segmental feature [P_s]. We hypothesized that the listener uses a feedback mechanism of the analysis by synthesis type using his knowledge of these archetypal patterns.

(7) We examined the data of an independently motivated psychoacoustic experiment. The data of this experiment was consistent with the notion of analysis by synthesis in terms of the archetypal patterns of the unmarked and the marked breath-groups and the segmental feature [P_s]. The data also showed that Swedish and American listeners perceived identical stimuli in different ways according to the phonologic features that may be operant in each language. The responses of the Swedish listeners showed that Swedish may have a feature that raises the tension of the laryngeal muscles throughout the breath-groups.

(8) We then examined some of the data of an experiment in which relevant physiologic and acoustic data was measured for four speakers of American English. The data of this experiment shows that these speakers indeed employed the archetypal articulatory gestures.

a - Eighty-seven percent of the breath-groups in a sample of 957 breath-groups were produced on a single expiration.

b - Quantitative calculations of the relationship between fundamental frequency and the subglottal air pressure were made for the utterances of three of the speakers. The fundamental frequency increased at a rate of 17 - 20 cps per cm H_2O. These calculations showed that the tension of the laryngeal muscles was relatively constant during the non-terminal portions of the breath-group.

c - The marked breath-group was always differentiated from the unmarked breath-group by an increase in the tension of the laryngeal muscles during the last 150-200 msec of phonation.

Detailed data for each of the three speakers was also examined. This data showed that speaker one's breath-groups were most often produced by means of the achetypal patterns. He placed emphasis on vowels by means of a momentary increase in subglottal air pressure - the archetypal articulatory correlate of [$+P_s$]. The data for speaker one also showed that he occasionally used alternate articulatory maneuvers to produce signals that were acoustically or perceptually equivalent. Speakers two and three used alternate articulatory maneuvers more often than speaker one. The segmental feature [$+P_s$] was most often manifested by means of alternate articulatory gestures. The acoustic correlates of [$+P_s$] in this data, i.e., fundamental frequency, duration, and amplitude, are consistent with the results of the acoustic analysis of English that were noted in chapter one.

(9) Other intonational features occur in "tone" languages like Chinese. While the scope of these features, like $[+P_s]$'s, is clearly segmental they nevertheless may interact with the breath-group at the acoustic and the articulatory level. Phonetic and acoustic analyses were briefly reviewed which indicated that the tones can interact with the overall suprasegmental intonation and $[+P_s]$ but the listener is able to deduce what the appropriate tone is, probably through a process of analysis by synthesis.

(10) In the hierarchy of phonologic features the breath-group is more basic than the segmental feature $[P_s]$. The basic form of the archetypal unmarked breath-group is indeed manifested in the initial cries of newborn infants. The breath-group may be a feature of every language. It is doubtful whether $[P_s]$ is used in evey language or whether it even occurs in a substantial number of unrelated languages. The distribution of $[P_s]$ is perhaps closer to the distribution of the segmental "phonemic tones" (e.g., the "tones" of Chinese).

Chapter Four

The "Phonemic Phrase"

We will show in this chapter that the suprasegmental breath-group is an explicit characterization of the "phonemic phrase". The breath-group can encompass different consitituents of the derived phrase marker. Though its scope is often the constituent sentence it can also occur on smaller constituents and a sentence can hence be divided into two or more breath-groups. We will discuss some of the circumstances that may motivate a speaker to break up a sentence into more than one breath-group. The segmental Trager-Smith analysis (1951) which is, in part, concerned with the manifestations of the "phonemic phrase" will also be discussed, and the effects of emotion on intonation which are confused with the linguistic aspects of intonation in the Trager-Smith analysis will be briefly summarized.

A - The Division of a Sentence into Breath-Groups

(1) Physiologic Reasons

In chapter three we observed that sentences were usually uttered on a single marked or unmarked breath-group. Two of the long sentences were, however, uttered on two breath-groups. The duration of a breath-group can, of course, be extended to encompass the duration of a long sentence. Small children usually utter declarative sentences on one unmarked breath-group. They will do this even when the sentence is quite long and they sometimes run out of breath before they come to the end of the sentence. Children will, for example, often utter sentences like, "I went to the zoo where I saw the lions, the tigers, the elephants, the bears...." The list of animals may be interminable and the child runs out of breath before he completes the sentence.

It is often physiologically more convenient to divide a sentence into more than one breath-group. When an adult speaker divides a sentence into two breath-groups the non-final breath-groups are marked. The presence of the terminal not-falling fundamental frequency contour of the marked breath-groups implies continuation; the sentence is not yet over. The breath-group here is analogous to the "phonemic phrase" or the "phonemic clause" in traditional terms.

This function of the breath-group is quite similar to the division of sentences proposed by the "Tune I and Tune II" analyses[1] of Armstrong and Ward (1926) and Jones (1932). Tune I on the acoustic level is equivalent to the unmarked breath-group while Tune II is equivalent to the marked breath-group. The examples of the application of Tunes I and II that are cited in these studies are fundamentally correct. Jones (op. cit., p. 254), for example, states that,

> Pauses are continually being made in speaking. They are made (1) for the purpose of taking breath, (2) for the purpose of making the meaning of the words clearer.
>
> Pauses for breath are normally made at points where pauses are necessary or allowable from the point of meaning.

(2) Disambiguation by Breath-Group Division

When a listener hears a sentence he must derive its underlying phrase marker in order to arrive at a semantic interpretation. Many sentences are unambiguous. If a linguistically competent listener hears a sentence of this type he will derive only one underlying deep phrase

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1. These analyses are discussed in chapter seven.

marker starting with the phonetic input. The sentence, I saw the boy who fell down the stairs. has, for example, only one deep phrase marker. Some sentences are, of course, ambiguous. The sentence, Flying planes can be dangerous, clearly has two distinct underlying phrase markers. The sentence can either mean that the act of flying a plane can be dangerous or it can mean that aircraft in flight are inherently dangerous. The two deep phrase markers have very similar derived phrase markers which result in identical phonetic outputs. When the sentence is part of an extended context, e.g., a discussion of the reactions of student pilots to emergencies, the sentence may appear to be unambiguous. The listener is able to use the information furnished by the context to guide his syntactic recognition routine. However, it is impossible to use intonation to disambiguate this sentence when it is spoken in isolation.[1]

Some sentences are, however, ambiguous if only the string of words that results from the derived phrase marker is considered. More than one deep phrase marker could have resulted in the same phonetic string of words. However, the different deep phrase markers each result in a derived phrase that has a different constituent structure. The derived phrase markers that resulted from the different underlying deep phrase markers thus have different constituent structures, though the phonologic component forms the same string of words from each derived phrase marker. If certain conditions are met these sentences can be disambiguated when they are spoken by dividing the utterance into breath-groups. The

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1. Verbal communication of experiment by Chomsky and Miller.

breath-groups can divide the speech signal into segments that acoustically manifest "breaks" in the constituent structure of the derived phrase marker. A string of n words can thus be segmented into two contiguous strings of i and j words, where i + j = n, by producing the first i words on one breath-group and producing the second j words on a second breath-group. The first breath-group would be marked, which would indicate that the sentence was not yet complete.

An ambiguous sentence can thus be "disambiguated" when the constituent structures of the several derived phrase markers can each be identified by unique continguous constituents. The following examples, some of which are drawn from the extensive literature connected with "phonemic" Trager-Smith pitch and stress transcriptions, will serve to illustrate this process. We will return to the question of what these segmental "phonemic" transcriptions really mean. For the moment it will suffice to note that the "phonemic" pitch notation[1] 231# is equivalent to an American English unmarked breath-group while the notation 232/ or 232// is equivalent to a marked breath-group.

A - Examples

Our first example was noted by Stockwell (1962, p. 51) who comments that his "...examples are real in the sense that they are caught on the fly, not constructed...." The sentence, "I'll move on Saturday." is ambiguous since it can either mean that the speaker is (A) moving his

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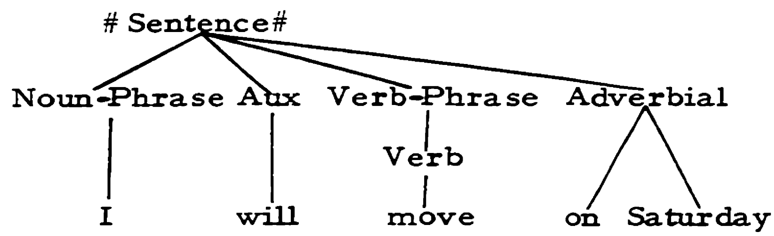
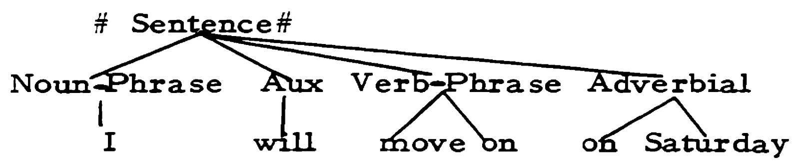
1. Trager and Smith term these sequences "phonemic clauses". The "phonemic phrase" to Trager and Smith is the sequence of words that is the scope of the breath-group.

household effects on Saturday or that he will (A^1) continue his wanderings on Saturday. The point is whether the verb phrase in the sentence is <u>move</u> or <u>move on.</u> The underlying phrase markers for (A) and (A^1) are:

A–

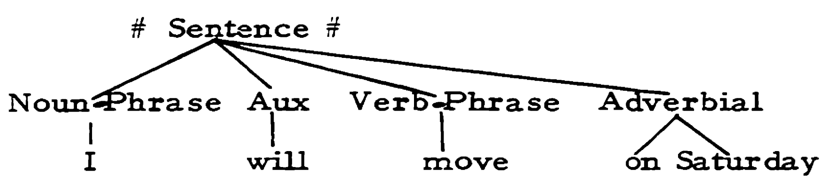


A^1-



The derived phrase marker that follows deep phrase marker A is:

A-d

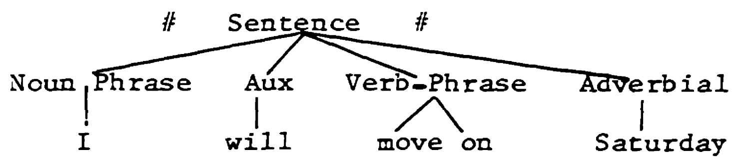


which can also be written in the form,

$$(_S\ (_N\ \text{I}\ )_N\ (_{Aux}\ \text{will}\ )_{Aux}\ (_{VP}\ \text{move}\ )_{VP}\ (_{Adv}\ (_P\ \text{on}\ )_P\ (_N\ \text{Saturday}\ )_N\ )_{Adv}\ )_S$$

The derived phrase marker that follows from deep phrase marker A^1 is,

$\underline{A^1\text{-d}}$



which can again be written in the form,

$$(_S\ (_N\ \text{I}\ )_N\ (_A\ \text{will}\ )_A\ (_{VP}\ (_V\ (\ \text{move}\ )\ \ (\ \text{on}\ ))_{VP}\ (_{Adv}\ \text{Saturday}\ )_{Adv}\ )_S$$

where the unlabelled parentheses on <u>move</u> and <u>on</u> represent word boundaries. Stockwell notes that the following two intonation patterns can occur:

(A) ^{2}Ì'll ^{3}móve / ^{2} ^{2}òn ^{3}Sáturday ^{1} #

(A^1) ^{2}Ì'll mòve ^{3}ón / ^{2} ^{4}Sáturday ^{1} #

We have presented Stockwell's original Trager-Smith transcription as well as a schematic notation that we shall use to indicate the scope of each breath-group. We will represent unmarked breath-groups with the symbol ——╲ and marked breath-groups with the symbol ——╱ .

The crucial aspect of this example is that the point at which the two breath-groups segment the sentence indicates that the words <u>move</u> and <u>on</u> are more closely "linked" in (A^1) than they are in (A). In this example these words are directly dominated by the constituent verb phrase in the derived phrase marker A'. The more closely related words are therefore in the same breath-group in utterance (A'). The closer relation of the two words move and on in (A') is only evident in relation to (A). There is no automatic procedure which will state that the sentence will be divided into breath-groups at one and only one point. The speaker, for example, could disambiguate the sentence by dividing it into three breath-groups as follows,

(A*) I'll, move, on Saturday.

(A'*) I'll, move on, Saturday.

If these sentences occurred in the course of a normal conversation the speaker would in all likelihood utter the entire sentence on one breath-group. If a listener were unable to resolve the ambiguity from the context of the conversation and asked the speaker what he meant, the speaker would again in all likelihood paraphrase the utterance. If he wished to convey utterance (A') he might not delete the particle on and he would say, "I'll move on on Saturday. The speaker need only consider the particular deep phrase marker that he wishes to convey when he disambiguates the sentence by paraphrasing it.

The process of disambiguating the sentence by means of breath-groups is by comparison fairly complex. The division of the sentence into several breath-groups can only indicate relative differences in the constituent structure of the ambiguous derived phrase markers. The scope of a breath-group can be any constituent of the derived phrase marker.

The sentence, The cat fell off the roof. could, for example, be slowly dictated. Each word could be produced on a single breath-group,[1] i.e.,

(B1) The, cat, fell, off, the, roof.

The same sentence could also be produced as follows,

(B2) The cat fell, off the roof or

(B3) The cat, fell off the roof.

The breath-groups can delimit any constituent of the derived phrase marker.

B-d $(_S\ (_{NP}$ (The) (cat) $)_{NP}$ $(_{VP}$ (fell) (off) $(_{NP}$ (the) (roof) $)_{NP}$ $)_{VP}$ $)_S$

The sentence can, of course, be produced on one breath-group,

(B4) The cat fell off the roof.

The alternate different intonation patterns (B1), (B2), (B3) or (B4) do not change the "meaning" of the sentence because there are no alternative derived phrase markerse that have similar formatives and different constituent structures. Only one deep phrase marker can underlie this sentence. Intonations (B1), (B2), (B3) and (B4) are all stylistic variants that are produced by placing breath-groups on some of the constituents of the derived phrase marker. The breath-groups that precede the sentence final breath-group are all marked. For similar reasons intonation patterns (A') and (A'*) had the same "meaning". The fact that the speaker chooses to say,

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1. The syllable is perhaps the smallest unit that can be produced on a single breath-group when polysyllabic words are considered.

(A') I'll move on, Saturday.

instead of

(A'*) I'll, move on, Saturday.

is simply a matter of efficiency; it is simpler to produce the sentence on fewer breath-groups so long as the duration of any breath-group does not exceed some critical time, T_c, where ventilation becomes necessary. The fact that the words I'll and move on are in the same breath-group in utterance (A') and in different breath-groups in utterance (A'*) has no linguistic significance. There are no deep phrase markers that could produce derived phrase markers in which these words[1] are more closely related in utterance (A'). Utterances (A') and (A'*) are therefore interpreted as stylistic variants.

The speaker might produce utterances (A*) and (A'*) if he wished to dictate the sentences and preserve their "meanings". However, speakers usually avoid dividing a sentence into many small breath-groups and intonation patterns (A) and (A') are probably more typical than intonation patterns (A*) and (A'*). A "trading relationship" probably exits. It is physiologically move convenient to utter a sentence using fewer breath-groups so long as the length of any breath-group does not become too long. On the other hand it may be important to manifest the derived constituent structure by dividing the sentence into breath-groups. The speaker apparently divides the sentence into the longest breath-groups that will still manifest the crucial aspects of the derived constituent

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1. to be more precise, the string of formatives on which the phonologic component of the grammar acts to shape these words, c.f. Katz and Postal (op. cit.)

structure[1].

In order to disambiguate the sentence, I'll move on Saturday, the speaker had to specifically consider wherein the derived phrase markers A-d and A'-d differed. The speaker may have intended to communicate deep phrase marker A' and he accordingly formed derived phrase marker A'-d. The sentence would normally be produced on one breath-group and it would be ambiguous. The speaker had to look at the string of words and derive deep phrase marker A in order to ascertain the constituent structure of derived phrase marker A-d. The speaker may perhaps perform a syntactic analysis of the words of the sentence that he wants to disambiguate with intonation. He may first derive the other deep phrase markeres that can underlie the string. He then computes the derived phrase markers of the alternative deep phrase markers. The speaker then can disambiguate the sentence if contiguous words have different constituent relationships in the derived phrase markers.

We will consider a few more examples of this process. Stockwell (1961, p. 48) noted the following two utterances in which "intonational morphemes" supposedly carry the meaning of the sentence.

---

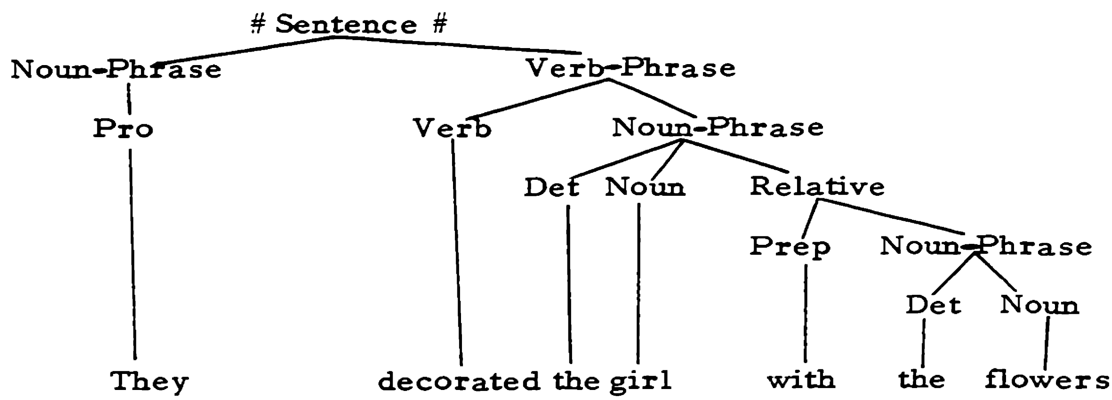
1. Bierwisch (1965) in his recent study of German sentence intonation proposes some further restrictions on the division of the derived phrase marker into breath-groups. He proposes an algorithm that takes into account the derived constituent structure, the presence of accented vowels, and the rate at which the speaker is talking. Bierwisch's algorithm correctly predicts, for example, that speakers will not produce the utterance (A*) I, will move on Saturday. The rate at which the speaker talks, is, of course, in part determined by whether he thinks that the sentence might be ambiguous if he didn't manifest the details of its constituent structure by dividing it into breath-groups.

2 3 2 2 3 1
(C) They decórated / the girl with the flówers #

2 3 2 3 1
(C') They decorated the gírl / with the flówers #

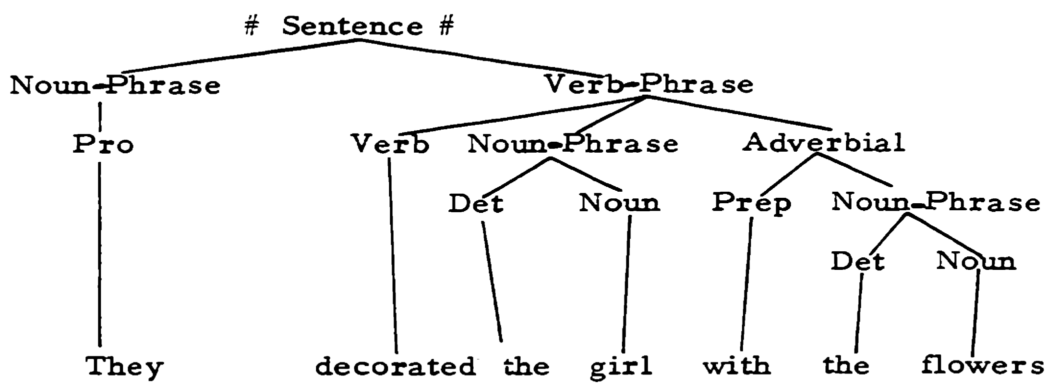
Utterance (C) may be paraphrased as, They decorated the girl who had the flowers. Utterance (C') may be paraphrased as, They decorated the girl by giving her flowers. The derived phrase marker of utterance (C) is

C-d



The derived phrase marker of utterance (C') is,

C'-d



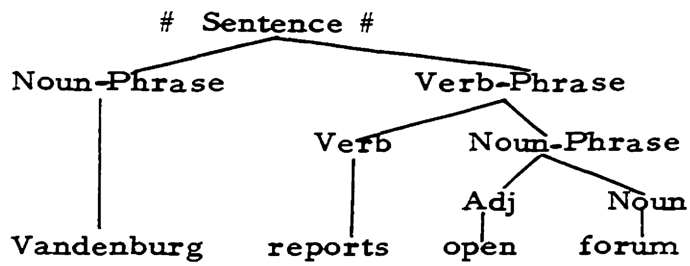
The words the girl with the flowers are more intimately related in C-d and they therefore occur in the same breath-group in utterance (C). Note that if we adopt the number of constituents at which "branching" takes place as a measure of relatedness, one node separates the strings {the girl} and {with the flowers} in C'd whereas no node separates them in C-d. If all the constituents that dominated these words were counted in the "path" betweeen all these words then 5 nodes would intervene in C'-d and 4 nodes would intervene in C-d. What we are trying to capture is an algorithm that measures how far "up" the tree diagram we have to go until all the formatives are dominated by the same constituent. Formatives that are dominated by constituents that are dominated by constituents that are "lower" in the tree are more intimately related. The words that are the phonetic outputs of the more intimately related formatives are produced on the same breath-group when the speaker attempts to disamgibuate the utterance by means of intonation.

Another example that demonstrates another aspect of disambiguation by breath-group division was noted by Sledd (1955). Sledd, in a review of Fries' Structure of English, noted that intonation can resolve the meaning of an utterance that is actually a deleted version of a full sentence. The newspaper headline, Vandenburg reports open forum, can be uttered with two intonation patterns,

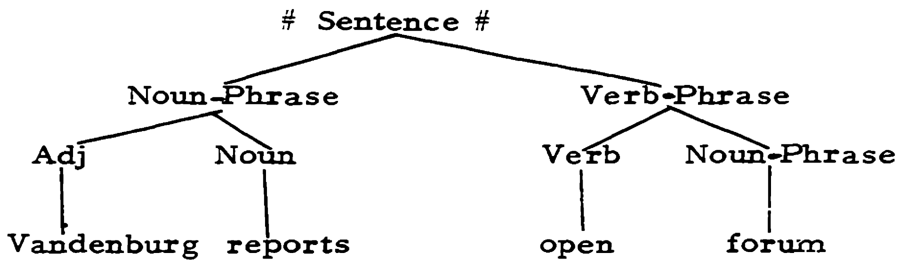
(D) Vandenburg [3 2] // reports open forum [2 3 1] #

(D') Vandenburg reports [3 2] // open forum [2 3 1] #

The derived phrase markers of these two utterances are as follows, D-d

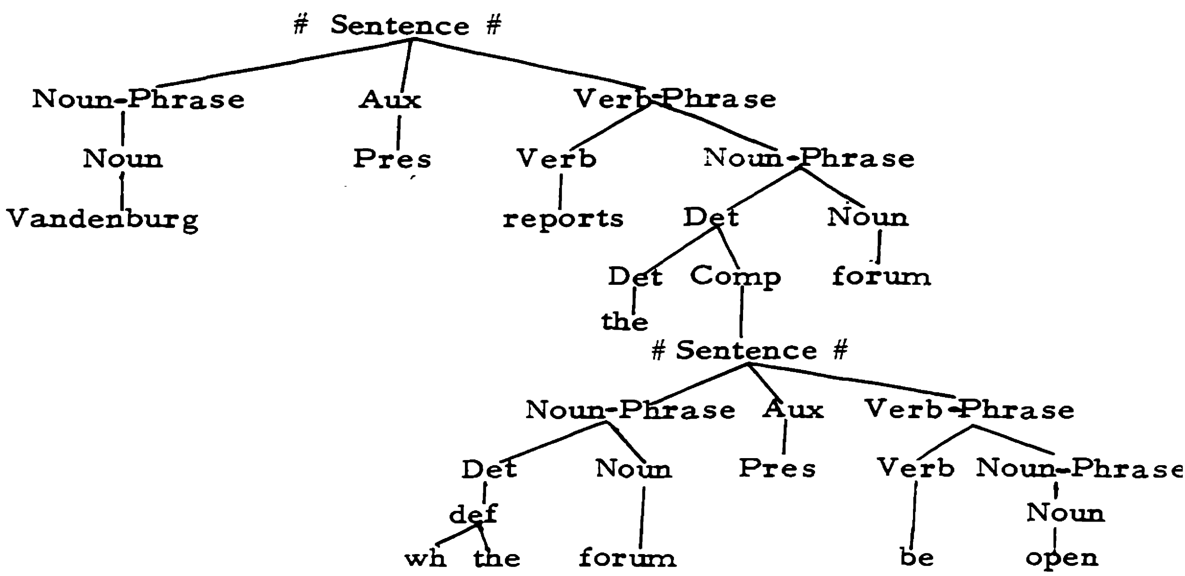


D'-d

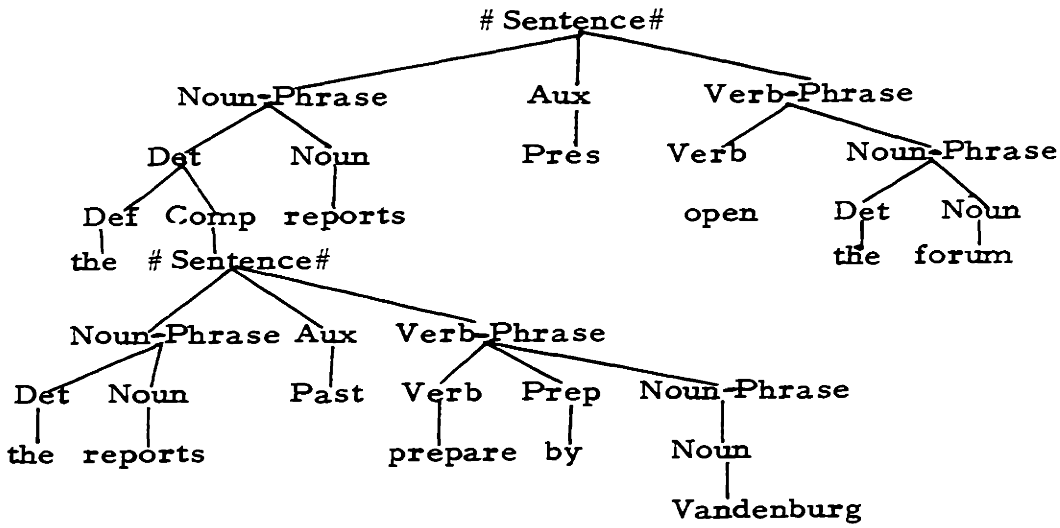


The division of the utterance into breath-groups again mirrors the constituent structure of the derived phrase markers. The deep phrase markers that underlie these deleted derived phrase markers could have the form:

D



D'



The full sentences that normally would follow from these underlying phrase markers are not ambiguous, i.e., Vandenburg reports that the forum is open. and The Vandenburg reports opened the forum. The telegraphic style of the words of utterances (D) and (D') causes the ambiguity. The division of the utterances into breath-groups disambiguates them. Figuratively speaking, intonation and lexical information - words - seem to have a trading relationship. Sentences can be disambiguated by either using more words or by using more breath-groups.

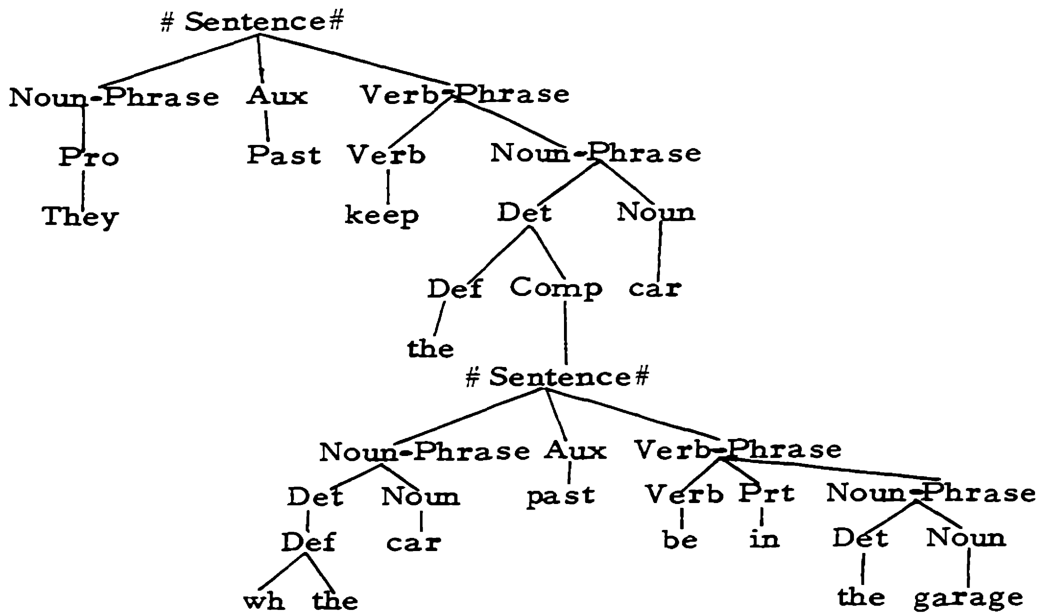
It is not hard to find many examples where it is possible to disambiguate an ambiguous sentence by dividing it up into breath-groups. The sentence They kept the car in the garage. which has two underlying deep phrase markers E and E', may be divided into two breath-groups as follows,

(E) They kept, the car in the garage.

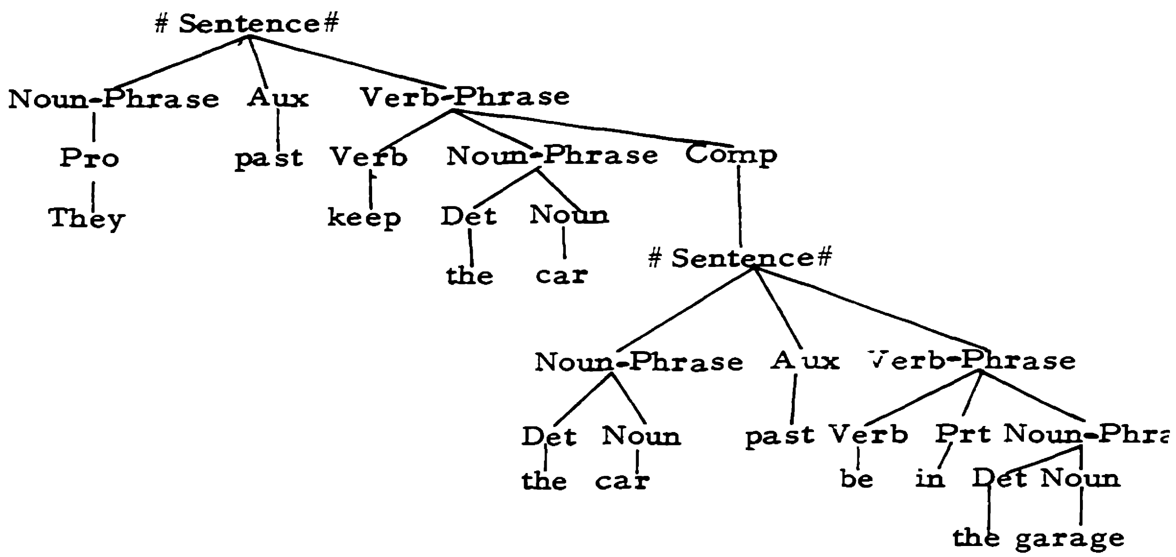
(E') They kept the car, in the garage.

The deep phrase markers are,

E -



E'



Deep phrase marker E would result in the sentence, They kept the car which was in the garage. and the sentence would not be ambiguous. However, the words which was do not appear in the phonetic output. Some optional transformations are probably applied in the syntactic processing of the deep phrase marker and the words that result from the derived phrase marker are ambiguous. The derived phrase markers that follow from E and E' however, have different constituent structures and the utterances are disambiguated by means of breath-group division. The sentence, I fed her dog biscuits is another simple example of the potential use of breath-group division to disambiguate a sentence, i.e.,

(F) I fed her, dog biscuits.

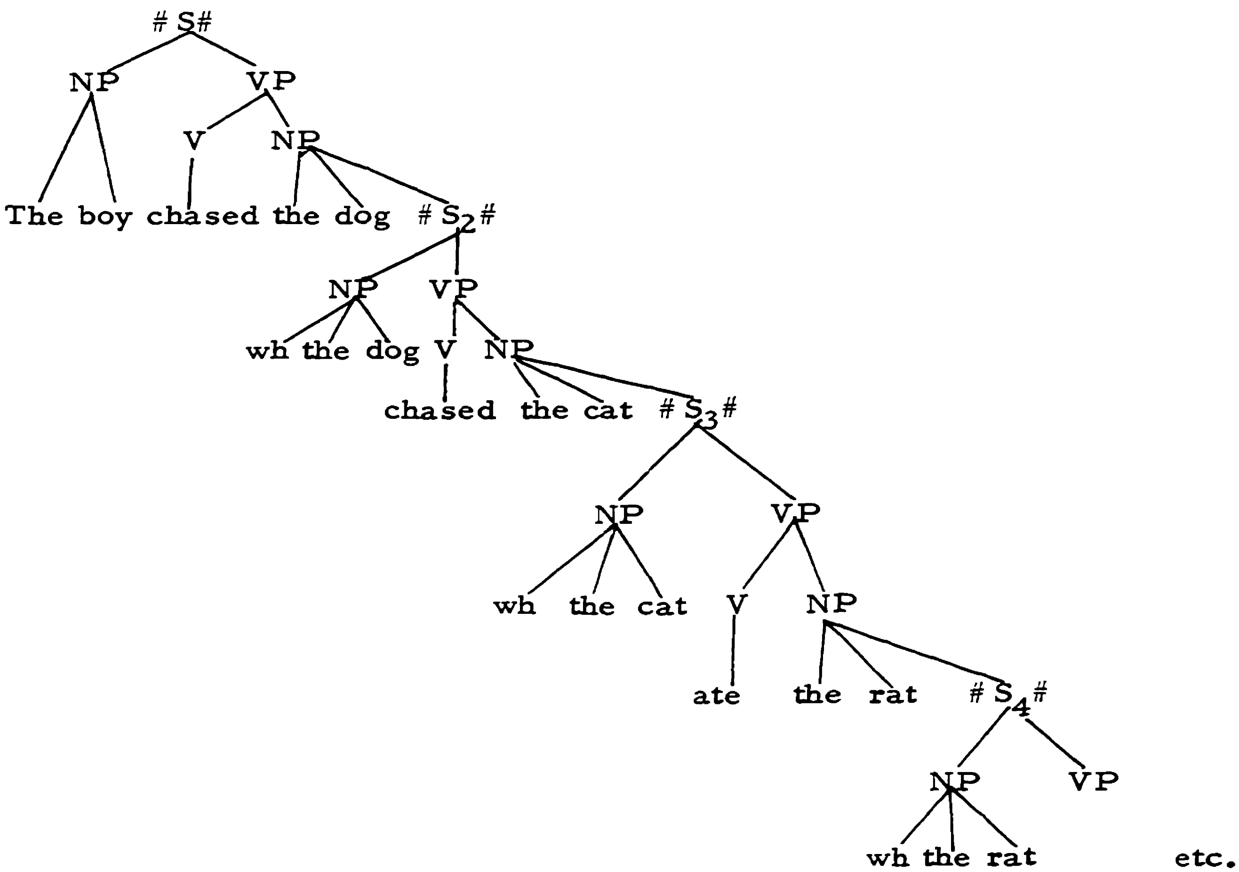
(F') I fed her dog, biscuits.

B - Suprasegmental Phonologic Features and the Syntactic Component

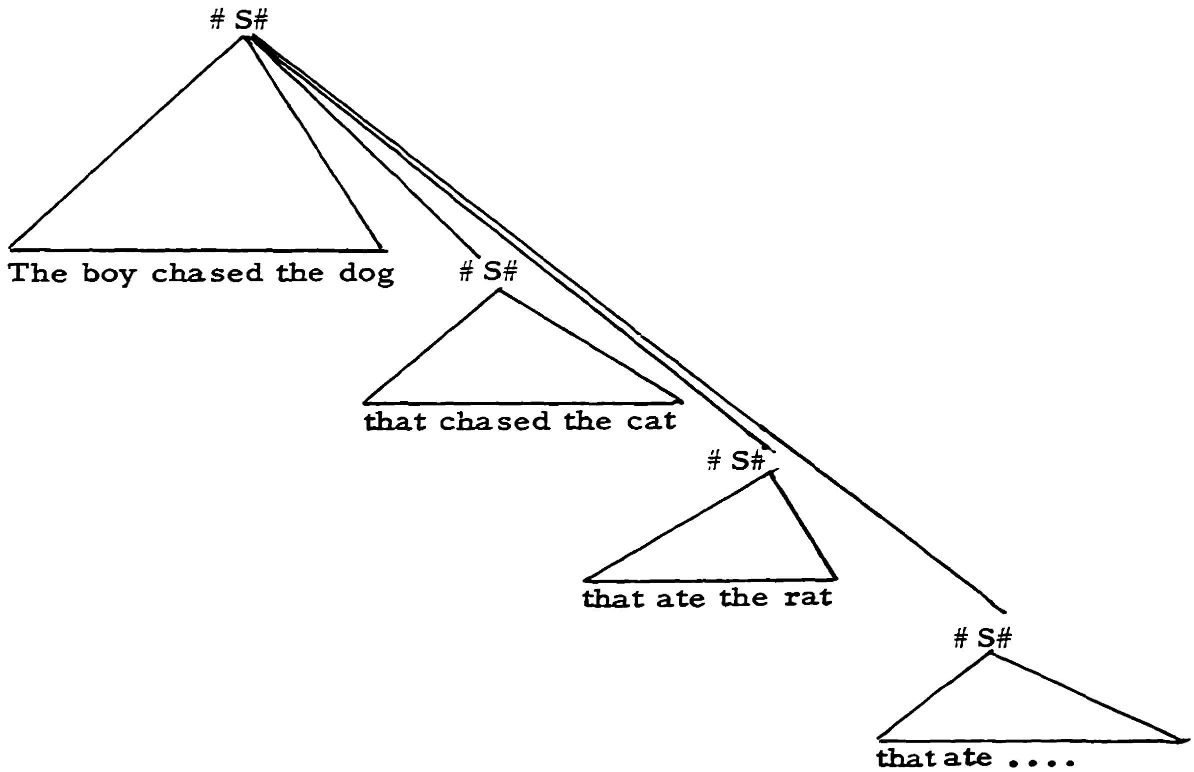
We have noted that the scope of the breath-group is an entire constituent rather than a single segment. This introduces an entire new class of suprasegmental phonologic features into the grammar which may motivate certain aspects of the syntactic component that tend to simplify the derived constituent structure. Chomsky, for example, has noted that the intonation pattern of the sentence, "The boy chased the dog, that chased the cat, that ate the rat, that...." is as follows,

(G) The boy chased the dog, that chased the cat, that ate the rat, that....

The usual derived phrase marker for this sentence is, G-d 1



We would like to say that the derived phrase marker of this sentence is still more simplified and has the structure, G-d 2



A single breath-group would then span each constituent sentence in the derived phrase marker. The simplication of the derived phrase marker might be viewed as an optimization procedure wherein the syntactic component produces a derived phrase marker that is most easily mapped out by the available phonologic apparatus, in this case the suprasegmental feature breath-group.

C - Emotion

Note that the specific intonation pattern of a sentence that follows from its division into breath-groups has no "meaning" of its own. It specificially does not indicate the attitude or emotion of the speaker. The breath-group is a phonologic feature. It has no independent semantic status. The semantic interpretation of a sentence follows from the underlying deep phrase marker.

The emotion of the speaker can modify the intonation of an utterance just as it can modify other aspects of the speech signal like the preciseness of the speaker's articulation, or the words that he may omit. However, these aspects of intonation are not primary linguistic phenomena. They are apparently superimposed on the linguistically predictable aspects of intonation, though it is, at present, not clear how they are manifested in the acoustic signal. However, the effects of emotion are independent of the linguistic aspects of the speech signal. One recognizes a yes-no question whether the speaker's voice expresses anger or not (Lieberman and Michaels, 1962). The acoustic correlate of the marked breath-group is still a not-falling terminal fundamental frequency contour. The breath-group still has the same "shape" though the average fundamental frequency may be quite different.

Several acoustic studies have discussed the emotional aspect of intonation. Some speakers apparently raise their average fundamental frequency when they are angry, but other speakers lower their average fundamental frequency. Extreme emotion may result in a wider f_o range or it may result in a lowered and narrowed fundamental frequency range. Extreme emotion sometimes results in the speaker's breaking the sentence into many breath-groups. Emotion sometimes causes the speaker to extend breath-groups to extremely long durations. The use of the marked breath-group is also said to indicate uncertainty in some sentences. The insertion of both "filled" and "unfilled" pauses[1] is said to reflect emotion or cognition (Goldman-Eisler, 1958). Other changes also take place. The sound pressure level may be either raised or lowered, the high frequency content of the voice may increase, the pitch perturbations of the speaker's fundamental frequency may diminish, etc. It is clear that some information is transmitted by the prosodic aspects of speech Lieberman and Michaels (1962), for example, in a forced choice test showed that listeners could differentiate eight emotional states 50 percent of the time when the prosodic features of complete sentences were isolated from the words of the sentence. Denes (1959), however, found that he got almost random responses when he isolated the prosodic features of isolated words and asked listeners to freely associate these prosodic contours with emotional states. Uldall (1960) and Hadding-Koch (1961) both noted that the emotion which the listeners associated with a particular contour was very much dependent on what the sentence's words were. There probably are some general aspects of intonation and stress that relate to particular emotional states. However, all that we can say at the present time, without knowing the idiosyncracies of a particular speaker, is that emotion is marked by a departure from the normal speaking habits of the individual.

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1. These "pauses" must be differentiated from the pauses that occur at the end of breath-groups. Boomer and Dittmann (1962) show that pauses that occur at the ends of "phonemic clauses" (i.e., juncture pauses) have a higher perceptual threshold than the "hestitation pauses" which occur unexpectedly within phonemic clauses. The phonemic clauses which map out the derived constituent structure are syntactically determined. The "hestitation pauses" appear to manifest congnition or emotion.

D - Taxonomic Analyses of Intonation and the "Phonemic Phrase"

One of the most widely accepted analyses of intonation is the system proposed by Trager and Smith in their Outline of English Structure (1951). They attempt to apply the principles of taxonomic segmental analysis to intonation. In chapter 7 we will discuss this theory in detail. Briefly, this system makes use of four pitch levels, three terminal junctures[1], and various vocal qualifiers to desicrbe the pitch contour of an utterance. It also uses four levels of stress to describe the stress relationships of the speech signal. Stress and pitch are supposed to be completely independent. The linguist is, for example, supposed to be able to perceive the stress levels of an utterance independently of his perception of the pitch levels.

Stress and pitch are supposed to relate to rather distinct linguistic levels in this system. Stresses are supposed to distinguish certain morphemic classes from each other while pitch levels and terminals are supposed to provide acoustic cues that tell a listener where the phrases of a sentence begin or end. In the words of the Outline of English Structure

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1. Trager and Smith essentially use these three terminal junctures to differentiate between the unmarked breath-group (contours that end with #), marked breath-groups that occur in sentence final position (//), and marked breath-groups that occur in the middle of sentences (/). They note that the juncture // corresponds phonetically to a rise in pitch whereas the juncture / corresponds phonetically to a sustension of pitch. This phonetic distinction may simply be a co-articulation effect. When a speaker uses a marked breath-group in the middle of a sentence he may not complete the tensioning of his laryngeal muscles at the end of the marked breath-group before he begins to relax these muscles for the breath-group that follows. Similar phenomena occur for the segmental features (c.f. Lindblom, 1963, for a careful study of co-articulation effects in vowels).

> The contribution of the phonological analysis of stress, juncture, and intonation patterns...is that it makes... the recognition of immediate constituents and part of speech syntax into solidly established objective procedures, removing once and for all the necessity of defending one's subjective judgments as to what goes with what. (p. 77)

Trager and Smith isolated "pitch morphemes" by considering pairs of utterances like,

```
      2    3     2     2                       3     1
(c)   They decórated  /  the girl with the flówers  #
      2                3  2      2          3     1
(C')  They decorated the gírl  /  with the flówers  #
```

These two utterances are phonetically identical except for the different intonation contours. Since the notion of an underlying phrase marker is not present in taxonomic "anti-mentalistic" grammars the "meaning" of the utterance must be conveyed by the morphemes that are present in the superficial structure. Utterances (C) and (C') form a "minimal pair" with respect to intonation and they have different meanings - hence the pitch contours are morphemes. Moreover since the "morphemes" were composed of individual pitches the latter were said to be "phonemes".

Unfortunately the same pitch contours often have rather different meanings when they occur in different sentences. Stockwell (1960), for example, comments,

> There is a good deal of evidence...that intonation patterns are the absolutely minimal differentiators of numerous utterance tokens though such evidence is always disconcerting in the difficulty it offers anyone who tries to assign semantic values to such differences in a way that will yield consistent results in a variety of contexts.

The way out taken by Trager and Smith was to state that the meaning of the intonation contour was the speaker's attitude towards the words of the sentence, which is sufficiently vague to fit any example, Much of the preoccupation of latter taxonomic studies with intonation perhaps stems from the desire to find some phonetic cues that would explain how sentences are semantically interpreted. Intonation seemed to provide a new set of "phonemes" that could permute with all the segmental phonemes to provide a greatly expanded set of semantic interpretations.

The main function of intonation in the Trager-Smith Outline of English Structure is, as they noted, to provide an "objective" basis for immediate constituent analysis. Trager and Smith observed that the intonation pattern could sometimes segment the speech signal into "phonemic phrases"[1] that reflected the constituent structure when utterances like (C) and (C') were produced. They erred, however, in assuming that the intonation reflected the constituent structure within all sentences. Normally, a speaker will produce an entire sentence on a single unmarked breath-group (pitch "morpheme" 231# in Trager-Smith notation). It is only when the speaker is trying to disambiguate the sentence that he will consistently segment smaller constituents by means of intonation. For nonambiguous sentences virtually any part of the constituent structure of the derived phrase marker can potentially be delimited by means of breath-group division. When a speaker pauses to

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1. We shall use the term "phonemic phrase" in place of the Trager-Smith "phonemic clause."

breathe, he obviously can stop talking at any word though he usually stops at some "major" break, i.e., a node that is nearer to the "top" of the tree diagram. People know how to recognize immediate constituent structure simply because they know the syntactic rules of the langauge that govern constituent structure and the lexicon of the language. They can recognize a phrase simply because it is a well formed phrase.

If it were necessary to have acoustic signals that provided specific cues for immediate constituent analysis it would obviously be impossible to understand written texts. It is only when ambiguity arises that intonation becomes important[2]. A speaker will normally not bother to divide a sentence into breath-groups because it is usually not necessary. However, Trager and Smith wanted to have "objective" cues for immediate constituent analysis and so many utterances were transcribed as though they always were produced with complex intonation patterns. These "objective" phonemic transcriptions have, however, been accepted with reservations by other linguists who, in theory, agreed with Trager and Smith on the utility of "objective" cues. Sledd (1955), in his review of the Outline of English Structure, comments:

> Anyone who has attempted to analyze or teach the English patterns of pitch and stress knows that competent observers may vigorously disagree and that a single observer may disagree with himself so often as to make secure confidence in his own judgments painfully difficult....

The results of a controlled psychoacoustic experiment (Lieberman, 1965) demonstrate that competent linguists do not simply consider the physically present acoustic signal when they transcribe the pitch and

---

1. An obvious parallel can be made with orthographic punctuation. Commas are only essential when a sentence might be ambiguous if the derived constituent structure was not indicated. Commas are otherwise not necessary for the understanding of the sentence. Trager and Smith, in effect, put all the commas into their transcriptions.

stress "phonemes" of an utterance according to the Smith-Trager system. In this experiment two linguists who were quite familiar with this system transcribed the utterances of two speakers who each read the words, they have bought a new car, as though they were a statement, a question, a message expressing fear, a message expressing happiness, etc. The fundamental frequency and amplitude contours of the utterances were then measured. The utterances were also electronically processed to yield a set of stimuli in which a fixed vowel, /a/, had a fundamental frequency and envelope amplitude contour that varied in the same manner as the original speech signal. The following observations followed from the data of this experiment:

1. When two competent linguists independently transcribe a set of sentences that include "emotional" as well as "normal" utterances, 60 percent of the pitch levels and junctures of the two Trager-Smith transcriptions vary.

2. The Trager-Smith pitch levels do not correspond to discrete relative ranges of fundamental frequency. These comments apply even when the data was limited to the transcriptions made by a single linguist who carefully transcribed the tape recorded sentences of a single talker.

3. The pitch levels of the Trager-Smith system do not even reflect the relative pitch levels of a single utterance of a single talker when it is transcribed by a single linguist. The fundamental frequency that corresponds to pitch level one, for example, may be identical to or greater than the fundamental frequency that corresponds to pitch level two.

The pitch levels reflect the relative fundamental frequency only during segments of speech in which there is continuous voicing.

4. A subclass of utterances was transcribed more consistently and accurately than the rest of the stimulus ensemble. These utterances were produced on either a single unmarked breath-group or a single marked breath-group. These contours were always transcribed by the linguists in terms of the "suprasegmental morphemes" 231#, 232/ or 232//. When the single contour extended over an entire unemotional utterance the pitch levels bore a reasonable relationship to the actual fundamental frequency contour of the utterance. However, in other instances, contours having the same "shape" but different fundamental frequency ranges were transcribed with exactly the same pitch levels and junctures. The linguists apparently responded to the suprasegmental breath-groups rather than to any pitch levels. For example, in Fig. 1, the fundamental frequency contours of two of the utterances are plotted. Fundamental frequency is plotted with respect to the ordinate and time with respect to the abcissa. Note that the final portion of fundamental frequency contour B (from approximately 0.6 seconds to the end of stimulus) bears the same Trager-Smith transcription as the entire contour in 1A, though the fundamental frequencies of the two contours are markedly different.

This example, which is typical of other instances in the data sample of this experiment, indicates that certain contours are perceived as complete entities. The linguist apparently "hears" the contour in 1A

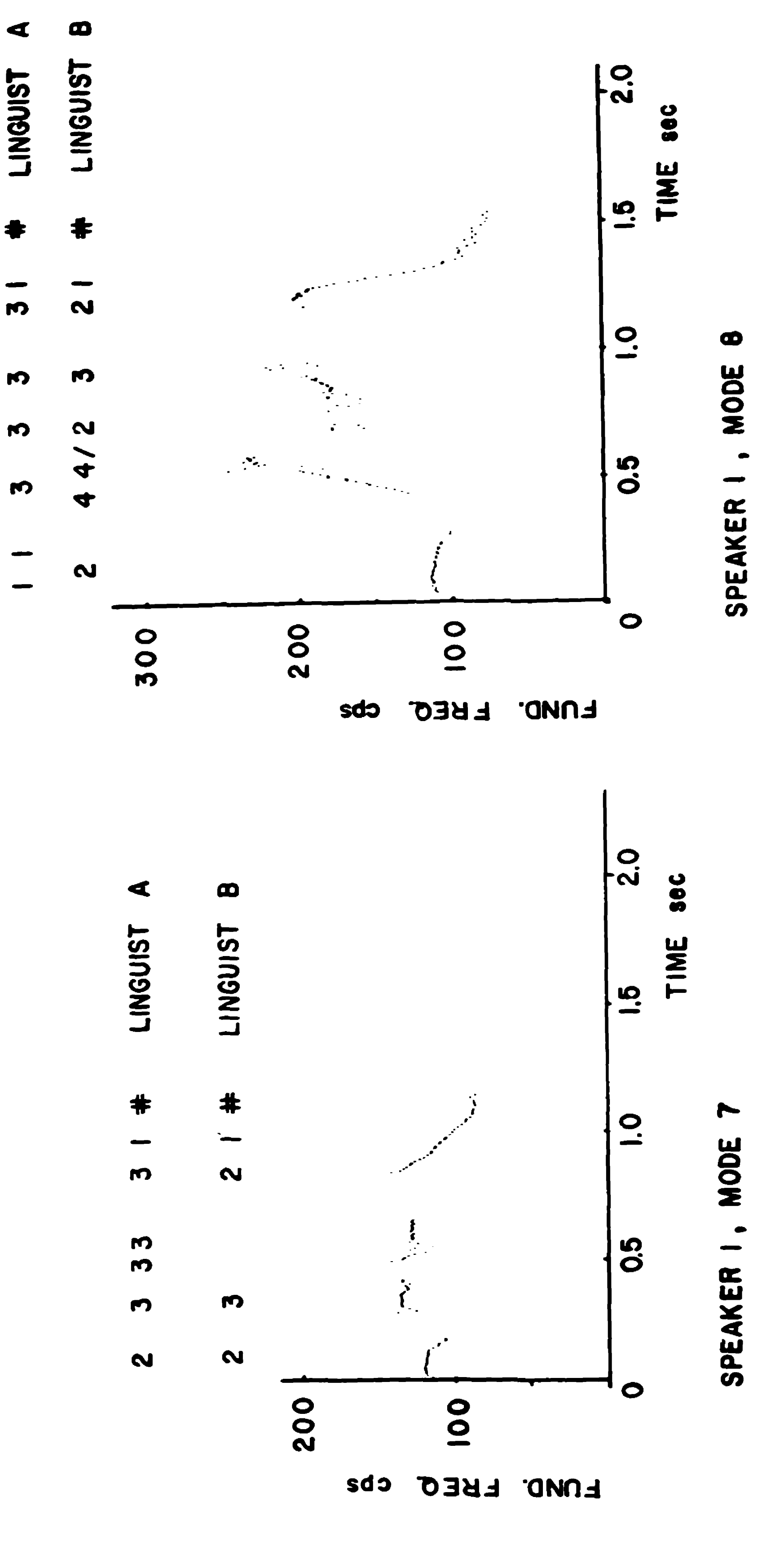
1 1 3 3 3 3 1 # LINGUIST A
2 4 4/2 3 2 1 # LINGUIST B
FUND. FREQ. cps
300
200
100
0
0.5
1.0
1.5
2.0
TIME sec
SPEAKER 1, MODE 8
B
2 3 3 3 3 1 # LINGUIST A
2 3 2 1 # LINGUIST B
FUND. FREQ. cps
200
100
0
0.5
1.0
1.5
2.0
TIME sec
SPEAKER 1, MODE 7
A

Fig. 1

and the final portion of the stimulus in 1B in the same way. He therefore assigns the same Trager-Smith transcription to both stimuli though they involve rather different fundamental frequencies. The linguist's perception seems to be organized in terms of suprasegmental breath-groups rather than segmental "phonemic" pitch levels, though he uses the pitch levels to transcribe the breath-groups.

5. The linguists heard stimuli in which the fundamental frequency and amplitude contours of the complete sentences were accurately reproduced as modulations of a fixed vowel. When the linguists transcribed these contours each linguist changed fifty percent of the pitch levels and junctures of his transcription vis-a-vis his transcription of the complete sentence where he, of course, heard the words of the message. The transcriptions of the fixed vowels were more accurate representations of the actual fundamental frequency contours than the transcriptions of the complete speech signal where the linguists heard the words of the message.

6. When the linguist heard the complete speech signal he was able to transcribe four degrees of stress. However, when the linguist heard the fixed vowels that were accurately modulated with the fundamental frequency and amplitude contours of the original speech signal, he was unable to accurately transcribe more than two degrees of stress, stressed or unstressed. Only 7 percent of the secondary stresses and none of the tertiary stresses that were transcribed for the complete speech signal were transcribed under these conditions. These results suggest that in

connected speech the fundamental frequency and amplitude contours of the speech signal can differentiate only two degrees of stress. These acoustic quantities (fundamental frequency, amplitude, and duration) can provide a physical basis for the listener's perception of stressed and versus unstressed vowels. Vowel reduction phenomena may perhaps provide an acoustic basis for differentiating a third level of stress in connected speech.

On the Independence of Pitch and Stress Levels

Trager and Smith explicitly relate stress to perceived loudness (op. cit., p. 36) but they do not state how loudness is perceived. In view of the hypothetical "objective" nature of the phonemic entities in this system it seems likely that stress is supposed to be directly related to some physical attribute of the acoustic signal. Although the highest pitch level of each "suprasegmental morpheme" almost invariably coincides with the primary stress, stress and pitch are supposed to be independent entitites.

Trager and Smith are, in a sense, correct when they state that pitch levels and stress levels relate to different structural levels. The Trager-Smith pitch levels are often used, in effect, to transcribe the marked and unmarked breath-group. The Trager-Smith levels, insofar as they relate to the actual promience of vowels in the speech signal, are transcriptions of the segmental feature [$+P_s$] which under certain conditions plays a part in acoustically manifesting linguistic stress.[1]

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1. We will duscuss this topic in chapter six.

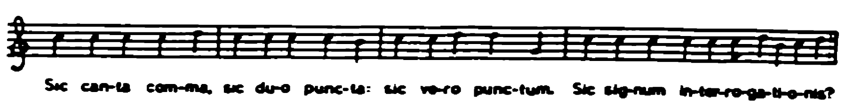
The suprasegmental breath-group is a more basic feature in the hierarchy of the grammar than the segmental feature $[P_s]$, the two features clearly have a different status. However, at the acoustic and articulatory level the segmental feature $[+P_s]$ interacts with the suprasegmental breath-group. The "phonemic ptich" and "phonemic stress" levels of the Trager-Smith analysis are thus related since they were directed at providing an accurate "objective" transcription of the acoustic signal.

Chapter Five

The Marked Breath-Group and Questions

In this chapter we will discuss some of the syntactic rules that relate marked breath-groups to questions. Sentences that end with a rising intonation have traditionally been associated with questions in English and other languages. Hadding-Koch (1961, p. 9), for example, cites a medieval rule for liturgical recitation from Munster which states that a fall in pitch corresponds to periods, a small rise to commas, and a large rise to interrogatives[1]. Jones (1932) and Armstrong and Ward (1926) give many examples of questions that are produced with Tune II. However, all questions in English do not end with a rising intonation; Trager and Smith (1951) and Pike (1945) indeed therefore claim that intonation is not related to the grammar. It supposedly conveys only the attitude of the speaker[2]. The notation of deep structure is not present in the grammars envisioned by Pike or Trager and Smith. If one considers the deep underlying structure as well as the superficial structure, certain regularities are apparent in the relationship between questions and intonation.

1.



2. We have already discussed one of the linguistically motivated functions of the breath-group in chapter four, where we also briefly reviewed some of the known effects of emotion on intonation. Intonation clearly does convey the emotion or attitude of the talker. Indeed, the entire speech signal probably does. However, the marked breath-group is clearly related to the deep phrase markers of questions through syntactic rules.

A - The Formation of Questions in a Number of Languages

Let us first consider the formation of questions in a number of languages besides English. The same general results will hold for English, which we will treat in more detail. In Japanese a question that takes the answer yes or no can be formed in two different ways. Abe (1955) notes that a statement like the expression Darekakita (Somebody came.) can be turned into a question by the addition of the interrogatory particle ka. The sentence becomes Darekakitaka? It usually retains the falling statement intonation. In Japanese, as in most languages, "neutral" statements usually conclude with falling pitch. However, Darekakita can be also turned into a question by concluding the sentence with a rising intonation. The question can also be formed by using the interrogatory particle and rising intonation. The utterance still remains a normal question. (He also states that Ida C. Ward noted a similar phenomenon in the Yoruba language.)

Peškovskij (1930) notes that in Russian a question can be formed by using an interrogatory particle (li), in which case the pitch may fall at the end of the utterance as it does for Russian statements, or else by the use of rising intonation without the particle, e.g., vy student?.

A similar effect also seems to take place in Chinese[1]. Chang (1958), in his study of the Chengtu dialect, noted that a particle with a rising intonation at the end of the sentence indicates that it is a question.

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1. I am indebted to Mr. T. R. Hofmann who pointed out the phonetic information for Chinese.

The particle has a falling intonation when the sentence is a statement. The phonemic tone of the last syllable of the sentence and the sentence intonation interact[1]. A high-faling phonemic tone may become a level tone when it occurs at the end of a question which has a rising intonation. In contrast, questions may be signalled by syntactic forms in other Chinese dialects[2]. The yes-no question, Did Joe eat his soup? in Mandarin Chinese may take the form Joe ate or did not eat his soup. The sentence ends with a falling intonation.

Danes (1960) notes that in Czech a special interrogatory contour is used "...only in yes or no questions which would not otherwise differ sufficiently, either lexically or grammatically, from statements." He also observes that German uses a special interrogative contour with yes no questions. "In Russian, on the contrary, with yes or no questions containing the interrogative particle - li this special question contour is not used."

Hadding-Koch (1961, p. 17) notes that in Finnish the interrogative is marked by an interrogatory particle and the sentence intonation for the question is like that of the statement. In Spanish, she observes, the only thing that distinguishes an interrogative question of the form Is my father coming" from the statement My father is coming is the intonation. Both the statement and the question can have the same word order. They differ only in that the question concludes with rising pitch while the

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1. In tone languages the sentence intonation is apparently superimposed on the individual tones (c.f., chapter 3).

2. F. Lee, personal communication.

statement concludes with a falling pitch. In Swedish, interrogatory sentences usually involve both obligatory word order inversion and rising pitch at the end of the sentence[1].

Daniel Jones' Intonation Curves (1909) reveals that in French interrogatives formed by means of word order inversion, e.g., Entends-tu? conclude with a rise in pitch. Interrogatives can also be formed by simply concluding the sentence with a rise in pitch. Questions that use Wh-words, like who or what, end with falling pitch in French. French yes or no interrogatives can also be formed using the particle est-ce que; the intonation then falls at the end of the sentence. Jones's curves shown that English yes or no interrogatives have a rising intonation when they are formed by inverting the order of the subject and auxilary verb. Yes-no questions in English like, John came home? have only a rise in intonation at the end of the sentence. However, there are some marginal English interrogatives that contain special interrogatory phrases like I suppose or I wonder, and end with a falling pitch. English questions with words like why, or what, also end with falling pitch.

DeBray (1961) notes that in Serbo-Croatian there are two main sentence intonations: "(1) a falling type, used in statements, commands, wishes, questions with an interrogative word initially, or questions with the enclitic 'li' as second word;" and (2) a rising intonation used in questions without an interrogative word. Lehiste (1961), in her acoustic study of the accents of Serbo-Croatian, notes that the sentence intonation

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1. Swedish and German interrogative questions apparently can also have a phonetic output a generally high pitch that is sustained throughout the entire sentence (c.f. chapter 3).

interacts with the word accents on the final syllable of a sentence. This finding is, of course, consistent with the data of chapter three, which indicated that the terminal falling subglottal air pressure of the breath-group and the increase in laryngeal tension of the marked breath-group occurred during the last 150-200 msec of phonation.

Abramson (1962) notes that Thai, another tone language, can also form questions by adding a rising intonation to a word or phrase that is unmodified in all other respects.

In Table I we have grouped these languages according to the ways in which questions are formed. The rows of the table indicate whether the language can form a question: (1A) by inserting a special interrogatory particle or phrase, e.g., li in Russian or I suppose in English (or by the use of Wh words like who or what); (2A) by a process or word order inversion (which may involve the use of auxiliary verbs in some cases); or (2B) without any change in word order. The columns of the table indicate whether the language has a phonetic form in which rising intonation contour can differentiate the question from statements. Neutral statements conclude with a falling pitch in all of these languages.

In all of these languages the underlying phrase markers of the questions must have morphemes that indicate that the sentence is a question. The underlying phrase markers undoubtedly all contain the morpheme Q and a wh - morpheme attached to some noun phrase or the sentence adverbial (c.f. Katz and Postal, 1964; Chomsky, 1965). Table I seems to show that the recoverability of the deep phrase marker is insured after the

TABLE I

		I	II
A (1)	Special Particle or phrase or word	Mandarin Chinese Finnish Russian French Japanese English Serbo-Croatian	
(2) A	word order inversion		Swedish French English German
(2) B	no Changes in word order		Thai Czech Spanish Japanese English French Russian Yoruba Serbo-Croatian Chengtu dialect (Chinese)
		Pitch falls at End of sentence	Pitch Rises, usually at end of sentence

syntactic and phonologic components of the grammar act on the deep phrase marker. The phonetic outputs either have special wh-words or they are uttered on breath-groups that end with a rising intonation. The listener is able to deduce that a question has been asked because he either hears a special word or hears a sentence final marked breath-group. In a loose sense a question can be signalled either by means of intonation or through a special word or words. A more precise characterization of this substantive linguistic universal would seem to be that under certain conditions the constituent Q and the wh-morpheme may be deleted by certain transformations. These transformations mark the sentence final breath-group. We will consider English questions in detail in the following section, which should explicate this notion.

B - English Question Formation: Diachronic and Synchronic Aspects

We will follow, in broad outline, the syntactic analysis of questions that is presented in Katz and Postal (1964, pp. 79ff). We will show that the generation of the sentence final marked breath-group follows from the general principle of the recoverability of the underlying phrase marker. As Katz and Postal point out,

> This principle requires that the distortions produced by the transformational removal of elements from a P-marker be unique. that is, a transformation T which operates by deleting elements or substituting for elements can apply to a P-marker only if the output of T on the P-marker permits unique recovery of that P-marker, given a description of T. The motivation for this principle, which receives its formation in the general theory of linguistic description, is both syntactic and semantic.

The syntactic evidence for this principel consists of evidence about particular natural languages which shows that the simplest transformational grammar involves this constraint. The semantic motivation for this principle is that the deep phrase marker is the input for the semantic component of the grammar, (c.f. Fodor and Katz, 1963). When a listener hears the phonetic output of the derived phrase marker, or reads the orthographic transcription, he must be able to reconstruct the deep phrase marker in order to arrive at a semantic interpretation of the utterance.

In Fig. 1 a simplified version of the underlying deep phrase marker[1] of the sentence, Who ate the fish? is presented, as a 'tree' diagram. Note the presence of the morphemes Q and wh- in the underlying phrase marker. As Katz and Postal (op. cit., p. 89) point out,

> The Q morpheme indicates semantically only that the sentence is a question, i.e., a paraphrase of an appropriate sentence of the form I request that you answer.... The function of wh is, however, to specify the element or elements of the sentence that are 'questioned'.

In Fig. 2 the underlying phrase marker of the sentence, What did the boy eat? is presented. The following ordered transformational rules are required for these underlying structures:

(T1) $\underset{1}{\# + Q}, \underset{2}{X}, \underset{3}{\text{Noun Phrase}}, \underset{4}{Y} \Rightarrow 1324$

where 3 dominates wh

(T2) $\underset{1}{\# + Q}, \underset{2}{X}, \underset{3}{\text{Noun Phrase}}, \underset{4}{\text{Tense} + Y}, \underset{5}{Z} \Rightarrow 12435$

where 2 dominates wh and Y is the part of the Aux adjacent to the tense marker.

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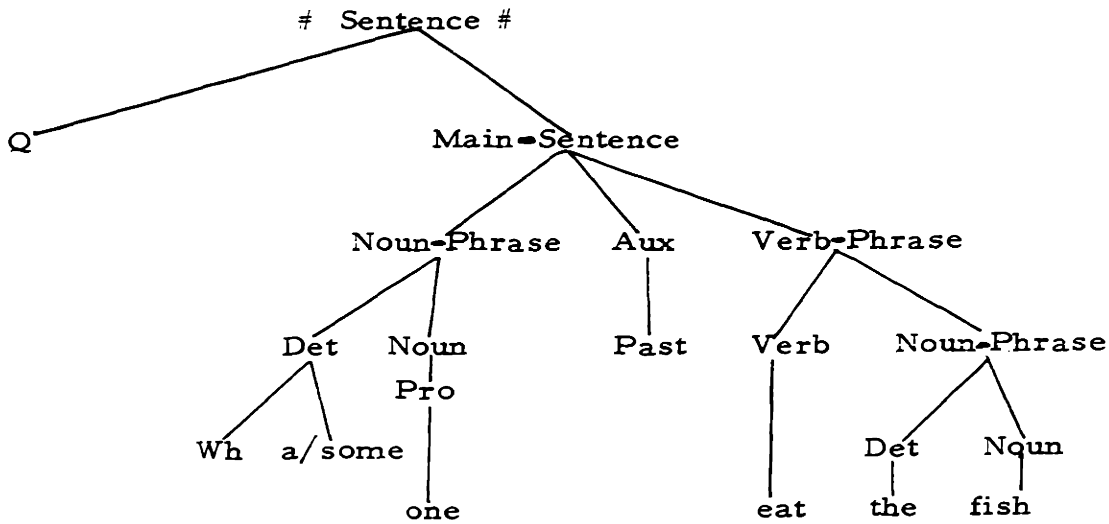
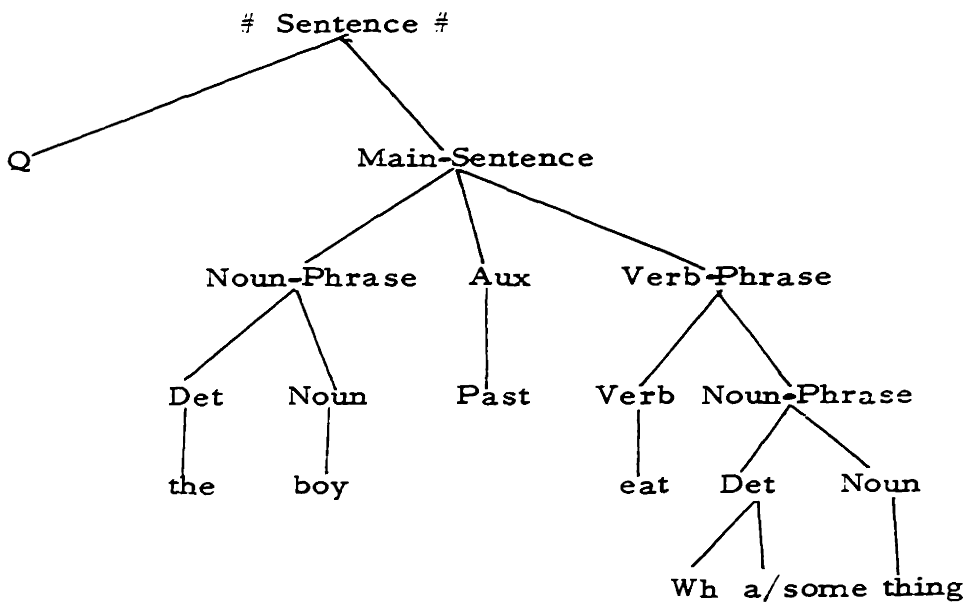
1. This simplified phrase marker is by no means complete (c.f. Chomsky, 1965) but it is adequate for the purposes of our exposition.



Who ate the fish ?

Fig. 1



What did the boy eat ?

Fig. 2

The string {Q + Wh + some+one} in the derived phrase marker has the phonetic shape _who_ while the string {Q + Wh + some+thing} has the phonetic shape _what_. The basic breath-group assignment rule spans each sentence with an unmarked breath-group. The sentences thus both end with a falling intonation contour.

The yes-no questions can be handled in a number of ways. Katz and Postal, for example, shift _Q_ to the end of the sentence (_op. cit._, p. 104). A morphophonemic rule then directly maps _Q_ into a rising intonation. Schubiger, in a traditional grammatical analysis (1935), simply stated that yes-no interrogatives end with a rising intonation. These discussions, however, do not furnish any insight into the possible function of intonation in these sentences. They do not, for example, formally explicate the reasons that might underlie the fact that for so many different languages the phonetic output of a question involves either special words or a rising intonation. Why do the yes-no questions of some languages, like English, always have a rising sentence final intonation? Why does English have sentences like, _Joe ate the soup?_ as well as _Did Joe eat the soup?_. Why does _Joe ate the soup?_ seem to have a different meaning than _Did Joe eat the soup?_

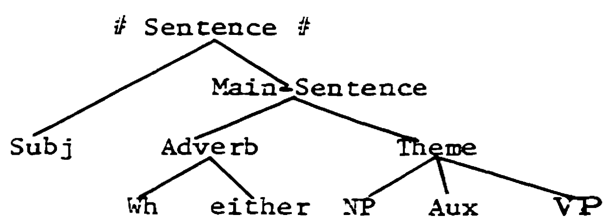
At least three types of "simple" yes-no questions occur in English. There is the "normal" yes-no question like, _Did Joe eat the soup?_ The question is neutral in the sense that it does not indicate whether the speaker believes that Joe ate the soup or that Joe did not eat the soup. The speaker wants to know what happened. In contrast to the normal yes-no question, sentences like _Joe ate the soup?_ also occur in English. We shall use the term intonation question for these forms. These sentences are phonetically distinct from statements because they have sentence final marked breath-groups. The rise in fundamental frequency for these sentences is similar to the rise in fundamental frequency at the end of the normal yes-no questions (c.f. chapter 3).

The intonation questions are ambiguous. They may be interpreted as paraphrases of metalinguistic sentences like Did you say that Joe ate the soup? The so called "echo" question is thus the deleted version of a metalinguistic question. It usually occurs in a conversation, when a listener wants some utterance repeated. The intonation question can, however, have a rather different semantic interpretation. The sentence Joe ate the soup? implies that the speaker has heard that Joe ate the soup but he can hardly believe it. It expresses a measure of doubt that is not conveyed by the normal question Did Joe eat his soup? The intonation question Joe ate the soup? is not neutral. It is a somewhat rhetorical question. The speaker has already formed an opinion and he does not really need any confirmation. The reply to the question, Are you going to drive down that rutted road? is either yes or no. The reply to the question, You're going to drive down that rutted road? is either a confirmatory silence or an explanation to the effect that the road is not really rutted, or that your car has a good suspension or that it is the only way you can reach your destination, etc. The speaker already knows that you are going to drive down the road. The underlying phrase markers of the intonation questions must reflect these differences. We will develop an analysis for the yes-no questions that explicates these semantic differences and is consistent with the treatment of the general wh questions.

In Table II we have cited several representative quotations from the Oxford English Dictionary for direct questions involving whether. The sentences cover the period c1000 to contemporary English. Throughout this period yes-no questions could also have a phonetic form that is equivalent to the contemporary "normal" English yes-no questions. In earlier periods the verb adjacent to the tense marker was preposed, e.g., Went John Home?. These interrogative sentences conclude with a rising intonation.

The following analysis seems relevant for the period that starts about 1000 and ends at the beginning of the 17th century.

1. English had a subjunctive mood. The base component of the grammar could generate phrase markers having the form:



2. The base component also generated phrase markers that had the form:

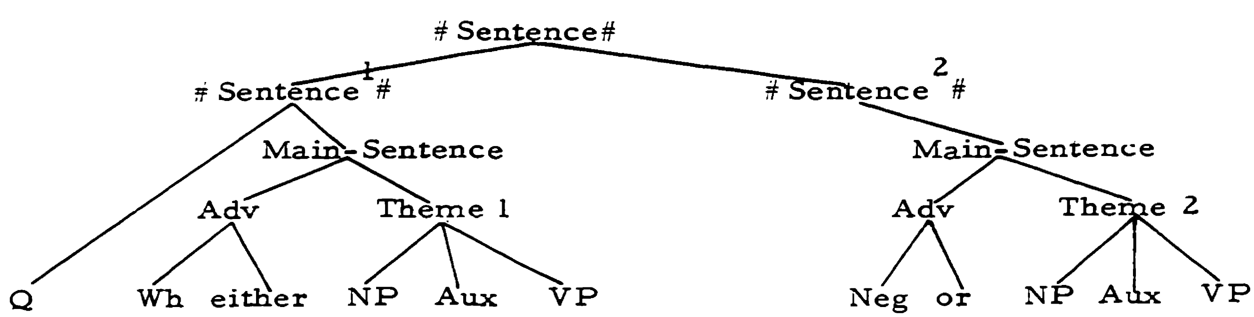


TABLE II

Category 1

c. 1000 *Ags. Gosp.* John IV:

Hwæðer æniz man him mete brohte ?

c. 1300 Havelok:

Godrich ... seyde, " Hweder sbe sholde be Quen and leudi ouer me ?

c. 1300 *Cursor Ms.*, :

Louerd ! quer I sal him euer se ?

1588 A' King translation of *Canesius Catech.*, :

Quhat is Battisme ? and quhidder it be necessare to all mankynde ?

Category 2

c. 1000 *Ags. Gosp.*, Matt XXI:

Hwæðer wæs iohannes fulluht, þe of heofonum, þe of mannum ?

c. 1400 Caxton *Pilgr. Soule*,:

Whether shall the lord refuse this seruaunt either els he shall
recevue him ?

1450 Myrr, *Our Layde*, :

Whither comst thou to chyrche to sleepe or to wake ?

1595 Shakespeare, *King John*, :

Whether hadst thou rather be a Falconbridge...
Or the reputed sonne of Cerdelion ?

1599 Shakespeare:

Was this a lover, or a Letcher whether ?

1713 Berkeley, *Hylas and Phil.*, :

Whether does doubting consist in embracing the Affirmative or
Negative side of a Question ?

1822 Shelley:

Whether do you demonstrate these things better in Homer or Hesiod ?

Category 3

1549 Latimer, *1'st Sermon Before Edw. IV*, :

Whither wyl he allowe a subject to much ?
Whether haue any man in England to much ?

The phrase structure rules of the base component of the grammar contained these rules:

Sentence $\rightarrow$ Sentence - Sentence

Sentence $\rightarrow \begin{Bmatrix} Q \\ Subj \end{Bmatrix}$ - Main Sentence

Main Sentence $\rightarrow$ (Adv) - Theme

Adv $\rightarrow$ (Wh) - (Neg) - Adv

Theme $\rightarrow$ Noun Phrase - Aux - Verb Phrase

Noun Phrase $\rightarrow$ Det - Noun

etc.

Type 1 and 2 deep phrase markers underlie the data listed in categories one and two in Table II. Rule (T2) or rather a modified version of it, (T2'), which transposes the entire verb, operates on these phrase markers. T2' would have the form:

$$\text{(T2')} \quad \underset{1}{\# + Q}, \ \underset{2}{X}, \ \underset{3}{\text{Noun Phrase}}, \ \underset{4}{\text{Tense} + W}, \ \underset{5}{Z} \Rightarrow 12435$$

where 2 dominates <u>wh</u> and W is the verb adjacent to the tense marker.

Rule (T2') was probably replaced with rule (T2) in the fifteenth century. An optional transformation (T3) deleted theme 2 when themes one and two were identical[1].

$$\text{(T3)} \quad \underset{1}{\#}\ [\underset{2}{Q,\ Adv},\ \underset{3}{[NP\text{-}Aux\text{-}VP]}_{Th\text{-}1}\ ]_{S1},\ \underset{4}{\#\#\ [Adv},\ \underset{5}{[NP\text{-}Aux\text{-}VP]}_{Th\text{-}2}\ ,]_{S2}\ \underset{6}{\#}$$

$$\Rightarrow 1,2,3,4,6$$

where 2 dominates Wh

4 dominates Neg $\qquad 3 = 5$

---

1. NP = Noun Phrase, VP = Verb Phrase, N = Noun, etc.

The operation of rule (T3) in contemporary English relates sentences like Did He hit you or not? to sentences like Did he hit you or didn't he hit you? Rule (T4), a second optional transformation, resulted in sentence in which or not was deleted.

$$\text{(T4)}\quad \underset{1}{\#\ Q,}\ \underset{2}{Adv,}\ \underset{3}{NP\text{-}Aux\text{-}VP}\ \#,\#\ \underset{4}{Adv}\ \# \Rightarrow 123$$

where 2 dominates Wh and 4 dominates Neg

The grammar could thus operate to form sentences like those in category three in Table II, e.g., Whither wyl he allowe a subject to much? Throughout this period the string $\left\{ \begin{Bmatrix} Q \\ Subj \end{Bmatrix} + Wh + Adv \right\}$ in the derived phrase marker had the phonetic shape whether. Rule (5) an optional transformation could operate throughout this period to produce sentences in which whether was deleted.

$$\text{(T5)}\quad \left[\begin{array}{cccccc} \multicolumn{6}{c}{\longleftarrow [-BG] \longrightarrow} \\ \#, & \begin{matrix} Q \\ Subj \end{matrix}\ -Wh - Adv, & Theme\ 1\ \#, & X, & Y & \# \\ 1 & 2 & 3 & 4 & 5 & \end{array}\right] \Rightarrow \left[\begin{array}{c} \longleftarrow [+BG] \longrightarrow \\ 1,\ 3,\ 4,\ 5,\ \# \\ \ \end{array}\right]$$

Where X = Adv and Adv dominates Neg and Y = Theme 2 = Theme 1

or X = Y = Null

Where the breath-group spans the entire sentence. Rule (T5) formally characterizes the "trading" relationship between the marked breath-group and the string {Q + Wh + Adv} . The presence of one or the other of these entities in the derived phrase marker aids the recoverability of the underlying phrase marker. Rule (T5) was optional until the beginning of the seventeenth century.

Note that rules (T2) or (T2'), the auxiliary inversion rule, can not apply to the type 1 deep phrase markers because of the presence of the subjunctive mood morpheme Subj. The sentences in category one in Table II all have the nominal preceding the auxiliary and main verbs. Dahlstedt (1901) and the editors of the Oxford English Dictionary regard sentences like those in category one in Table II to be examples of the subjunctive mood. The earlier Old English examples were inflected in the subjunctive mood since the presence of the morpheme Subj also made obligatory subjunctive marking transformations obligatory. These transformations later became inoperative and the superficial manifestations of the subjunctive for the most part disappeared except for the absence of Aux inversion. The subjunctive sentences express uncertainty or speculative enquiry. The interlocutor does not really expect to get a yes-no reply. However, it is hard always to be really certain on semantic grounds about what constitutes a subjunctive and what constitutes a "neutral" question. Let us for the moment assume that the sentences listed under category one in Table II have type 1 deep phrase markers. We will see that this leads to an insight into the grammar of contemporary English.

After the beginning of the 17th century whether disappeared in sentences like those listed in categories one and three in Table II. Rule (T5) became obligatory. In Hamlet, Act III, Scene I, the following conversation occurs:

Hamlet. Ha, Ha! Are you honest?
Ophelia, My Lord?
Hamlet. Are you fair?

Whether still occurs in sentences like those listed in category two in Table II, since rule (T5) can not operate because Theme 2 is not identical to Theme 1. Hamlet thus states,

> Whether 'tis nobler in the mind to suffer
> The slings and arrows of outrangeous fortune
> Or to take arms against a sea of troubles

Thus for contemporary English the two deep phrase markers that follow would result in the sentences A - _John ate the fish_? and B - _Did John eat the fish_? _Did John eat the fish or didn't he eat the fish?_, and _Did John eat the fish or not_? Rules (T2) and (T5) operate[1] on phrase marker A to produce the sentence _John ate the fish_?. Rules (T2) and (T5) operate on phrase marker B to produce the "tag" question. _Did John eat the fish or didn't he eat the fish_. Rules (T2), (T3) and (T5) operate on phrase marker B to produce the tag question, _Did John eat the fish or not_? Rules (T2), (T3), (T4), and (T5) operate on phrase marker B to produce the "simple" question, _Did John eat the fish_? The semantic interpretations of the two tag questions and the simple question that have underlying phrase marker B are identical and our analysis mirrors this fact since the optional transformations neither add nor bring any new semantic information.

To many speakers of English, _John ate the fish_? denotes a certain air of rhetorical doubt relative to the other sentences. This slight semantic difference is explicated in this analysis through the presence of the subjunctive morpheme in the phrase marker that underlies this sentence. For some speakers there is often little difference betweeen normal, simple yes-no questions and the intonation questions. This is particularly so in

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1. Obviously many other rules figure in the shaping of the derived phrase marker and the phonetic output, c.f., Chomsky (1957, 1964, 1965) and Halle and Chomsky (1965) for pertinent discussions of the syntactic and phonologic components of the grammar.

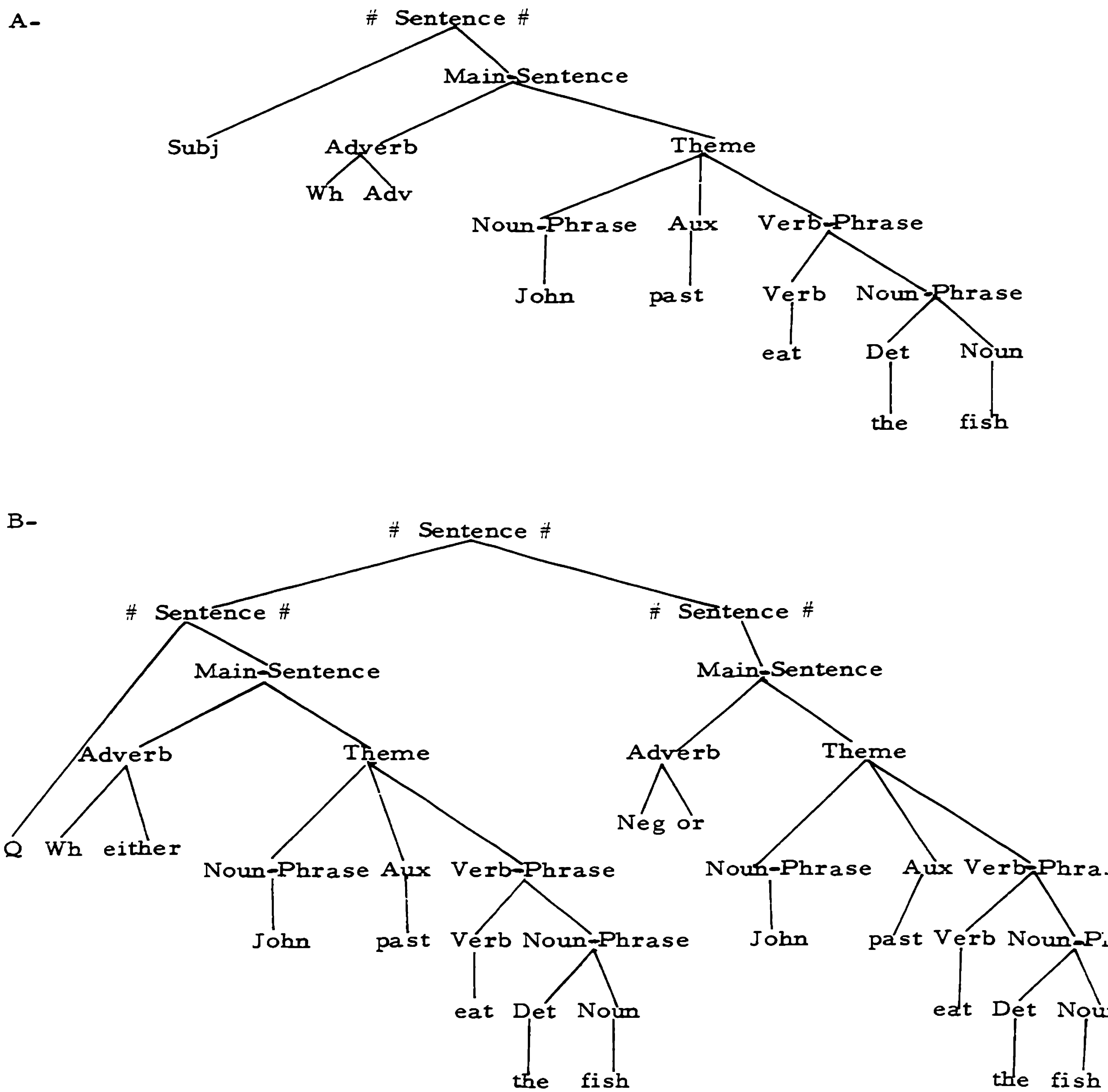
A-
Sentence
Main-Sentence
Subj
Adverb
Theme
Wh
Adv
Noun-Phrase
Aux
Verb-Phrase
John
past
Verb
Noun-Phrase
eat
Det
Noun
the
fish
B-
Sentence
Sentence
Sentence
Main-Sentence
Main-Sentence
Adverb
Theme
Adverb
Theme
Neg
or
Q
Wh
either
Noun-Phrase
Aux
Verb-Phrase
John
past
Verb
Noun-Phrase
eat
Det
Noun
the
fish

Fig. 3

some conversational styles. At other times there seems to be a strong semantic difference between intonation and normal questions, e.g., the normal yes-no question, Are you going to drive down that rutted road? versus You're going to drive down that rutted road? The wide variation in the semantic distinctness of the normal and the intonation yes-no question is perhaps a function of the marginal status of the subjunctive mood in English. Perhaps the projection rules of the semantic component of the grammar assign a conditional status to the subjunctive,i.e., the mood is subjunctive if the subjunctive constituent is present in the deep phrase marker and if other conditions are met.

This analysis of the intonation questions is consistent with the other syntactic manifestations of the subjunctive mood in English. We stated that the manifestations of the subjunctive are for the most part absent in contemporary English. This is not strictly so and sentences like If I were the Queen of...., If I were there...., etc., commonly occur. The verb is modified by the presence of the subjunctive constituent. In contrast to the subjunctive inflection in these examples the verb in the subjunctive intonation question I was there? is not modified. This phenomenon is, however, quite consistent with the inflectional system of English. Chomsky (1965, p. 221) points out that case in English, is determined by the position of the noun in the surface structure rather than in the deep structure. The pronoun in the sentence, He was struck by a bullet. He is easy to please. is in each case the direct object of the verb in the underlying deep structure.

Nevertheless, the form is he rather than him. Rule (T5) deletes the subjunctive constituent; the verb in the derived phrase marker of the sentence I was there? is therefore not inflected.

Chapter Six

Prominence, Stress, and Emphasis in American English

In this chapter we will discuss some of the acoustic manifestations of linguistic stress in American English[1]. In particular we will discuss the role of the segmental feature [$+P_s$]. We will present evidence that demonstrates that perceived linguistic stress is often a secondary manifestation of the derived constituent structure. The listener mentally "computes" the linguistic stress by means of the derived constituent structure of the utterance. The listener determines the derived constituent structure by means of the words of the sentence, by the breath-group division that we discussed in chapter 5, or through "disjuncture". We will discuss the acoustic properties of disjuncture in detail.

A - Definitions of Prominence, Stress, and Emphasis

There is a grat deal of uncertainty in linguistic and phonetic literature with respect to the terms prominence, stress, and emphasis. We will try to preserve the following distinctions.

(1). Prominence - We will use the term prominence for the occurrences of the distinctive feature [$+P_s$]. Perceptually, prominence is therefore the perceived "loudness" of a vowel relative to its environment. The acoustic correlates of prominence are duration, fundamental frequency, and sound pressure level (or amplitude). Prominence thus will refer to the occurrence of the segmental feature [$+P_s$].

(2). Stress - We will reserve the term stress for the abstract

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1. We will also briefly discuss some similar effects in German.

entities that are generated by the phonologic rules of the "stress cycle". Most studies of English agree that the vowels of words, short phrases, and sentences are differentiated by relative degrees of stress or "loudness". Sweet (1892) differentiated "...three degrees of stress or loudness...strong, half strong, and weak...." Jeserson (1907) used four levels of stress, Bloch and Trager (1942) and Trager and Smith (1951) also used four levels of "phonemic stress" for English. Pike (1945) believes that "...only one phonemic innate stress contrast can be demonstrated to exist in English...." Jones (1932) is vague about the number of levels of stress that can be perceived when single words or short phrases are uttered. However, he notes that in connected speech only two degrees of stress need be transcribed.

Stress[1,2] in these studies is a phonetic element that has definite acoustic correlates in the speech signal that are independent of the acoustic correlates of the segmental phonemes . Chomsky, Halle and Lukoff (1956) and Chomsky and Halle (1966) have shown that cyclical

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1. Except for Jones, wo notes that stress may be perceived by virtue of the listener's knowledge of the structure of the language rather than by means of any special acoustic cues (1932, p. 227).

> "When a strong stress is given to a syllable incapable of receiving any noticeable increase of loudness, a person unfamiliar with the language would be unable to tell that a stress was present.... A person familiar with the language would not perceive the stress objectively from the sound... but he perceives in a subjective way; the sounds he hears call up to his mind (through the context) the manner of making them, and by means of immediate 'inner speech' he knows where the stress is."

2. Stress level 1 is the "strongest" stress, level 2 is "weaker" than 1, level 3 is weaker than 2, etc.

phonologic rules will assign a set of stress "levels" to the vowels of a word or phrase. These stress levels that are assigned to a word are a function of the phonemic structure of the word, its syntactic function (e.g., whether it is a noun or a verb in the derived phrase marker), and the constituent structure of the derived phrase marker.

Chomsky (1965) has recently suggested that stress graduations can readily be accounted for if it is assumed that, as a universal principle, rules assigning primary (1) stress require stress lowering in all previously stressed syllables. It will then follow that, in order to account by general rules for the location of promience in English sentences, it will be necessary to assign secondary, tertiary, etc., stress to some syllables. For example, the words easy and chair each have a primary stress when they are produced as isolated words,

```
   1
[easy]
   1
[chair]
```

When they are produced in the phrase <u>easy chair</u> the stress rules assign primary stress to easy. The stress on chair is therefore lowered,

```
  1      2
[easy  chair]
```

This principle is consistent with the data that follows in this chapter, since it implies that the listener can calculate the secondary and tertiary stresses once he knows where the primary stress is. The phonologic rules shift only the primary stress but each time they assign primary stress to some vowel they lower all the stress levels on all other vowels. If the listener thus perceives where the prominence is he can calculate the stress levels of the other vowels by using his knowledge of the phonologic rules that assign primary stress. The listener also has to know the constituent structure of the derived phrase marker because the phonologic stress rules operate in terms of the derived constituent structure and the segmental feature bundles (the phonemes).

In most cases the listener deduces the constituent structure of the language through the words of the utterance. He simply knows what may constitute a well formed phrase or sentence. In certain cases, the constituent structure of a phrase may be ambiguous. We will show that in these cases the acoustic feature of "disjuncture" may be used to disambiguate the constituent structure of the derived phrase marker in a manner analogous to the disambiguation of sentences by breath-group division.

(3). Emphasis - We will use the term emphasis to identify instances where the distinctive feature [$+P_s$] produces extra prominence on the vowel or vowels of a word (and its consonants), apart from the stress that the vowels of the word would have received from the phonologic stress rules. In other words emphasis is prominence that is not predicted by the stress cycle. It may result from the presence of an emphatic morpheme in the underlying deep phrase marker. The syntactic component of the grammar results in a derived phrase marker where the segmental feature [$+P_s$] can follow from the presence of emphatic elements. in the deep phrase marker.[1] In chapter three, for example, we presented

1. c. f. Klima (1964) for a discussion of Emphasis and some of its other phonetic manifestations.

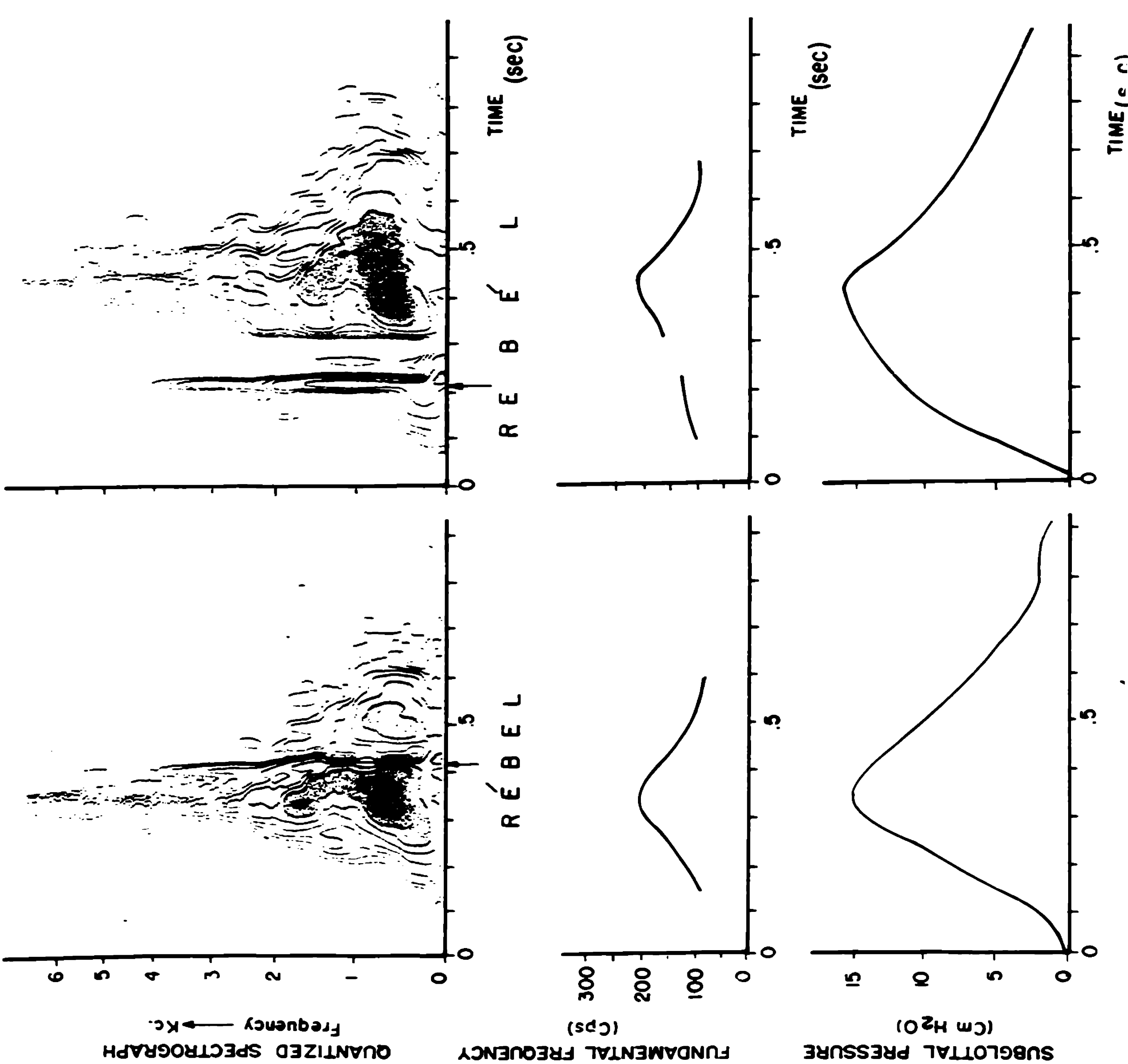
QUANTIZED SPECTROGRAPH
Frequency → Kc.
FUNDAMENTAL FREQUENCY
(Cps)
SUBGLOTTAL PRESSURE
(Cm H2O)
RÉBEL
RÉBÉL
TIME (sec)

Fig. 1

a group of sentences where either the word soup or the word Joe was emphasized in the sentences, Joe ate his soup, and Did Joe eat his soup? The vowels of the emphasized monosyllabic words were marked with the feature [$+P_s$]. The term "contrastive stress" could have been used for emphasis but it might cause some confusion. We want to preserve the distinction between the distinctive feature [$+P_s$] and its underlying source. The phonologic feature [$+P_s$] in the phonetic output can be the manifestation of either emphasis in the underlying phrase marker or in certain circumstances the "stronger" stresses generated by the phonologic stress cycle. In itself it has no more "meaning" than the phonologic feature [+voicing].

B - Some Phonetic Manifestations of Stress

Let us start by considering the simplest case, the manifestations of stress when two syllable words are carefully spoken in isolation. In Figs. 1A and 1B quantized sound spectrograms, and plots of the fundamental frequency and subglottal air pressure with respect to time, have been presented for speaker one reading the words rebél and rébel in isolation (c.f. chapter 3). Each word was produced on a separate unmarked breath-group.

The segmental feature [$+P_s$] occurred on the stressed vowel in each case. Compare the plots of subglottal pressure with those in Figs. 10 and 11 in chapter three. In Fig. 10, chapter three, [$+P_s$] was not placed on any vowel. In Fig. 11 in chapter three [$+P_s$] was placed on the vowel of the word Joe. Speaker one consistently used the archetypal articulatory correlate of [$+P_s$] to produce prominence, i.e., he used a momentary increase in the subglottal air pressure of approximately[1] 4 to 6 cm H_2O. In Figs. 1A and 1B each isolated word has been produced on a short breath-group and the peak subglottal pressure occurs on the vowel marked with primary stress. In the data presented in chapter three it often was not evident whether the peak stress subglottal air pressure occurred on a single vowel or whether it was deliberately placed on an entire syllable. These utterances, which were produced at a slower, more deliberate rate, show that the scope of $[+P_s]$ is a single vowel.

The prominent vowels have the peak fundamental frequencies, amplitudes and durations. The unstressed vowels have been reduced. The acoustic correlates of primary linguistic stress in this two syllable word pair are thus in agreement with acoustic studies by Lieberman (1960), Hadding-Koch (1961), and Ladefoged and McKinney (1963) as well as psychoacoustic studies by Fry (1955, 1958). The distinction that occurs in all of these studies is, however, binary. The stressed vowel of the bisyllabic word is prominent whereas the other vowel is not prominent. Can "degrees" of prominence differentiate intermediate levels of stress? Can a listener compute some sort of "prominence" function from the fundamental frequency, amplitude and duration of each vowel, and differentiate stress level one from stress level two and further differentiate stress level two from stress level three? The results of a number of independent psychoacoustic experiments suggest that listeners

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1. These values must be regarded as only an approximation since the relationship of true subglottal pressure to the measured balloon pressure has been quantitatively determined only for steady state or quasi-steady state conditions, c. f., chapter three.

can make only binary categorical distinctions along the dimension of prominence when they listen to connected discourse[1]. However, what categorical distinctions can be made when a word or phrase is spoken in isolation?

In Figs. two and three, quantized spectrograms, and fundamental frequency and subglottal pressure plots have been presented for speaker one reading the phrase (light house) (keeper), i.e., someone who tends to a light house, and (light) (house keeper), i.e., a woman who keeps house and is not heavy. Each phrase was produced on a separate breath-group.

The linguistic stress predicted by the stress rules for the utterance plotted in Fig. 2 is light[1] house[3] keep[2]er[4]. Note that the fundamental frequency, amplitude, and duration of the vowel of house, which is assigned stress level 3, are greater than those of the vowel /i/ in keeper, which is assigned stress level 2. The fundamental frequencies of the vowels in light and house are about the same, though light bears stress level 1 while house bears stress level 3. The peak amplitude of the first formant of light is, however, 6 db greater than

---

1. The experiment discussed in chapter four (Lieberman, 1965) demonstrated that amplitude, f_o, and duration (the acoustic correlates of $[+P_s]$ in connected speech) can differentiate only two degrees of stress, level one versus everything else. Hadding-Koch (1961) found that the stress levels, assigned by listeners other than level 1, were randomly distributed. Armstrong and Ward (1926) and Jones (1932, 1962) transcribe only two degrees of stress for connected speech, as does Pike (1945). Lisker, in a personnal communication, notes that students of the Trager-Smith notation consistently produce random results with respect to differentiating the intermediate stress levels.

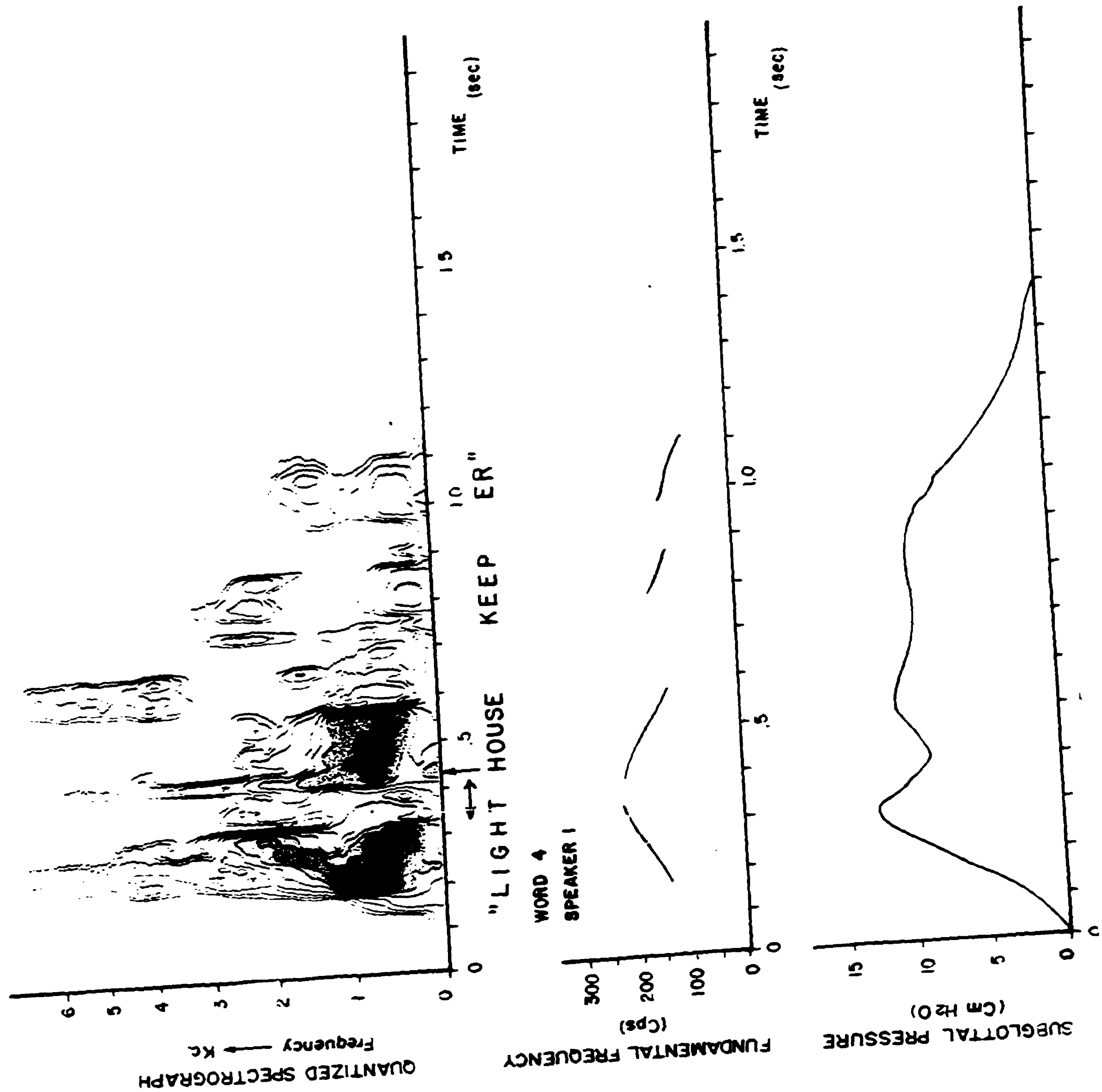

QUANTIZED SPECTROGRAPH
Frequency → Kc
FUNDAMENTAL FREQUENCY
(Cps)
SUBGLOTTAL PRESSURE
(Cm H2O)
"LIGHT HOUSE KEEPER"
WORD 4
SPEAKER I
TIME (sec)

Fig. 2

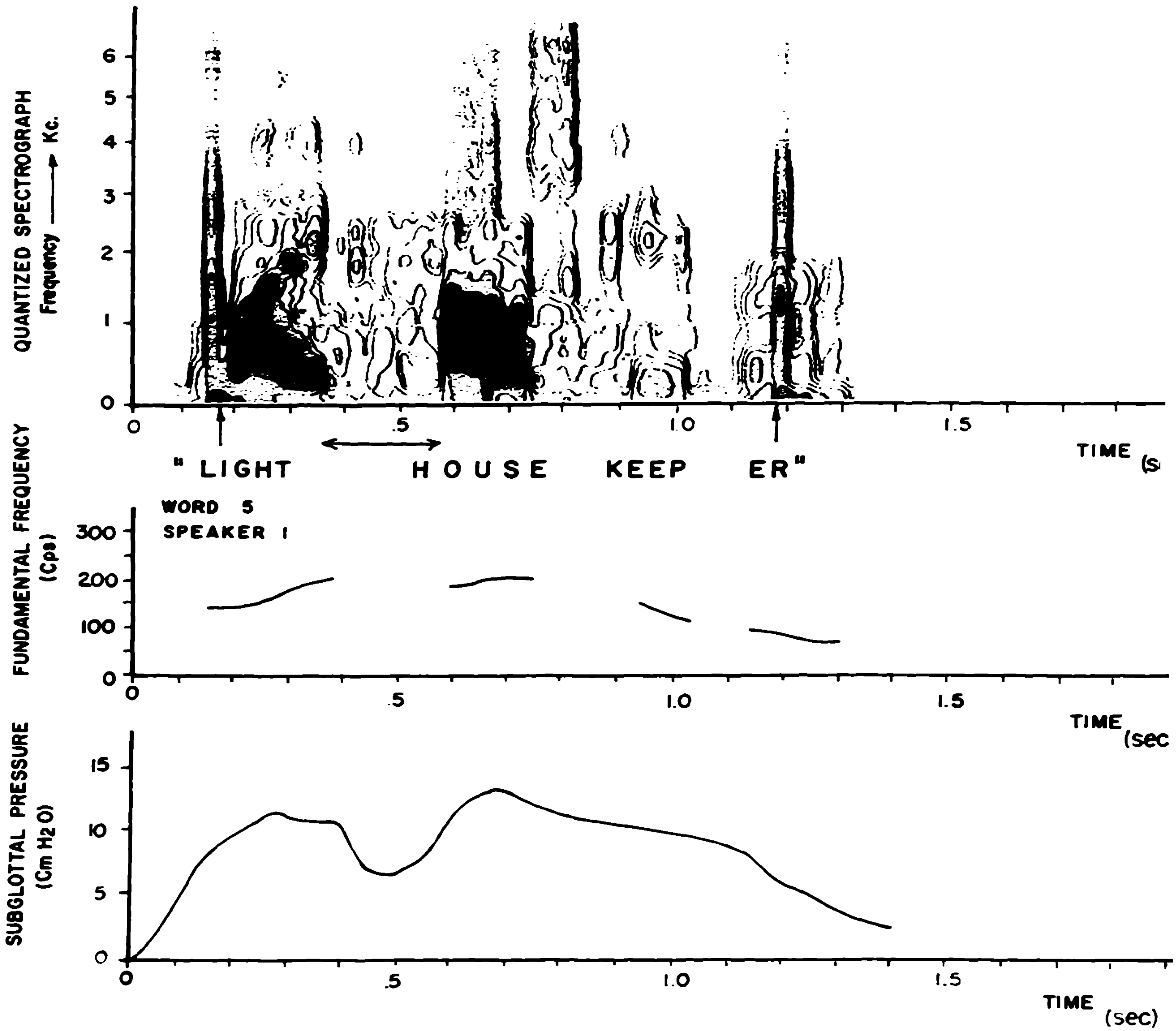

QUANTIZED SPECTROGRAPH
Frequency → Kc.
TIME (sec)
" LIGHT HOUSE KEEP ER"
WORD 5
SPEAKER 1
FUNDAMENTAL FREQUENCY (Cps)
TIME (sec)
SUBGLOTTAL PRESSURE (Cm H2O)
TIME (sec)

Fig. 3

TABLE ONE

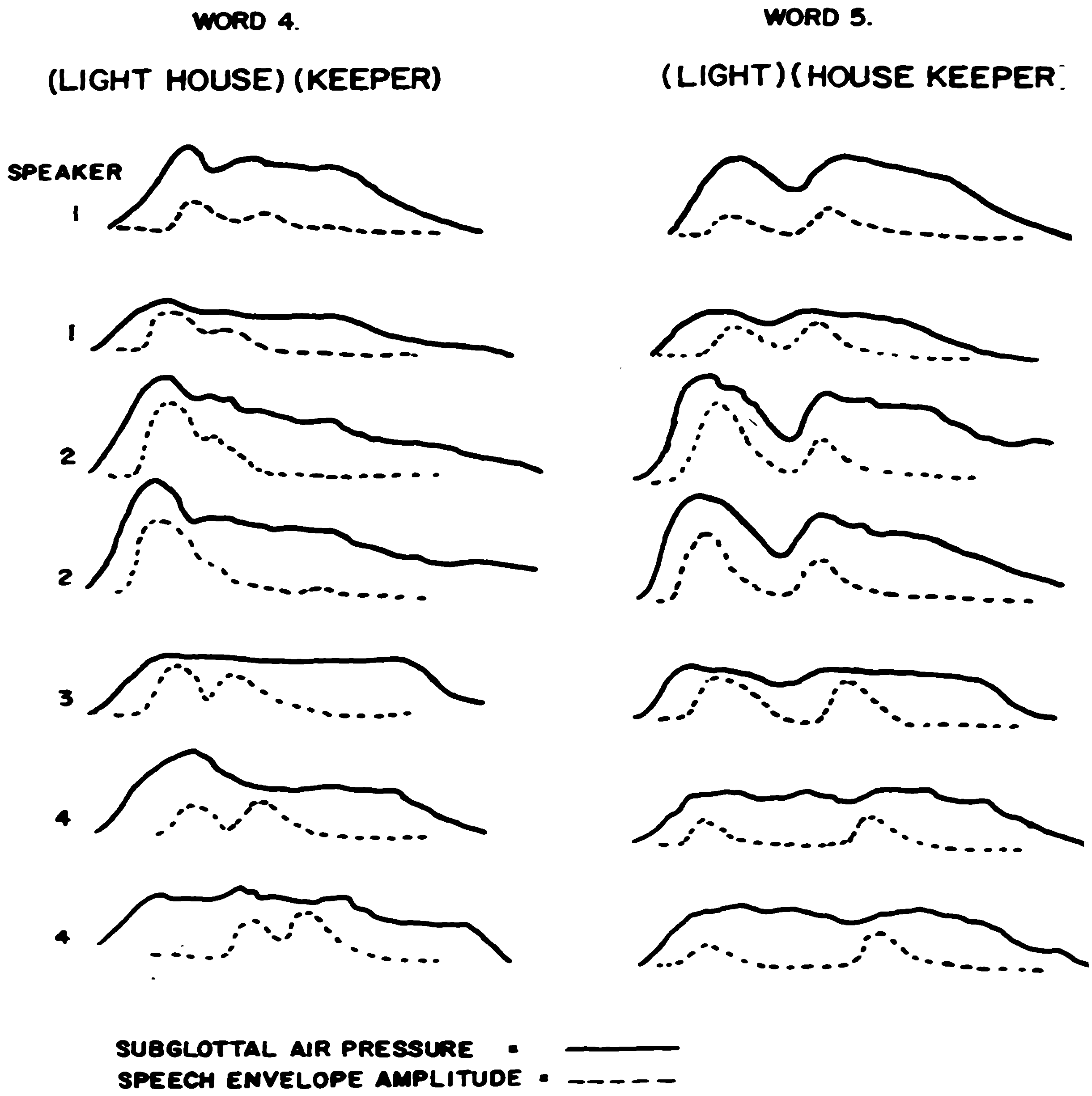
	1		3		2		4	Stress Pattern
Fig. 2	light	______	house	______	keep	______	er	
Duration segment (msec)	180	40	170	190	90	100	120	
Average Fundamental Frequency (cps)	160		140		140		120	
Peak Fundamental Frequency	200		180		140		120	
Minimum Fundamental Frequency	120		120		140		120	
Peak Amplitude (db)	48		42		30		24	

	2		1		3		4	Stress Pattern
Fig. 3	light	______	house	______	keep	______	er	
Duration segment	240	220	160	180	90	110	110	
Average Fundamental Frequency	200		200		140		90	
Peak Fundamental Frequency	240		200		140		90	
Minimum Fundamental Frequency	180		200		140		90	
Peak Amplitude (db)	48		48		30		30	

that of house. Note the duration of the interval between the vowels of light and house, which is marked with an arrow on Fig. 2. This duration was accurately measured form a conventional wide band (300 cps analyzing filter bandwidth) spectrogram on which the beginning and end of phonation was clearly visible. It is presented in Table I, where the duration, average fundamental frequency, maximum and minimum fundamental frequency, and relative amplitude (to the nearest 6 db step above the noise level of the spectrogram) of each vowel of the utterances plotted in Figs. 2 and 3 are presented.

In Fig. 3 the same data is presented for (light) (house keeper)
2 1 3 4
which should have the stress pattern light house keeper. The average fundamental frequency of the vowel of house is higher than that of light, though both vowels have the same peak fundamental frequency. Both vowels have the same relative peak amplitude. The vowel /i/ in keeper has almost the same amplitude, duration, and fundamental frequency in Fig. 2 and Fig. 3. Note that the duration of the interval (marked by means of an arrow) between the vowels of light and house is 220 msec, in Fig. 3 whereas it is only 40 msec in Fig. 2. The duration of the interval between /ay/ of light and /i/ in keeper, is, however quite similar in both utterances.

Now what acoustic cue differentiates these two utterances? The answer to this question is that the disjunctures, which we will define as the intervals between the vowels, are the relevant acoustic cues. Bolinger and Gerstman (1957) first noted this effect in an experiment in which they used tape splicing techniques to change



ISOLATED WORDS 4 AND 5.
SPEAKERS 1, 2, 3 AND 4.
FIGURE 4.

Fig. 4

the utterance (light house) (keeper) into (light) (house keeper) and vice versa by simply changing the interval between light and house. We replicated their results using a digital computer to "splice" intervals of speech, without any noticeable experimental artifacts[1].

In Fig. 4 subglottal air pressure functions and envelope amplitude functions of (light house) (keeper) and (light) (house keeper) are plotted for the four talkers who were recorded in the physiological experiment that we discussed in chapter three. Note that the peak subglottal air pressure cannot be correlated with stress level one. The duration of the interval between the two air pressure peaks always correlates with the constituent structure, of the utterances. The disjunctures rather than the magnitude of the air pressure peak differentiates the utterances.

Similar effects also seem to occur in German. In Fig. 5
2 4
spectrograms are presented of the two German phrases eine Handvoll
1 2 3 1
Kirschen and eine Hand voll Kirschen as they were spoken by a native speaker of German. In Table 2 the durations and average fundamental frequencies of the vowels and the durations of the disjunctures are tabulated for the utterances in Fig. 5. Note that the acoustic correlates

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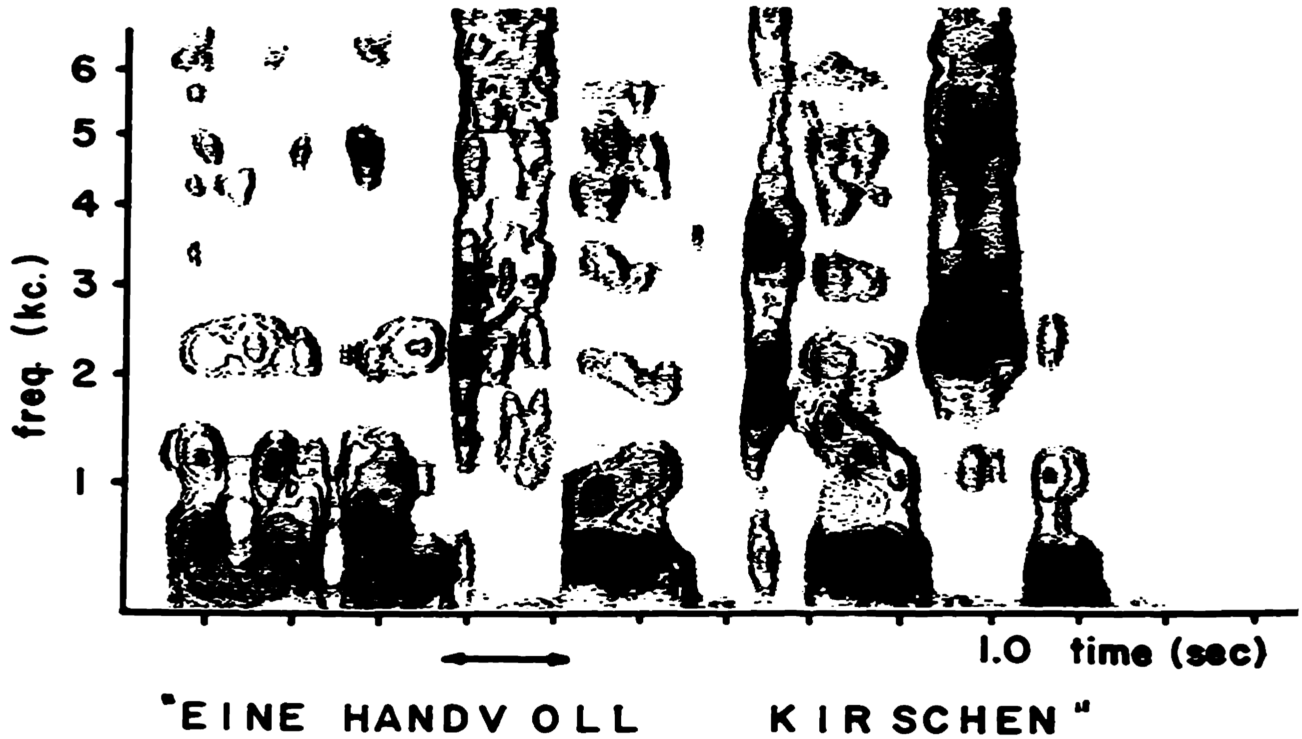
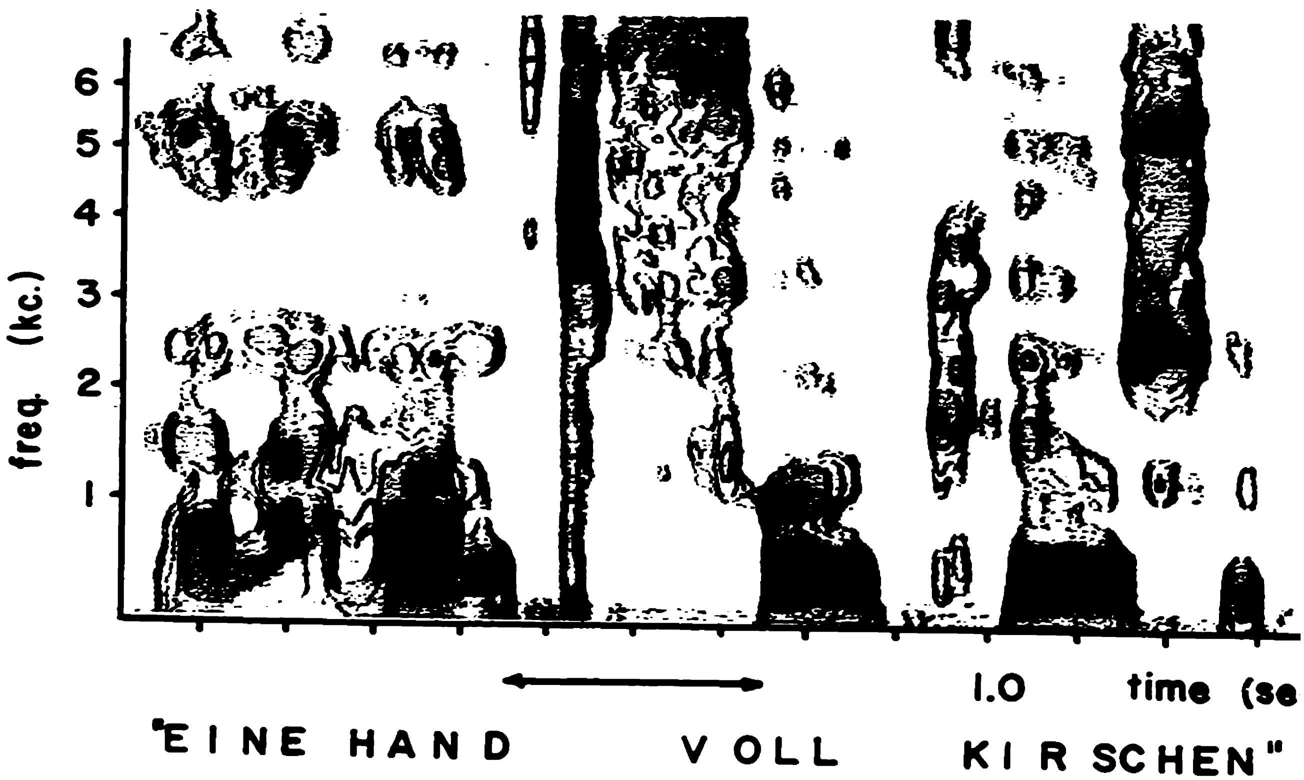
1. The speech signal is sampled 10,000 times per second and quantized along a linear scale with 7 bits using an analog to digital converter and a PDP-1 computer. The digit sequence is recorded on magnetic tape. A computer program is used to display the waveform on a scope and simultaneously play the signal. The operator can mark any part of the waveform to the nearest 0.0001 sec. and remove any interval to a storage tape. Up to thirty seconds of speech can be stored, divided, and recombined. If "cuts" are made at zero crossings in the vicinity of intervals of comparative silence, or the beginning or end of voicing, objectional transients can be minimized.



freq. (kc.)
6
5
4
3
2
1
1.0 time (sec)
"EINE HANDV OLL KIRSCHEN"



freq. (kc.)
6
5
4
3
2
1
1.0 time (se
"EINE HAND VOLL KIRSCHEN"

Fig. 5

TABLE TWO

	2		4		1	
Fig. 5	(Hand	______	voll)	____	(Kirschen)	eine Handvoll Kirschen
Duration Segment (msec)	350	140	150	50	470	
Average Fundamental Frequency (cps)	90		90		90	
Peak Amplitude (db)	30		30		30	

	2		3		1	
Fig	(Hand)	______	(voll	______	Kirschen)	eine Hand voll Kirschen
Duration Segment (msec)	440	260	130	60	360	
Average Fundamental Frequency (cps)	80		70		70	
Peak Amplitude (db)	36		36		36	

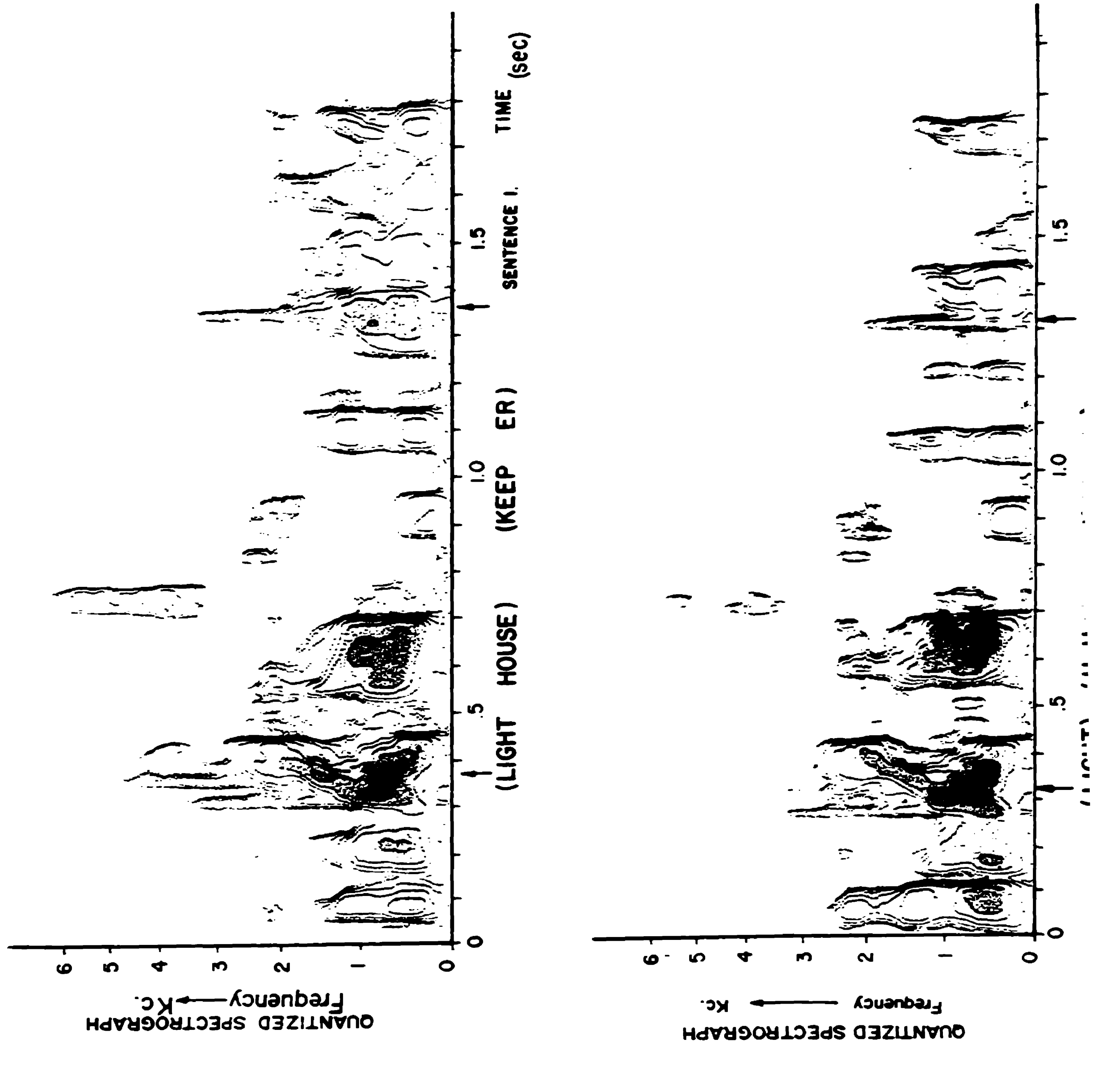

QUANTIZED SPECTROGRAPH
Frequency → Kc.
(LIGHT HOUSE) (KEEP ER)
SENTENCE I.
TIME (sec)
QUANTIZED SPECTROGRAPH
Frequency → Kc.

Fig. 6

of prominence do not divide into any ordered classes that would support a series of stress levels. The disjunctures marked on Fig. 5 again seem to indicate the differing constituent structures of these utterances. The disjuncture may be filled as it is in this case with the fricative. It does not have to be a silent pause.

It is conceivable that the disjunctures are themselves acoustic correlates of stress levels. We might think of a system in which vowels were either prominent or not-prominent and where the length of the disjuncture between two prominent vowels was inversely proportional to the difference between the two stress levels. The data, however, does not support this hypothesis. In Fig. 5, for example, the disjuncture between voll and Kirschen is identical for A and B. The same situation occurs in Figs. 2 and 3. The duration of the disjuncture between house and /i/ or keeper is similar, though the stress levels of the vowels are dissimilar. What seems to be happening is that the increased duration of the disjuncture in Fig. 3 and Fig. 5B indicates the constituent structure of the utterance. As we will see in the examples thatfollow, the disjunctures manifest those aspects of the constituent structure that may not be evident from the rest of the stimulus ensemble.

In connected speech, disjuncture may still be used to mark constituent structure. In Fig. 6 spectrograms of the phrase light house keeper are presented for the instances when it was spoken by speaker one in complete sentences. The context furnished by sentence one[1],

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1. In the list in Table I, chapter three.

The life of a light house keeper formerly was very lonely, indicates the appropriate constituent structure, as does sentence four, Our maid weighted 180 pounds, but the Jones' had a light house keeper for more than twenty years. The disjunctures still mark the constituent structure, probably because the speaker was aware of the contrast when he carefully read each sentence.

The context of the entire sentence actually overrides the effect of the disjunctures. It is possible to use a digital computer to "excise" or cut out the light house keeper phrases from each sentence and switch them without causing any objectional artifacts[1]. It is then impossible to hear any difference between the stress patterns of the altered sentences and the original sentences. In sentence one, one hears the phrase as (light house) (keeper) whether or not the original sentence or the sentence with the phrase excised from sentence four is heard. The context of the entire sentence indicates the appropriate constituent structure and the listener "hears" the correct stress pattern.

It is difficult to assess the extent to which disjuncture reflects constituent structure in normal speech. In Fig. 7 spectrographs are presented for a male native speaker of American English who read the phrases A - (light house) (keeper) B - (light) (house keeper) and C - (light) (heavyweight). Each phrase was read in isolation in sequence. The disjuncture between the first two words is marked. Note that phrases A and B are differentiated by disjuncture whereas C is not. The

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1. Using the same technique that we discussed on page 238.

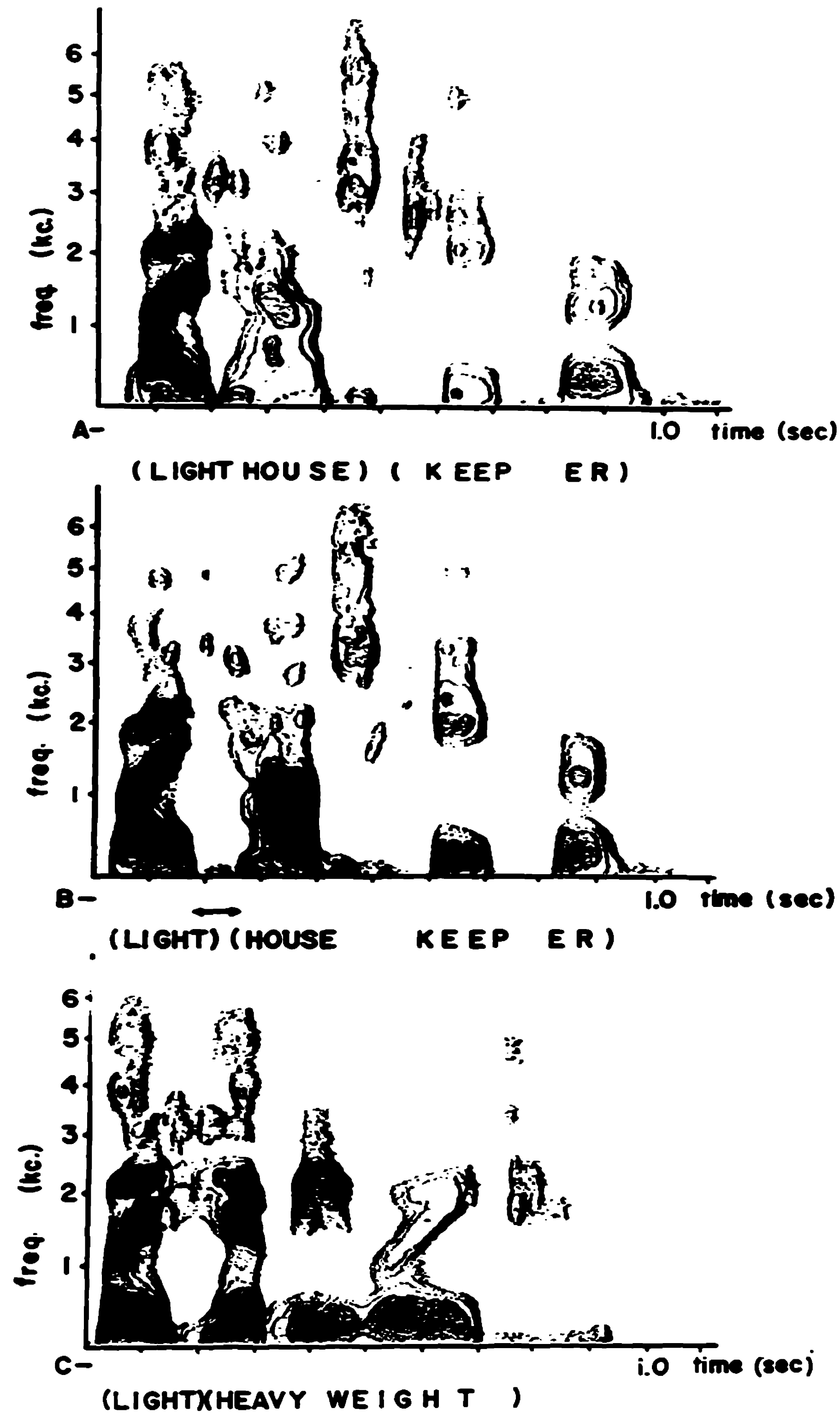
freq. (kc.)
6
5
4
3
2
1
A–
1.0 time (sec)
(LIGHT HOUSE) (KEEP ER)
B–
1.0 time (sec)
(LIGHT) (HOUSE KEEP ER)
C–
1.0 time (sec)
(LIGHT)(HEAVY WEIGHT)

Fig. 7

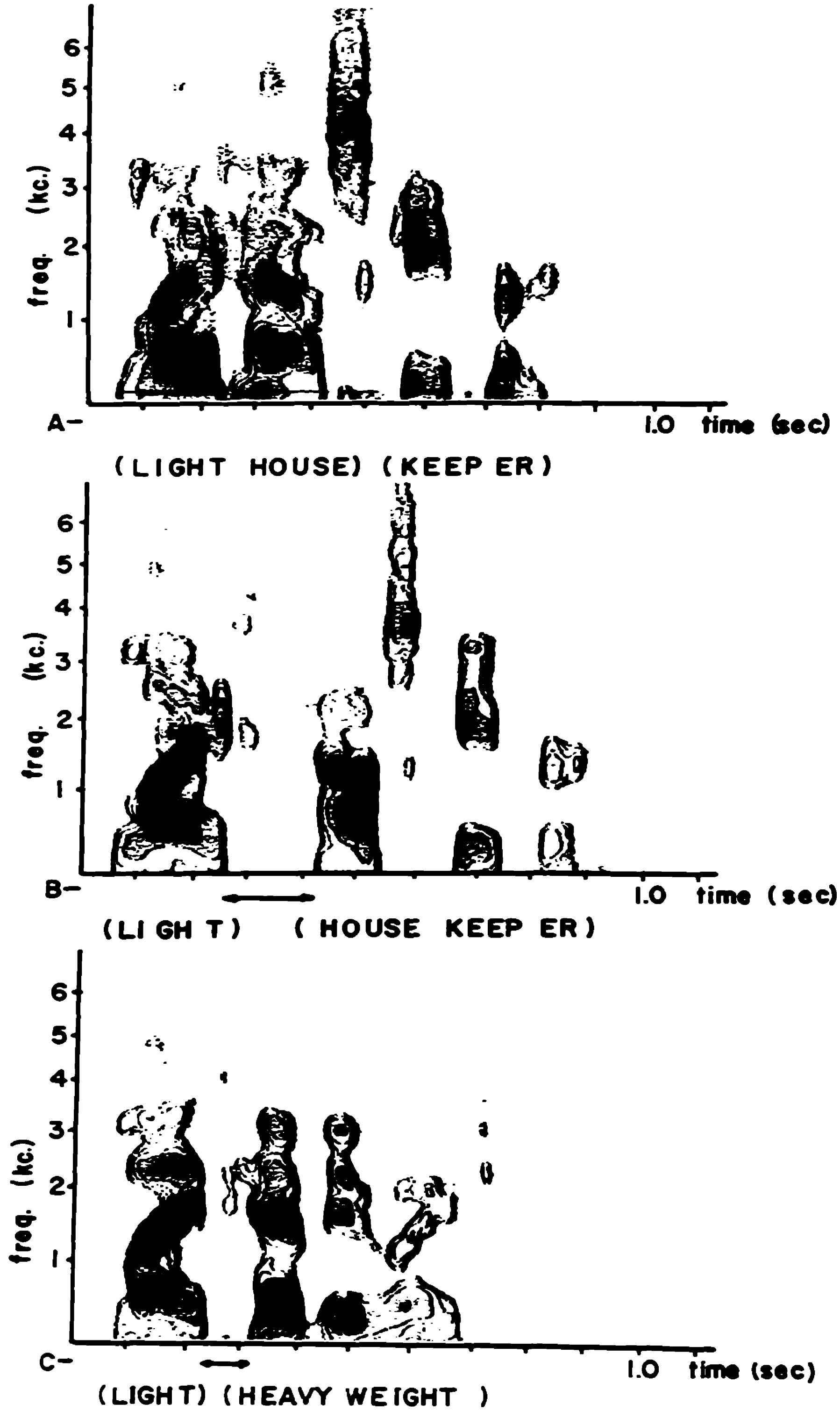
freq. (kc.)
6
5
4
3
2
1
A–
1.0 time (sec)
(LIGHT HOUSE) (KEEP ER)
freq. (kc.)
6
5
4
3
2
1
B–
1.0 time (sec)
(LI GH T) (HOUSE KEEP ER)
freq. (kc.)
6
5
4
3
2
1
C–
1.0 time (sec)
(LIGHT) (HEAVY WEIGHT)

Fig. 8

constituent structure of phrase C is relatively unambiguous if only the string of segmental phonetic elements is considered. The speaker apparently does not bother to increase the disjuncture between the vowels of light and heavy. Instead he utters the phrase at an even rate. The junctural contrast is wiped out. The speaker apparently only uses the minimum effort that is sufficient to insure that the utterance will be understood. In Fig. 8 the spectrographs of the same three utterances are presented for a second male native speaker of American English. Note that the duration of the disjuncture between the word light and the rest of the utterance reflects the constituent structure of each phrase. In this instance the disjuncture is especially short for A, quite long for B, and has an intermediate duration for C. The relative ambiguity of the constituent structure of each phrase with respect to the words only, affects the degree to which the disjunctures reflect the constituent structure. Words that are more closely related tend to be separated by shorter disjunctures when the constituent structure may be in doubt. Note that in all these examples the disjunctures between house and keeper never change appreciably. There is no need to modify these disjunctures though the constituent structure is different, because the modification of the disjuncture between light and house provides enough information for the listener to interpret the utterance correctly.

In summation, we might conceive of a process whereby the phonetic outputs of linguistic stress were formed in the following manner:

1. Let X be the "stress level" of each vowel which is assigned by the phonologic rules.

2. All vowels where $X \leq X_i$ are marked $[+P_s]$.

3. All vowels where $X > X_i$ are $[-P_s]$.

4. All vowels where $X \geq X_j$ are reduced.

The magnitudes of X_i and X_j are functions of the rate at which the speaker is talking, the context, etc. In rapid discourse X_i might equal 0 and no vowels would be marked $[+P_s]$ as the result of linguistic stress. In careful speech X_i probably equals 1.

Disjunctures would manifest the constituent structure where it would otherwise not be clear from the total context of the message. The perception of intermediate degrees of stress always follows from the listener's application of the rules of the grammar on the derived phrase marker. However, the derived phrase marker is manifested by different phonetic signals in different situations.

C - Categorization Versus Discrimination

We have stated that promience exercises only a binary function with regard to the perception of linguistic stress. Many of the objections to this view perhaps stem from a basic confusion between categorical and comparative decisions. For example, under optimal conditions, the threshold for detecting a difference in frequency between two successively presented sinusoidal tones is of the order of 1 part in a 1000 (Rosenblith and Stevens, 1952; Harris and Stuntz, 1950). On the basis of comparative judgments of this type, it has been estimated that human listeners can distinguish about 350,000 different pure tones

(Stevens and Davis, 1938). In contrast to this differntial sensitivity is the relative inability of a listener to identify and name (i.e., categorize) sounds presented not for direct comparison, but for individual identification. Pollack (1952), for example, has shown[1] that listeners can consistently identify no more than four or five pure tones when each tone is individually presented for identification. The gross disparity between the estimate of human performance that is based on a projection of human discriminatory abilities, and the actual categorical performance, reflects the basic difference betweeen categorical and comparative decisions.

It is, for example, possible to produce the sentence, Joe ate his soup. with virtually any degree of promimence on Joe. If two of these utterances are successively presented to a listener he will be able to discriminate extremely small differences in prominence. If the listener were asked to state what each utterance "meant" he would undoubtedly associate many fine shades of "meaning" with each degree of prominence. The "shades of meaning" might reflect some of the emotional attributes of intonation or they might refer to incidents in the listener's life history. Many of the "minimal intonation pairs" that are discussed in linguistic literature are comparative. They may have some relevance to the emotional aspects of intonation but they are not directly relevant to the linguistic aspects of intonation. Linguistic decisions are categorical. Two male speakers may produce the vowel /a/ with formant

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1. Pollack expressed his results in terms of information transmitted (c.f. Shannon, 1948). The rate of information transferred was 2.0 - 2.3 bits.

frequencies $F_1 = 720$, $F_2 = 1080$, and $F_3 = 2600$ cps for one talker and $F_1 = 720$, $F_2 = 1110$, and $F_3 = 2700$ cps for the other talker. The two vowels will both be categorized as /a/ though listeners can easily discriminate between the two sounds (Stevens, 1952).

Geisler, Molnar, et. al., (1958) performed an interesting experiment in which listeners were asked to categorize short "clicks" according to their loudness. Listeners were seated one at a time in an anechoic chamger and monaurally presented with 0.1 msec clicks through a PDR-10 headphone. The clicks were presented at five second intervals and the amplitudes of the clicks were varied in either five or ten db steps in three sessions over a range of intensity that went from 10-80 db or 35-80 db over the mean threshold of the subjects taking part in the experiment. Twenty listeners heard these stimuli. The listeners were asked to place the stimuli into five categories. The performance of the subjects varied. Some subjects were unable to form five categories. One listener, for example, classified most of the stimuli that were less than 40 db in the "weakest" category and placed the stimuli that were over 40 db into one of the other four categories without regard to their relative intensity. Essentially he formed only two categories. Other listeners were able to form five categories. Each listener's performance was remarkably stable and remained unaffected by further training.[1] The listeners apparently had different categorization procedures. These results contrast with those reported by Pollack (1953),

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1. Personnal communication from C. E. Molnar.

who investigated the categorization of pure tones according to amplitude. He found that listeners could consistently form the equivalent of 3-4 categories. The differences in the performance of the listeners when they listened to clicks rather than to sustained pure tones may reflect the use of linguistic criteria by some listeners and non-linguistic criteria by others, just as the performance of the listeners in the Hadding-Koch, Studdert-Kennedy (op. cit.) experiment (c.f. chapter three), reflected the use of linguistic rather than "pure" psychoacoustic criteria.

One additional comment can be made regarding the possible import of psychoacoustic experiments that deal with "elementary" auditory cues like pure tones. Pollack (1952), as we noted, found that listeners could form the equivalent of four of five categories with respect to frequency. If language made optimum use of the potential to form these psychoacoustic categories we might expect to find some language where four or five "pitch levels" had a phonemic status. However, it is impossible to find any examples where four or five static pitch levels each have a phonemic status. Languages like Chinese, which have phonemic pitch contours, instead build up the pitch phonemes out of the binary distinctive features high pitch, low pitch, rising and falling (Chang, 1958). Linguistic "codes" apparently avoid making extreme demands on the human auditory system. They operate with a "margin for error". Since loudness can be categorized, under optimum conditions, to only 3-4 levels it is not surprising to find that only two degrees of prominence function as linguistic cues in connected speech.

Chapter Seven

A Survey of Some Recent Linguistic Studies of Intonation

We shall discuss, for the most part, analyses of British and American English that were published in the twentieth century. Instrumental studies based on measurements of the acoustic signal have only been feasible during the past thirty years and they are still quite difficult to perform; therefore most of these analyses are based upon observations by phoneticians and linguists. We will not attempt to discuss every recent linguistic analysis of English intonation, but we shall try to discuss some of the studies which have most influenced current trends.

The goal of most of these studies has been the development of a notation for the objective representation of intonational phenomena. Some of the studies have attempted to relate certain aspects of intonation to linguistic structure in a systematic way. However, these attempts have for the most part been unsuccessful.

Three fundamentally different approaches have evolved since 1900. One approach, typified by the British school which has become identified with Daniel Jones, has made use of suprasegmental "tunes" which, on the acoustic level, are quite similar to the breath-group. The second approach, which also has been largely identified with British phoneticians, has described pitch contours by means of "tones" which occur on specific vowels. The sequence of tones which may rise and fall determines the intonation pattern of the utterance. Some of the linguists who employ these tones group the tones into suprasegmental "tone patterns". While the "tunes" or "tone patterns" are often related to certain sentence types, most of these studies do not attempt systematically to relate intonation to a formal grammar.

The third approach has been developed principally by American linguists who tried to apply the segmental techniques of taxonomic phonemics to intonation. In these studies intonation has been analyzed in terms of segmental pitch levels, stress levels, and junctures. The segmental elements, however, have been grouped into suprasegmental "phonemic phrases", "phonemic clauses", and "suprasegmental morphemes". An attempt has been made to relate these suprasegmental elements to the constituent structure of the sentence. However, these studies have been preoccupied, in general, with the problem of furnishing "objective" cues for immediate constituent analysis, and with providing "morphemes" that will yield a semantic interpretation of a sentence directly from the superficial phrase marker.

We will first discuss the British "tone" and "tune" analyses before we go on to the American "phonemic" descriptions and other analyses that do not quite fit into any of these categories.

A - Sweet (1892), New English Grammar

Although Sweet's New English Grammar was published in 1892 the phonetic elements[1] that Sweet briefly outlined in it in two pages (pp. 228-229) are the basis of all of the "tone" analyses that have since been published. Sweet set up "three degrees of stress or loudness...strong, half strong, and weak.... Sounds which can occur only in unstressed syllables are called weak.... Intonation is either level, rising or falling.... The level tone may be either high or low and the other tones may begin in a high or low pitch". Sweet also stated that, "When excited we speak

1. These phonetic elements have a long history and were probably first used by Walker (1787).

9. An English postmaster, then, is also a banker?

10. He is to a certain extent.

11. But any important business, I suppose, devolves on the head offices?

12. Just so. The nearest of these is the head district office at Charing Cross.

13. Oh, that is where I have had my poste-restante letters addressed to. I will go there.

14. I imagine even the grocers, or any other branch office would keep letters for you, if marked: "To be left till called for."

(After Jones, 1909)

Fig. 1

in a high pitch or key, when depressed in a low key. The non-level tones can pass through different intervals, the greater the interval, the more emphatic the tone becomes."

Sweet had two other "compound" intonation symbols. ∨ which meant a falling intonation followed by a rising intonation and ∧ which meant a rising followed by a falling intonation. Both of these compound tones could start at either a high or a low pitch. Sweet seemed to equate intonation to the pitch or fundamental frequency of the voice and stress to loudness. It seems quite clear that by loudness he meant the perceptual impression of loudness and not any acoustic measurement of the speech waveform. Sweet appears to have used this notation simply to transcribe intonation. He was using the tones as phonetic symbols in a manner analogous to the segmental IPA notation for vowels, consonants, etc.

Recent research (Lieberman, 1965) shows that Sweet's intonation notation can be used to transcribe the intonation patterns of English utterances quite accurately. A trained linguist can accurately transcribe the change in fundamental frequency of a segment of speech relative to its immediate surround using this notation.

B - Jones (1909), Intonation Curves

Although Jones was quite familiar with Sweet's notational system he performed a quasi-instrumental study of intonation. He obtained a set of recordings of English and French conversations and dramatic readings. He listened to those records and lifted the "...needle off the gramophone...." at regular intervals and noted the pitch that he last heard on a musical scale. When he was in doubt he repeated the passage. He then placed a phonetic transcription of the recordings under the pitch notations. These transcriptions are probably quite accurate since the ear can resolve variations smaller than 1 cps in the fundamental frequency of vowel-like sounds (Flanagan and Saslow, 1958).

In Fig. 1 some of these curves are reproduced for English conversations. Jones published these recordings without any general comments except for noting that perhaps there were more breaks and inflections in the contours of each sentence because the talkers spoke quite carefully for the recordings. Jones does not attempt to discuss the "meaning" of the contours. He simply states that the contours are useful pedagogic aids. However, Jones's ready acceptance of the "two tune" theory of Armstrong and Ward (1926) was probably due, in part, to the fact that their theory fits the data in Intonation Curves.

C - Palmer and Blandford (1924), A Grammar of Spoken English

Palmer and Blandford in this study employ Sweet's tones but they group them into suprasegmental "tone-patterns". They attempt to relate the use of these tone-patterns to various types of sentences, but they fail to differentiate the emotional aspects of intonation from the linguistic aspects.

They use high or low falling tones, which they mark as  or high or low rising tones marked by  or  , and one "rise-fall-rise" tone which they mark  . Each nucleus tone is preceded by a "head" and followed by a "tail". The heads and tails essentially connect the nucleus tones in connected speech. Six "tone-patterns", which each consist of a head and nucleus, are described. They "may be designated by the following symbols and numbers[1],"

(p. 16)

(Tone pattern 4 has two alternate forms.) The "tails" that go with these tone-patterns continue in the direction established by the nucleus tone when a sentence is spoken on only one tone-pattern. When several tone-patterns occur in one sentence the "tail" of one tone-pattern must join the "head" of the next tone-pattern. The tone-patterns are supposed to have definite "Functions and Meanings" which are set forth in pages 18-24.

Tone-pattern 1 is used, "In statements having the nature of "declarations" or 'assertions'...commands... questions beginning with an interrogative word...and 'rhetorical' questions. It is the pattern that occurs with by far the greatest frequency." Tone-pattern 2 is used in "assertons" and "special questions with a one word prominence." e.g., "Where?" Its use "implies 'then in that case', 'that begingso'." Tone-pattern five "expresses a certain kind of contrast, thesemantic nature of which is most difficult to define or even describe. It implies concession...." Tone-pattern six also has "semantic and stylistic functions...(that) are difficult to describe." Tone-pattern four is used for yes-no interrogatives and "echo" questions and tone-pattern 3 is used in " "statements...having the nature of comments." The rest of the book's treatment of intonation is concerned with the special "meamings" that occur in sentences having several tone-patterns.

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1. Palmer in a slightly earlier work (1922) used the same system of tones but did not try to group them into tone-patterns.

Palmer and Blandford note that stress and pitch are interrelated and they define stress in terms of "Force of utterance" (p. 5). They state that the linguistic stress indicates "...which syllable of a word is eligible for becoming the nucleus of a tone group...." (p. 6).

The division of the intonation pattern into a head, nucleus and tail seems to be rather arbitrary, as are many of the "meanings" set forth in this book. One soon gets the impression that every possible intonation pattern has its own subtle, arbitrary meaning.

The studies of Schubiger (1935), Kingdon (1939), and Jassem (1952) all essentially follow the pattern of this study. A reasonably accurate phonetic transcription of a large corpus of utterances is associated with a vast catalog of "meanings" and the linguistic aspects of intonation never are clearly differentiated from the emotional aspects.

<u>D - Armstrong and Ward (1926), Handbook of English Intonation</u>

This work attempts to differentiate the emotional aspects of intonation from its linguistic function. The authors state that,

> The aims of this work are primarily pedagogic, attention is given to the simplest forms of intonation used in conversation.... The writers are aware that there are other varieties and deeper subtleties of intonation than are here recorded. Such variations, however, are not essential for correct and good English, and their absence would not be missed by anyone who had not made a special study of intonation. (p. 1).

Armstrong and Ward define stress in terms of breath force. They state that a speaker stresses the important words in a sentence: "If he feels one idea to be important he stresses the words embodying that idea, if many ideas, he stresses many words." Intonation is defined in terms of perceived pitch, The authors note that, 'waɪ dɪd ʃɪ 'kʌm 'nau, | wɛn wɪ ə sou 'bɪzɪ?

ju məst 'ɔ:l bɪ ↑vɛrɪ 'kaɪnd tə hɜ, | ən du 'ɔ:l ju 'kæn tə 'hɛlp.

hi dɪs'kʌvəd ðət ʃɪ wəz dɪs↑paɪzd baɪ ðə 'sɜ:vnts | hu 'kwaɪt 'oupnlɪ ɪn'sʌltɪd hə.

aɪ 'hævnt 'taɪm tə 'du: ɪt, | sou aɪ l 'li:v ɪt tɪl tə'morou.

hi 'kudnt 'kʌm, | əz hi wəz ə'weɪ frəm 'houm.

ðə 'sʌn wəz 'ʃaɪnɪŋ, | ənd 'ɛvrɪθɪn lukt 'braɪt.

b) Tune I repeated more than once.

'ʤon sɛd 'sʌmθɪŋ 'mɔə | wɪʧ ðə 'ʧɪldrən kudnt 'kæʧ | ən 'væniʃt.

aɪ 'ju:st tə 'si: hɪm ɪn ↑kɛnzɪŋtən 'gɑ:dnz | wɛə hi 'keɪm ɪn ðɪ 'ɑ:ftə'nu:nz | ə'kʌmpənɪd baɪ ə ↑vɛrɪ 'smɔ:l 'gɜ:l.

hi 'ʃʌt ðə 'dɔər əz ↑kwaɪətlɪ əz 'pɒsɪbl, | ɪn'tɛndɪŋ tə gou ↑streɪt tə 'bɛd | ənd ə'vɔɪd ɛnɪ 'fɜ:ðə kɒnvə'seɪʃn.

ʃɪ 'stɒpt 'ʃɔ:t ɪn 'wɒt ʃɪ əd bɪn 'seɪɪŋ, | 'noutɪsɪŋ ðət ɪ ↑wɒznt 'lɪsnɪŋ | ənd wəz 'lukɪŋ ət hɜ wɪð ɪk↑stri:m 'ɜ:nəstnəs.

ɪt wəz ə 'fjuərɪəs 'wɪndɪ 'mɔ:nɪŋ, | wɪð ə 'skaɪ 'mʌʧ 'klɪəd, | ənd 'lɒŋ 'ɪntəvlz əv 'sʌnʃaɪn.

aɪ l 'kʌm ən 'sɪt baɪ ðə 'faɪə | ən 'gɛt 'wɔ:m, | ən 'ðɛn aɪ ʃl 'fi:l 'kʌmfətəbl.

ðə 'θɪŋ 'dɪdnt 'mu:v, | ɪt hæd 'nou 'pʌls, | 'nou 'brɛθ, | 'nou 'kʌlə | – ɪt wəz 'dɛd.

aɪ məst 'gɪv ɪt 'ʌp | ənd 'straɪk 'aut fə maɪ'sɛlf, | ənd 'hæŋ ðə 'kɒnsɪkwənsɪz.

c) Tune II followed by Tune I.

'æz aɪ wəz ɪn ə 'hʌrɪ, | aɪ tuk ə 'tæksɪ.

hi 'spɛnt hɪz 'mʌnɪ | əz ɪf hi wər ə 'mɪljən'ɛə.

'wɛn ðeɪ ə'raɪvd ət ðə 'steɪʃn | deɪ 'faund ðət ðə 'treɪn həd 'gɒn.

wɒt'ɛvə 'mɛθəd hi əd 'traɪd, | ɪt wəz 'klɪə hi həd 'feɪld.

'ɪf hi d 'steɪd ənʌðə 'fɔ:tnaɪt, | ðə 'wɜ:k wud əv bi:n 'dʌn

fər əbaut 'tu: 'maɪlz | ðə 'roud 'klaɪmz 'ʌpwədz.

Fig. 2

> These two elements, stress and intonation, are very closely connected. So close is the connection, indeed, that it is often difficult to decide whether stress or intonation or a combination of the two is responsible for certain effects. (p. 3).

A word spoken in isolation may have a certain stress pattern. however, "in connected speech this word stress is often dropped (p. 3)." When sentences are spoken slowly "...slight variations in intonation and stress are to be observed which would not occur in quick speech. Some of the syllables which would normally be unstressed...have some stress.... These variations are not essential...."

Armstrong and Ward transcribe the overall sentence intonation by a series of dots and dashes. Each dot marks the relative pitch of an unstressed syllable and each dash marks the relative pitch of the stressed syllable. The vertical position of the dot or dash reflects the relative pitch of each syllable.

The most important aspect of this system is that two "tunes" are defined. Tune I essentially starts on a medium pitch and continues on this pitch with some upwards variations on stressed syllables until the end of the sentence where the pitch then falls rapidly. Tune II starts at either a high or a middle pitch and gradually falls, but it ends with rising or level pitch. Sentences are divided into "sense-groups" and each "sense-group" is an intonation group which <u>may</u> have the contour of Tune I or II.[1] In short sentences that have only one "sense-group" tune I is used for statements and imperatives. Tune II is used for some interrogative yes-no questions and for sentences in which the speaker

---

1. Armstrong and Waed really use the term sense-group and intonation-group rather interchangeably. They never attempt a definition of "sense-group".

wishes to imply some uncertainty.

Longer sentences may consist of many sense-groups. They note that:

> I. Different people divide their speech into different sense-groups, and there is a corresponding difference in their intonation groups.
>
> II. A speaker varies his sense-groups and consequently the rhythm and intonation of the passage he is reading or speaking, according to the style of his subject matter and the speed or deliberation with which he speaks.
>
> III. In conversational style the sense-groups are longer than in description or narration. The more deliberate the speech the more groups are made....

Tune II is usually used in longer sentences for sense-groups that do not terminate the sentence. Tune I occasionally can be used for non-terminal sense-groups in long sentences under certain conditions.

> Sentences of this type are, for the most part, co-ordinate sentences or phrases with a logical, though not necessarily a grammatical dependence on each other. If in the speaker's mind the logical connection is very close, the first intonation group may be said with the second tune. But there are so many cases in connected speech where we have to rise at the end of the first group that it is a relief to fall when a choice is at all possible (p. 26).

In Fig. 2 some transcriptions from this study are reproduced.

Armstrong and Ward in effect isolated the acoustic and perceptual manifestations of the breath-group. The two tunes are each suprasegmental. Tune I is equivalent to the unmarked breath-group, while Tune II is equivalent to the marked breath-group. The height of the syllables in their transcription is a phonetic transcription of the fundamental frequency variations that are superimposed on the breath-group.

Armstrong and Ward also noted that stress, which is equivalent to the "force of utterance" ($[+P_s]$), may interact with the tunes. They differentiate perceived prominence from stress and intonation. They note, for example, that,

> When the speaker wants to pick out a certain word (or words) and distinguish it from others in the sentence by making it specially prominent, he does so chiefly by a change in intonation. Increase of stress often accompanies this change, but it does not ever appear to be essential. (p. 48).

However, they are not quite consistent throughout their book regarding the roles of stress and intonation. On page 26 they state that,

> The meaning of words or sentences can be intensified.
>
> I. By simply increasing the stress on the normally stressed syllables, the intonation remaining the same as for unemphatic utterance.
>
> II. By widening the range of intonation of the whole sentence (in addition to increasing stress).
>
> III. By lowering and narrowing the range of intonation (in addition to increasing the stress).

Armstrong and Ward do not discuss the meanings of the contours associated with each sentence. They simply discuss the general functions of Tune I and Tune II, make some general statements about "intensifying", "distinguishing" and stressing words (with increased vocal effort) and then give many examples of correctly pronounced English sentences (Received Pronunciation). Their study is extremely significant since they realized that the linguistic aspects of intonation could be transcribed in terms of the two Tunes and pitch (intonation) and breath-force (stress) deviations from the two Tunes.

E - Jones (1932), An Outline of English Phonetics, 3rd Edition

Jones in this work adopted the Tune I, Tune II Armstrong-Ward analysis, and he expands on it. He note that intonation can be used to "make the meaning" of an utterance clearer and he gives an "operational definition" of the relationship betweeen intonation and "sense-groups":

> Pauses are continually being made in speaking. They are made (1) for the purpose of taking breath, (2) for the purpose of making the meaning of the words clearer.
>
> It is usual to employ the term breath-group to denote a complete sentence that can conveniently be said with a single breath, or, in the case of very long sentences, the longest portions that can conveniently be said with single breaths.
>
> Pauses for breath are normally made at points where pauses are necessary or allowable from the point of view of meaning.
>
> Sentences are usually divisible into smaller groups between which pauses may be made, though they are not essential. The shortest possible of such groups (i.e., groups which are not capable of being further subdivided by pauses) are called sense-groups. Each sense-group consists of a few words in close grammatical connection, such as would be said together in giving a slow dictation exercise. (p. 254).

Jones notes that, "Intonation is a ...different thing from stress." Intonation is essentially defined as perceived pitch. He relates prominence, stress and intonation as follows:

> In every spoken word or phrase there is at least one sound which is heard to stand out more prominently than sounds next to it. (p. 55).
>
> The prominence of a given sound may be increased or diminished by means of any one of the three sound attributes, length, stress, or intonation, or by combinations of these. A common and effective means...is to increase the stress. In English increase of stress is generally accompanied by a modification of intonation and sometimes by an increase of length. (p. 228).
>
> It is important not to confuse stress and prominence. The prominence of a syllable is its general degree of distinctness, this being the combined effect of the timbre, length, stress and intonation of the syllabic sound. The term "stress" refers only to the degree of force of utterance, it is independent of length and intonation, though it may be combined with these. (p. 228).

Jones essentially says that stress and intonation are independent at the articulatory level. Prominence is a perceptual quantity that may be effected by either stress or intonation. To Jones, stress seems to be an articulatory gesture and he explicitly states tht its perception involves a knowledge of the structure of the language and "analysis-by-synthesis."

> When a strong stress is given to a syllable incapable of receiving any noticeable increase of loudness, a person unfamiliar with the language would be unable to tell that a stress was present .... A person familiar with the language would not perceive the sound objectively from the sound... but he perceives it in a subjective way; the sounds he hears call up to his mind (through the context) the manner of making them, and by means of immediate 'inner speech' he knows where the stress is. (p. 227).

It is not entirely clear whether he thinks that all "prominent" sounds may be also perceived from the listener's linguistic analysis of the context or whether he thinks that only stress can be perceived in this way. He may believe that only stress can be perceived in this way since his reasoning seems to follow from the articulatory facts peculiar to stress, i.e., that increased force of utterance or breath may occur on a sound having low inherent sonority (e.g., nasals).

Jones's definitions of stress, intonation, and prominence are quite clear and his subjective evaluations of their acoustic correlates have, for the most part, been substantiated by psychoacoustic and acoustic experiments (c.f. chapter one). He also clearly expresses the notion that intonation can potentially be used to clarify the meaning of a sentence though, of course, he does not state how a sentence is understood.

Although Jones rather carefully defines stress [$+P_s$] he does not note that inherently it is a different type of entity from the supra-segmental tunes. Jones's insights into the perception of stress, however, are quite interesting.

"Phonemic Analyses"

F - Bloomfield (1933), Language

Bloomfield's treatment of intonation and stress is not so important for its detail as for the direction in which it channeled later American "phonemic" analyses. Much of the subsequent American work is an expansion and codification of Bloomfield's basic premises and assumptions. In contrast to Jones, who differentiated perceived prominence from stress (force of utterance) and the acoustic correlates of stress. Bloomfield implies that perceived loudness is equal to stress. The perceived loudness is equated to the intensity of the acoustic signal;

> "Stress - that is, intensity or loudness - consists in greater amplitude of the sound waves...." (p. 110)

Bloomfield's definition of stress seems to reflect his preoccupation with "objective" measurements. Bloomfield's followers treat stress and pitch as independent phenomena, which they are if stress is simply supposed to be the amplitude of the acoustic signal and pitch the fundamental frequency. However, stress is also supposed to be equivalent to perceived loudness and it is clear that the perception of the loudness of a short segment of speech involves its amplitude, duration and fundamental frequency (c.f. chapters one, three and six).

Bloomfield asserts that pitch phonemes constitute separate morphemes and carry their own meanings independent of the words of a sentence:

> Differences in pitch...are used in English, and perhaps in most languages as secondary phonemes...pitch is the acoustic feature where gesture-like variations, non-distinctive but socially effective, border most closely on genuine linguistic distinctions. (p. 114).

> ...The pitch phonemes in English are not in principle attached to any particular words or phrases, but vary, with differences in meaning, in otherwise identical forms. (p. 116)

The pitch phonemes, however, have other functions in speech. Intonation is supposed to play a part in expressing "...the actor-action construction...." in "the favorite" English sentence forms. (p. 172).

> In English and many other languages, sentences are marked off by modulation, the use of secondary phonemes. In English, secondary phonemes of pitch mark the end of sentences, and distinguish three main sentence-types: John ran away [.] John ran away [?] Who ran away [¿]. (p. 170).

> This use of secondary phonemes to mark the ends of sentences makes possible a construction known as <u>parataxis</u>, in which two forms united by no other construction are united by the use of only one sentence-pitch. Thus if we say <u>It's ten o'clock [.]</u> <u>I have to go home[.]</u> with the final falling pitch of a statement on <u>o'clock</u>, we have spoken two sentences, but if we omit this final pitch (substituting for it a pause pitch), the two forms are united...into a single sentence.... (p. 171).

This function, of course, sounds rather like a vague version of the functions of Tune I and Tune II in connected speech.

Bloomfield, in effect, argues that intonation contours must be morphemes because intonation carries meaning. Since the intonation contours are determined by various pitches these pitches must be phonemes. He also notes that these pitch "phonemes" play a role in forming syntactic "constructions". The principal effects of Bloomfield's work were to channel subsequent studies towards the isolation of these "pitch phonemes" and the explicit characterization of their role in defining syntactic "constructions".

<u>G - Bloch and Trager (1942), Outline of Linguistic Analysis</u>

Bloch and Trager in their section on phonetic analysis briefly discuss the "...prosodic features of quantity (length), stress (loudness), and tone (pitch); the last two are grouped together as features of accent (p. 34)." They do not discuss either quantity or tone in detail. "Tone levels (higher and lower) and tone contours (rising, level, falling, etc.) may be indicated by accent marks over the letters, by superior numerals with assigned values, or by other devices." (p. 35).

Though they initially define stress in terms of loudness they also note the classical articulatory definition in terms of force of utterance. They observe that stress may depend "...also in part on the pitch of the voice. Different grades ('loud', 'half-loud', 'strong', 'weak', etc.) are commonly indicated....(p. 35)" Several degrees of stress are necessary to distinguish English words. About the only departure from Jones's treatment of stress is that Bloch and Trager imply that several degrees of stress must always be indicated in order to distinguish English words, whereas Jones feels that though several degrees of stress may be perceived when a word is spoken in isolation, only two degrees of stress, stressed versus unstressed, must be discerned when words are spoken in fluent speech.

Juncture is also briefly mentioned. They note that "The three words nitrate, night-rate, and dye-trade illustrate three ways of joining sounds in the sequence -[ajt]- ." (p. 35). They note that the aim of a phonetic transcription is "...to record as accurately as possible all features of an utterance or a set of utterances which the writer can hear...." (p. 35).

H - Wells (1945), The Pitch Phonemes of English

Wells professes to have applied, "...to pitches...all the principles and methods of segemental phonemics." (p. 28) (Segmentation, bi-uniqueness, and no overlap are all supposed to apply to this analysis.) "There are four pitch phonemes, designated by Arabic numerals from 1 (lowest) to 4 (highest)." (p. 30). He proposes to use the technique of complementary distribtution, yet he is not bothered by the fact that:

> In proving the existence and distinctness of the four pitch phonemes by minimal contrast, we ought to consider the same string of segmental phonemes with minimally contrasting pitch contours imposed on it; but it is difficult to find one such string equally well adapted to two minimally contrasting contours. (p. 32).

He asserts that the pitch phonemes "are organized into meaningful sequences called pitch morphemes, which are the strict analogues of segmental morphemes composed of segmental phonemes." (p. 34). However, he does not state what these morphemes are or what meanings they may possibly carry, or for that matter how they can be reasonably compared to the segmental morphemes in view of the passage quoted above.

Wells follows Bloomfield's lead. He takes a group of 19 sentences (pp. 31-32) which presumably have meaning differences that are the result of different intonation morphemes. He transcribes these pitch "morphemes" by means of four numbered pitch levels[1] and he notes that these strings of numbers contrast. He therefore says that he has demonstrated a set of phonemic contrasts. However, the differences in meaning that Wells notes either follow from the deep structure of the

---

1. Ripman in 1922 used from three to five numbers to represent the pitch levels of syllables in a connected text. Ripman, however, did not make any claims about the phonemic nature of these pitch levels.

sentences or the emotional aspects of intonation. The phonetic reality of these number sequences is moreover rather dubious (c.f. chapter four).

Wells's study also contains some additional phonetic deficiencies. He notes that contour 231 is the most usual contour in American English (the unmarked breath-group) and that pitch phoneme 3 always occurs on the main stress. Nevertheless, he criticizes Palmer for relating pitch and stress. Wells also has no way of indicating rapid glides in pitch. This defect was corrected by the Pike and Trager-Smith "phonemic" analyses which, however, retained the four phonemic pitches that Wells uses in this paper.

<u>I - Pike (1945), The Intonation of American English</u>

The phonemic aspects of Pike's analysis are based on the premise that pitch contours are independent morphemes.

> English words have basic, intrinsic meanings...that are indicated only by the requisite consonants, vowels, and stress, and a context where such a meaning is possible; in that sense that lexical meaning is intrinsically a part of the word itself and not dependent on extraneous phenomena such as pitch produced by emotion.
>
> The intonation meaning is quite the opposite.... Rather than contributing to the intrinsic meaning of the word, it is merely a shade of meaning added to our superimposed upon that intrinsic lexical meaning, according to the attitude of the speaker.... In English, then, an INTONATION MEANING modifies the lexical meaning of a sentence by adding to it the SPEAKER'S ATTITIDE toward the content of the sentence (or an indication of the attitude with which the speaker expects the hearer to react). (p. 21).
>
> ...all speakers of the language use basic pitch sequences in similar ways under similar circumstances.
>
> In English, many intonation contours are explicit in meaning. Whenever a certain sequence of relative pitches is heard, one concludes that the speaker means certain things over and above the specific meanings of the words themselves. (p. 20).

Pike wishes to "...follow Bloomfield's attempt at a phonemic analysis of intonation...." and he has devised the "...mechanical details of a technique for discovering the contrastive levels of pitch of a system such as English contains." (p. 11)

Before we get involved with the significant details of Pike's analysis it would be well to point out that Pike does not find any contours that "are explicit in meaning". He usually does not even try to give the meanings of the contours that he describes in this book. When he does it is apparent that a particular contour never has a specific meaning. On page 51, for example, he gives four different sentences that illustrate the function and the meaning of one contour (contour 03-2). The contour has four different meanings in the four sentences. The only element common to the four different meanings is that they involve "supplementation" of some type. However, on page 53 the same contour implies a question[1]. Pike notes that, "meanings were very difficult to define--and are still subject to revision". (p. 2).

Pitch Levels

Pike describes intonation contours in terms of four pitch levels and two "pauses". The four pitch levels are relative levels and may vary from one person to the next, and may even vary in the speech of the same person from time to time. The pitch levels are numbered from 1 to 4; 1 corresponds to the highest and 4 to the lowest relative pitch. Pike notes that "this number is not an arbitrary one.... The four levels are enough to provide for the writing and distinguishing of all of the

---

1. The contour is a marked breath-group.

contours that have differences of meaning so far discovered.... A description in terms of five or six levels would leave many theoretically possible combinations of pitches unused." (p. 26).

Pauses

There are two "pauses" in this analysis. The "tentative" pause, [|]"... tends to sustain the height of the final pitch of the (preceding) contour" though there may be "occasional slight drift upward." The final pause, [||], modifies the preceding contour by lowering in some sense the normal height of the contour." (p. 31).

> The tentative pause tends to occur at all places where the attitude of the speaker includes uncertainty, or nonfinality. (p. 32).
>
> The final puase occurs where the speaker's attitude, at the time of pause, is one of finality, and for this reason occurs most often at the end of statements.
>
> Frequently, pauses in the middle of sentences separate large grammatical units such as clauses, or separate smaller units in such a way as to contribute to their internal unity. In the next illustration a routine pause separates clauses; in the second illustration the pauses...set off the units three plus two:

If	'Tom goes,	'I	will	'too
3-	°2-4-3/	2-4-	-4-3	°2-4//

'Two,	times	'three	'plus	two,	is	'ten.
°2-4-3/	4-	°2	°1-	-4-3/	3-	°2-4//

Pike is thus somewhat more explicit than Jones with regard to using pauses to clarify the "meaning" of a sentence.

Stress

> ...only one phonemic innate stress contrast can be demonstrated to exist in English, utilizing words which differ by stress,

> but have the same vowel and consonant phonemes....(i.e., word pairs minimally different by stress)
>
> ...no analysis of stress can be valid if it fails to account for its relation to intonation.... (p. 82).

Stress is directly related to intensity. (p. 83).

<u>Primary and Precontours</u>[1]

The intonation contour of a sentence can be divided into "primary" and "precontours".

> A stressed syllable constitutes the BEGINNING POINT for every primary contour; there is no primary contour without a stressed syllable, and every heavily stressed syllable begins a new contour.... The beginning of the primary contour will be shown by the degree sign [°] placed before the number of the pitch level. (p. 27)
>
> Immediately preceding the stressed syllable of a primary contour there will sometimes be one or more syllables which... are unstressed. These syllables may be called PRECONTOURS, and depend for their pronunciation on the syllables which follow them. (p. 29).

<u>On the Subdivision of Sentence Contours</u>

> A single contour is not necessarily exactly as long as a sentence. One sentence may have several contours.... (p. 20).
>
> When a phrase becomes quite long, the contour may be subdivided, since a long contour is somewhat awkward to pronounce; sometimes contours may be spread out over long sequences of syllables without being subdivided; at other times the stresses and arrangement of words cause even a five syllable phrase to be divided. (p. 24).

Pike in the first part of his book apparently uses the term "contour" to mean the actual acoustic pitch contours that occur when a speaker

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1. Pike's treatment of precontours is rather like the treatment of the unstressed syllables at the start of Tune I or Tune II by Jones and Armstrong and Ward. The ptich of these syllables follows the pitch a of the start of the Tune that follows. Palmer and Kingdon adopt the same treatment for their "heads" and "tails" which occur on unstressed syilables.

utters a sentence. On page 34, however, Pike suddenly redefines "contour" to mean a potential pitch contour that could occur if a speaker produced a primary contour on each stressed syllable. Pike then uses the term "rhythm unit" to mean what "contour" used to mean before page 34, i.e., the pitch contours that the speaker acutally produces. The presentation is rather confusing since Pike does not indicate that he has redefined "contour" to mean a potential rather than an actual pitch contour.

> English sentences are spoken with recurrent bursts of speed, with long or short pauses or with intonation breaks between. A sentence or part of a sentence spoke with a single rush of syllables uninterrupted by a pause is a RHYTHM UNIT. (p. 34).

> Potentially a rhythm break may occur after the end of any word at all, but the potential after a primary contour is much stronger than elsewhere. A slightly slower rate of utterance will often break a complex rhythm unit into two simple units, even without a marked change of the speaker's attitude or attention, simply by introducing a pause after the first primary contour. In general, pauses can be introduced elsewhere in the sentence only when the speaker changes his attitude, or speed, or emphasis quite sharply. (p. 37).

The only significant difference between Pike's discussion of "rhythm units" and "primary contours" and Jones's treatment of "breath-groups" and "sense-groups" (aside from the fact that Jones is much clearer and does not pretend to be giving a "phonemic" solution) is that Pike stresses the point that there are preferred ways of dividing a sentence into breath-groups.

Vocal Quality

Pike also discusses "other intonation characteristics that may be affected or caused by the individual's physiological state -- anger, happiness, excitement, age, sex and so on." (p. 20).

> Excited speech tends to use WIDE INTERVALS between the pitch levels of the intonation contours. Monotonous, weary, or professional style tends to utilize NARROW INTERVALS. Excited speech tends to be relatively FAST, whereas deliberate, or whining, or grief-filled speech tends to be relatively SLOW. Excited speech, further, tends to be HIGH in general pitch or KEY, whereas grief or scorn tends to be LOW. (p. 100).
>
> In general, a qualitative characteristic is applicable to an entire utterance, or series of utterances, or even to one's entire speaking time. This is quite different from an intonation contour which is usually limited to a short phrase. (p. 100).

The two most significant aspects of Pike's analysis are his isolation of the "pauses" that occur at the end of "rhythm units" and his drawing attention to the fact that the acoustic modifications that reflect emotion affect the entire utterance rather than part of it. It is rather surprising that Pike did not notice the similarities between his analysis and the Tunes I and II, Armstrong-Ward analysis.

<u>J - Wells (1947), Immediate Constituents</u>

In this paper, Wells makes the point that the "pitch morphemes" also have the function of indicating the immediate constituent structure of the utterance. He notes that:

> One can be sure that any segmental morpheme which ends the scope of a pitch morpheme also ends a constituent (or else the whole utterance); but it is not always true that the beginning of the scope of a pitch-morpheme similarly coincides with the beginning of a constituent (or of the utterance). If, in our orthography, we marked a parenthetical expression by placing a closing parenthesis) at the end but no corresponding opening parenthesis (at the beginning, we should have a parallel to the manner in which the beginning and end of the scope of a pitch-morpheme may be said to mark the limits of a constituent.

The "scope" of a pitch morpheme is the sequence of segmental morphemes that it is supposed to modify. The purport of this paper

Pike notes that there are potential pitch contours that may be realized by a speaker to make the meaning of a sentence clearer. Wells notes that these potential pitch contours are tied to the structures, that is the immediate constituent analysis of the superficial phrase marker. However, he still allows for some variation and uncertainty in the way that the pitch contours signal the immediate constituent structure to the listener. Smith and Trager, however, tie the pitch contours directly to the immediate constituent structure. They imply that these pitch contours are always physically realized. The suprasegmentals always provide "acoustic" cues that tell the listener how to divide the sentence for syntactic analysis. The Trager-Smith analysis of intonation is thus the logical extension of Bloomfield's hunt for "objective" facts. The "objective" facts have been related here to the level of immediate constituents.

In chapter five we briefly reviewed the results of an experiment (Lieberman, 1965) that demonstrated that the pitch levels and stresses of the Trager-Smith system often have no physical basis. The linguist acquainted with the system may fill in the pitch and stress notation that is appropriate for the immediate constituent analysis of the utterance that he hears. He determines the phrase structure of the utterance through the words of the message rather than through any special phonetic cues.

The great value of the Trager-Smith analysis is that it correctly noticed that the intonation of an utterance could reflect its immediate constituent structure. Wells had noticed this, and Trager and Smith refined the segmental analysis of intonation, but they went too far.

The "phonemic clause" was defined in terms of the segmental pitch phonemes that were used to transcribe an utterance. As we noted in chapter four, breath-groups can delimit the constitutent structure of a derived phrase marker. Under the conditions that we discussed in section A-2 the division of a sentence into breath-groups can aid in the recovery of the deep phrase marker when the sentence would be ambiguous if the derived constituent structure were not manifested. The situation is quite parallel to the use of commas in the orthography

Trager and Smith saw that the intonation patterns of certain utterances could change their "meanings". However, since the notion of an underlying phrase marker does not occur in their grammar, they assumed that the difference in meaning somehow was part of the intonation itself. Since intonation contours can have many different meanings it must be possible to form many different intonation "morphemes". It obviously would be absurd to say that Tune II has, for example, 50 different "meanings". Hence there must be many pitch "phonemes" that can be concatenated into many pitch "morphemes". Unfortunately, the only elements of the Trager-Smith system that do seem to have a reasonably consistent physical basis are the "morphemes" 231# and 232// (or 232/) which are equivalent notations for the unmarked breath-group and the marked breath-group.

The distinction that Trager and Smith draw between pitch levels and stress levels is in a sense justified since the segmental pitch "phonemes" serve as a notation for the suprasegmental "phonemic clauses". The phonemic clauses really reflect the potential division of the utterance into breath-groups, whereas the stress levels reflect prominence (+P_s) and the subordination principle (c.f. chapter six). Thus insofar as the stress and pitch levels reflect the segmental feature [P_s] and the suprasegmental breath-group they relate to features that are far apart in the hierarchy of phonologic features.

Recent Non-"Phonemic" Analysis

L - Harris (1944), Simultaneous Components in Phonology

In this study, Harris attempted to analyze intonation in terms of suprasegmental morphemes at a time when many other linguists were attempting segmental analyses. Harris, like Bloomfield, states that intonation contours are morphemes,

> ...pitch and stress have been found to constitute the elements of special morphemes...they constitute morphemes by themselves independent of the rest of the speech with which they are simultaneous. (p. 182).

However, in contrast to the theories of Pike, Wells, Trager and Smith, these morphemes are clearly suprasegmental:

> ...the pitch sequence is a single component whose length is that of a whole utterance or phrase. (p. 190).

Harris offers no procedures whereby these "special morphemes may be identified. He notes that

> ...the components described in this paper are not complete physical events; therefore they cannot actually be substituted for each other to see if any two of them are free variants or repetitions of each other. (p. 201).

The intonation morphemes, in other words, can not be separated from the lexical contexts with which they are supposed to be simultaneous.

M - Stetson (1951), Motor Phonetics: A Study of Speech Movements in Action

In this work Stetson believes that he can study "the movements of speech" without regard to their linguistic function. Stetson comments,

> Motor phonetics is the study of the skilled movements involved in the process of handling articulatory signals. Motor phonetics deals with theorganized series of actual syllables or nonsense syllables shaped by the language mechanism. "Phonetic" refers to such physiological processes in the study of the signals of a language independent of the meaning of the signals. (p. 6).

However, one could reasonably argue that Stetson was studying the phonologic component of French and English since he did confine his study to the words, phrases and admissable "nonsense syllables " of these languages. The principal difficulty with this interpretation is that Stetson pursued his investigation without regard to any linguistic frame of reference and so it is sometimes difficult to see whether he is discussing a significant aspect of the language or some idiosyncracy of the particular speaker.

Stetson attempts to develop a consistent physiological model for the production of the suprasegmental aspects of speech. The basis of this physiological model is Stetson's view of the physiology of the lungs. He apparently believed that the chest was similar to a hand bellows. He believed that when the chest was inflated the air in the lungs was not under pressure in the absence of the activity of the muslces between the ribs (the intercostal muscles). He comments:

> When the chest is slightly infalted for speaking, the air is not under pressure; like a hand bellows for blowing a fire, the volume is increased, but the nozzle is open and there is no flow of air....
>
> If one makes quick strokes of the hands while holding the inflated

air bellows, the nozzle emits little pulses of air; as the quick strokes are repeated the air pulses reduce the volume of the air, and the arm muscles must bring the boards of the bellows closer and closer to accomodate for the loss of air.

In much the same way the vocal apparatus makes a series of vowel syllables, "Oh, Oh, Oh...." The chest is inflated by the larger muscles, the quick strokes for each air pulse are made by the short muscles between the ribs, and as the chest volume gets less and less, the larger outside muscles and the abdominal muscles accomodate the walls and floor of the chest to the changing volume.

The muslces between the ribs (intercostals) produce the syllables "Oh, Oh, Oh...." as units included in the slower movement of the breath-group which is made by the larger muscles of the chest and abdomen. The rapid muscle contractions (of the intercostals) are like ripples of the wave of the expiratory movement of the breath-group. (pp. 1-2).

Stetson's physiologic model is unfortunately erroneous. The air in the inflated lungs <u>is</u> under pressure. The elastic recoil force that is generated by the distended walls of the chest is the primary motive force for expiration (c.f. chapters one and three). Indeed the loss of elasticity by the walls of the chest is one of the pathologic conditions that characterizes Pulmonary Emphysema where the patient has difficulty in expiration[1]. The function of the intercostal muscles is moreover in doubt. It is not even clear whether they are expiratory muscles (Agostoni, 1964). Even if they were expiratory muscles, and even if a peak subglottal air pressure occurred on each syllable when it was produced as part of a string of stressed syllables, it would be difficult to ascertain which muscles contracted to produce the peak pressure without extensive data on the entire respiratory muscle complex and the alveolar air pressure and lung volume. Stetson's measurements of gastric pressure

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1. Dr. Jere Mead, Harvard School of Public Health.

can not be accurate measures of the pressure of the air in the lungs as he claims. He does not compensate for the effects of the elastic recoil force on the pleural pressure since he apparently did not know how the respiratory system normally functions. The only aspect of Stetson's theory that seems to have a firm basis is the subglottal air pressure function that is associated with the breath-group, i.e., a positive air pressure function that is normally associated with an expiration bounded by inspirations. Stetson's physiological definition on the breath-group,

> The breath-group is an abdominal movement; the driving rectus and parietal muscles of the abdomen reciprocate with the diaphragm and the thoracic muscles. This movement groups the syllable pulses and adjusts the chest-abdomen to the slight reduction in volume due to the outgo of the chest pulses. (p. 32).

is wrong since the elastic recoil force of the lungs actively reduces the volume of the lungs during expiration.

Stetson's study is, in short, misleading in its conception of the articulatory maneuvers involved in inspiration and the production of speech. Its data also is often erroneous. Its principal value lies in the fact that it focused some attentioned on the linguistic role[1] of subglottal articulatory maneuvers.

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1. Twaddell (1953), in an interesting paper, attempts to define the Trager-Smith junctures and other transitions in terms of Stetson's model. He states, for example,

> "The first step is to define pause with utmost rigor as an inspiration." (p. 438).
>
> "The preinspiration transitions /#, || / are produced by characteristic actions of the abdomen - diaphragm musculature...."

"With /+/ the controlling mechanism is the intercostal musculature." Twaddell defines other transitions in terms of the "internal intercostal action" and the "external intercostal action", etc. (p. 441). Twaddell essentially uses a binary notation for these definitions which are based on Stetson's incorrect model.

N - Bierwisch (1965), Regeln für die Intonation deutscher Sätze

Bierwisch, in a recent study of German sentence intonation that to some degree complements our study, demonstrates that it is possible to generate an intonation contour for a German sentence if only the superficial syntactic structure, primary accents, and "syntactic intonation markers" (SIM) are considered. Bierwisch defines intonation in terms of the perceived pitch contour of the utterance. He notes that the fundamental frequency of the utterance is the primary acoustic correlate of intonation. Bierwisch's study is similar to our analysis and he believes that accent, i.e., stress, is an abstract characteristic of the sentence that is determined by its derived phrase marker.

The syntactic intonation markers include Question and Emphasis morphemes. Boundary symbols are introduced that always mark the end of sentences and can mark the ends of clauses within the sentence. The potential points at which boundary symbols can be located are determined through algorithms that take account of the derived constituent structure and the distribution of accented vowels. These algorithms place some necessary restrictions on the division of a sentence into breath-groups.

Bierwisch uses the boundary symbols, the primary accents, and the SIM to generate a linguistically determined intonation contour which he carefully differentiates from the possible emotional aspects of intonation in marked contrast to the Trager-Smith and Pike analyses. By means of a complex set of segmental rules Bierwisch in essence generates a breath-group between each set of boundary symbols.

The breath-group extends over the entire sentence if no boundary symbols occur within the sentence. If the sentence has several boundary symbols then it is divided into several breath-groups. The presence of the Question SIM essentially marks the breath-group. Bierwisch notes that it results in a pitch rise at the end of the sentence.

Bierwisch transcribes his breath-groups by means of a pitch contour that ascends and descends in a number of steps. Each step occurs on an accented syllable. In effect, Bierwisch is using a phonetic transcription that is not unlike Jones's (1932). He connects the stressed syllables by means of horizontal and vertical lines.[1] However, he does not claim that the fundamental frequency of the speech signal is a series of discrete steps. He notes that the phonetic transcription is not equivalent to the output of the articulatory apparatus. He instead regards it as an input to a universal articulatory theory which also accepts the emotional state of the speaker as an input. Bierwisch thus does not actually generate the acoustic output signal though his phonetic output is transcribed as a pitch contour. Since Bierwisch notes that the fundamental frequency is the primary acoustic correlate of perceived pitch it would be less confusing if he used some measure other than pitch for the transcription of his phonetic output.

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1. This phonetic transcription was motivated by a psychoacoustic study by Ĭsacenko and Schädlich (1963), who synthesized intonation contours in terms of small frequency steps with a Vocoder. The experimental procedures of this study make it difficult to evaluate its results. It is not quite clear whether the psychoacoustic data is statistically significant or whether the responses are meaningful since the listeners were essentially asked to discriminate between sets of signals rather than to categorize them, c.f. chapter six for a discussion of categorization versus discrimination.

Bierwisch considers the effects of emotion on intonation and he considers the possibility of generating special intonation morphemes in the base component of the grammar. He correctly concludes that this course is inadvisable. Emotion affects all aspects of speech production. If we include rules for emotion in the deep structure we would also have to include an entire repertoire of "emotional phonologic features" as well as optional emotional syntactic rules to account for the deletions and insertions that are characteristic of certain emotional styles. Bierwisch instead correctly proposes that the effects of emotion be superimposed on the phonetic output of the grammar.

Bierwisch preserves the fact that the scope of the breath-group is suprasegmental since the boundary symbols delimit the constituent structure of the derived phrase marker. However, he does not explicitly use the breath-group as a phonologic feature. The position of each "pitch step" in the contours that Bierwisch generates by means of his segmental rules may, or may not be, syntactically determined. The data presented in chapter three and the studies of Cowan (1936), Denes (1959), Uldall (1960) and Hadding-Koch (1961) suggest that these small variations often have no syntactic significance. In any event, these variations probably should be treated as departures from the breath-group. Bierwisch indeed discusses this possibility. The incorporation of the feature breath-group into his analysis would greatly simplify its phonologic rules.

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