**Title**
WPP, No. 3: Some Phonetic Specifications of Linguistic Units: in Electromyographic Investigation

**Permalink**
https://escholarship.org/uc/item/93q328tn

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**Publication Date**
1965-10-01

# some phonetic specifications of linguistic units: an electromyographic investigation

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October 1965


Some Phonetic Specifications of Linguistic Units:
an Electromyographic Investigation

by
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Finally, I would like to express my deepest appreciation and thanks to my husband, Jack and my son, Mark for their never-failing understanding and support of my efforts.

# CHAPTER I

## PHONETICS AND PHONOLOGY

A. <u>Introduction</u>

The aim of the research described in this thesis was to improve the precision with which certain categories of speech sounds may be described. From the time that de Saussure differentiated phonetics, as part of the science of 'parole', from phonology, part of the science of 'langue', many linguists have considered objective phonetic descriptions outside the scope of linguistics. It is contended here that such an approach contradicts the existence of linguistics as an empirical science.

This introductory chapter attempts to demonstrate that 1) while differences of opinion among linguists, have existed, and still exist, regarding the relation of phonetics to phonology, a phonetic base underlies all phonological analyses; 2) this phonetic base assumes the existence of universal phonetic categories which should be stipulated by a universal phonetic theory; 3) while the units of the theory may be abstracted from the data of any stage of the speech act, since speech is basically a physiological process, the features should be physiological in nature; 4) the validation of the theory can only be accomplished by relating the abstract units of the theory

to the empirical, observable data of physical phonetics; and 5) while impressionistic descriptions of the phonetic features do not satisfy the criteria laid down by science, it is now possible to provide rigorous specifications by means of instrumental research methods.

## B. Historical Background

The finiteness of the human being and of the general range of his activities is strongly conducive to the belief that the range of speech sounds of which he is capable is limited no matter how large it may be. This belief underlies the widespread acceptance, implied or explicit, of the idea of a universal phonetic theory. But all linguists do not support such a view. Nor is there agreement among linguists as to the nature of the relationship between phonetics and phonology. To understand some of the problems involved, it is advisable to consider the historical background of the problem.

The belief in universal phonetic categories is by no means recent. In 1686 Francis Lodwick published an article titled "An Essay Towards an Universal Alphabet" in which he stated that his aim was "to provide an alphabet which should contain an Enumeration of all such Single Sounds or Letters as are used in any Language." (Abercrombie 1949,6)

Two centuries later Ferdinand de Saussure, said to be the founder of modern Linguistics, also showed a definite interest in defining universal principles. The sphere of linguistic study as defined by Saussure should include the determination of

> the forces that are permanently and
> universally at work in all languages...
> (de Saussure, 6).

He was probably the first linguist to differentiate phonetics as the study of 'parole' from linguistics, the study of 'langue'. He viewed the total speech act as four stages: 1) production of a vocal sound by a speaker; 2) the acoustic reception of the sound resulting in a sound-image; 3) the linking of the sound image with the mental concept of an object; 4) the real object itself. (68-70) The study of the first stage he called 'phonology' (phonetics) and considered it "an auxiliary discipline (belonging) exclusively to speaking". (33) He considered the main province of language and the central concern of linguistics the relationship between stages two and three. The sound-image, which he called the signifier ('signifiant') unites with the concept, the signified ('signifié') to form the linguistic sign.

> The latter (is) not the material sound, a
> purely physical thing, but the psychological
> imprint of the sound, the impression that it
> makes on our senses. (66)

This has been interpreted by some linguists to mean that according to Saussure phonetic reality -- the material sounds -- has no relation to the linguistic sign. Such an interpretation fails to recognize that the sound-image is the imprint of a sound, which is a material thing. And the sound, which Saussure called a 'phoneme' (now called 'phone')

> is the sum of the auditory impressions
> and articulatory movements, the units
> heard and the unit spoken, each conditioning
> the other. (40)

While he considered language "a system of pure values" (111) the two elements which are involved in its functioning are ideas and sounds. Both must be included.

> Language can also be compared with a
> sheet of paper: thought is the front
> and the sound the back; one cannot cut
> the front without cutting the back at
> the same time; likewise in language,
> one can neither divide sound from thought
> nor thought from sound; the division could
> be accomplished only abstractedly...(113)

While Saussure maintained that the speaker has unlimited freedom in regard to articulation of individual sounds (51) he asserted that restraints are imposed by the joining of two sounds.

> We must bear in mind the possibility of
> linking articulatory movements. To give
> an account of what takes place within
> groups, there should be a science of
> sound that would treat articulatory
> movements like algebraic equations...
> Whereas traditional phonology (phonetics)
> generally gives rules for articulating
> all sounds -- variable and accidental
> elements of languages -- and stops there,
> combinatory phonology limits the possibilities
> and defines the constant relations of
> interdependent phonemes. (emphasis mine)
> (51)

The notion that a universal phonetic theory must include the restrictions on the combinations of phonetic features is still accepted today. (Chomsky 1964, Ladefoged 1965) These restrictions are obviously based to a great extent on the physiological limitations of the vocal mechanism, which is the same for all men. Regarding the suggestion that a speaker has "unlimited freedom" Saussure presented what could be interpreted as a contradictory opinion:

> In a phonational act, the one thing which
> has a universal character that places it
> above all the local differences of its
> phonemes is the mechanical regularity of
> the articulatory movements. (51)

This mechanical regularity imposes restrictions on the speech sounds which can be produced. These restrictions, in turn, form a basis for establishing universal phonetic categories.

It is not being suggested here that the phonetic

substance of 'parole', the individual acts of speaking, is included as part of Saussure's linguistic model. Rather, it is suggested that the phonetic reality is the substance from which the sound-image is abstracted, and that he based his abstractions on observable phenomena. In this sense, phonetics to Saussure was not unrelated to linguistics. Saussure's deep interest in phonetics is best revealed by the three lectures which he gave in 1897 on the Principles of Phonology, which form the appendix of his Course in General Linguistics.

Rulon S. Wells (1951) has pointed out that different followers of Saussure have interpreted him quite differently. Both Hjelmslev's Glossematics, and the Prague School can be considered direct successors to his ideas. Yet, the theories of Jakobson and Troubetzkoy, founders of the Prague School, contrast sharply with those of Hjelmslev.

Hjelmslev elaborated on Saussure's statement that "la langue est une forme, non une substance" (Saussure, 122) and concentrated on the Saussurian conception of language as a system of values. He adopted with modifications the concept of the linguistic sign, calling the 'signifiant' the expression form, and the 'signifié' the content form. These two forms make up the two linguistic planes. Both the plane of expression and that

of content were divided by Hjelmslev into substance and form.  Hjelmslev considered the substance of either plane outside the scope of linguistics.  Following Saussure's statement that "language is a form not a substance" he interpreted this to totally exclude substance from linguistic analysis.  Phonetic descriptions belong solely to the substance of the expression plane.  Hjelmslev rejected the idea that a phoneme is a phonetic abstraction and stated that

> linguistics describes the relational
> pattern of language without knowing what
> the relata are but only by means of
> describing the relations between their
> parts and parts of their parts.
> (Hjelmslev 1947,75)

It is true that differences between phonemes may be stated, e.g. /p/ and /t/ in English, as in pin and tin, by merely stating that there is some phonetic difference which differentiates the meaning without specifying what the difference is.  But as Eli Fischer-Jørgensen (1952) pointed out

> ...the only reason for combining initial
> /p/ and final /p/ into one phoneme, and
> initial /t/ and final /t/ into another,
> and not, for instance, initial /p/ and
> final /t/, initial /t/ and final /p/
> will very often be a reason of phonetic
> substance...Without recourse to substance,
> one identification will be as good as
> another, and it will be impossible to
> proceed further.  (8)

Hjelmslev attributed his acceptance of the non-material

basis of the relata to Saussure.   Yet, reference to

Saussure would seem to contradict this view.

> The linguistic mechanism is geared to
> differences and identities, the former
> being only the counterpart of the latter.
> Everywhere then, the problem of identities
> appears; moreover, it blends partially
> with the problem of entities and units
> and is only a complication...of the larger
> problem.  This characteristic stands out
> if we draw some comparisons with facts
> taken from outside speech.  For instance,
> we speak of the identity of two '8:25 p.m.
> Geneva-to-Paris' trains that leave at
> twenty-four hour intervals.  We feel that
> it is the same train each day, yet everything
> -- the locomotive, coaches, personnel -- is
> probably different.  ...what makes the
> express is its hour of departure, its
> route, and in general every circumstance
> that sets it apart from other trains.
> Whenever the same conditions are fulfilled,
> the same entities are obtained.  Still,
> the entities are not abstract since we
> cannot conceive of a...train <u>outside its</u>
> <u>material realization</u>.  (emphasis mine)
> (Saussure 109)

Hjelmslev's total exclusion of phonetic substance from

linguistics led him to abandon "the old dream of a

universal phonetic system" which he believed "will remain

without any possible contanct with linguistic reality."

(Hjelmslev 1943, 77)

> ...linguistics must then see its main
> task in establishing a science of the
> expression and a science of the content
> on an internal and functional basis; it
> must establish the science of the expression
> without having recourse to phonetic or
> phenomenological premises...Such a linguistics
> ...would be one whose science of the expression
> is not a phonetics...(ibid 79)

It is hard to understand how such a theory would be

> capable of yielding, in all its implications,
> results that agree with so-called...
> empirical data. (ibid 14)

Hjelmslev attempted to explain this by making a sharp division between a theory and its theorems, and the hypotheses which are constructed from it. In his view, it is not the fate of the theory which depends on verification, but only the fate of the hypotheses. (ibid 14) The use of the word 'theory' in this sense is different from its usual use in science.

> A theory, in our sense, is in itself
> independent of any experience...It
> constitutes what has been called a purely
> deductive system...A theory permits us to
> deduce theorems...Such a theorem asserts
> only that if a condition is fulfilled
> the truth of a given proposition follows.
> In the application of the theory it will
> become manifest whether the condition is
> fulfilled in any given instance. (ibid 14)

In his attempt to make linguistics a theoretical science, Hjelmslev ignored the major concepts of the most highly developed theoretical sciences. Einstein (1934) pointed out that

> Pure logical thinking cannot yield us
> any knowledge of the empirical world;
> all knowledge of reality starts from
> experience and ends in it. Propositions
> arrived at by purely logical means are
> completely empty as regards reality. (14)

The attempt to make of linguistics a purely deductive science ignores the fact that

> in an imperfect science still in the
> process of being shaped (which branch of
> science can be said to be otherwise?)
> deduction...cannot lead to really new
> truths.  (De Broglie 1962, 204)

Hjelmslev went so far as to desavow any

> connection between sounds and language.
> (1935, 51)...The long supremacy of
> conventional phonetics has, moreover,
> had the effect of restricting the
> linguists' conception even of 'natural'
> language in a way that is demonstrably
> unempirical...It has been supposed that
> the expression-substance of a spoken
> language must consist exclusively of
> 'sounds'.  (1943, 104)

He then listed the other 'substances' in which language

form can be manifested, i.e. gestures, flag-waving, etc.

He concluded from this that the

> entities of linguistic form are of
> 'algebraic' nature and have no natural
> designation.  (ibid 105)

Consistent with this view, he did not call the units on the

expression plane 'phonemes' as this word implied to him a

certain phonetic value, but 'cenemes', i.e. empty units.

(ibid 49)

It is not the concern of this paper to argue the

question of the basic substance of language.  What is clear,

however, is that linguists who are concerned with a theory

which describes, explains, and predicts the facts of

spoken language can hardly accept such a position.  If

phonetic substance is totally divorced from linguistic

theory the result can only be an abstract calculus --
Hjelmslev's stated desire -- which is unrelated to the
empirical reality of spoken language.  Such a calculus
has no physical utility.

> Experience remains...the sole criterion
> of the physical utility of a mathematical
> construction.  (Einstein 1934, 18)

Hjelmslev's exclusion of phonetic substance went far
beyond even those linguists who would exclude physical
phonetics from phonology.  His theory has been discussed
at some length since it has bearing on the question of the
role of phonetic substance in linguistic theory which will
be discussed below.

Whereas the linguist Hjelmslev excluded the study of
phonetics from the sphere of language, the phonetician
Henry Sweet believed that the study of phonetics was
inseparable from the study of language.  In a letter to the
Vice Chancellor of Oxford University in 1902 he wrote:

> My own subject, Phonetics, is one which
> is useless by itself, while at the same
> time it is the foundation of all study
> of language whether theoretical or
> practical.  (as quoted by Firth 1957, 95)

Troubetzkoy, another follower of Saussure's, took
issue with Sweet's viewpoint.

> ...there are...linguists who may
> recognize the difference between
> distinctive and nondistinctive oppositions
> of sound, but who nevertheless do not want
> to separate phonology from phonetics.
> (Troubetzkoy 1939, 9)

He referred here particularly to Sweet and to

Jesperson. Following Saussure, he recommended the

separation of the studies of sound into two disciplines:

> We designate the study of sound of the
> speech event by the term p h o n e t i c s, the
> study of sound of the system of language by
> the term p h o n o l o g y....In accordance
> with their different subject matter, both
> branches of the study of sound must use
> quite different methods for investigation:
> the study of sounds of the speech event
> which is concerned with concrete physical
> phenomena must use the methods of natural
> science, the study of sound of the system
> of language, on the other hand, purely
> linguistic methods or the methods of social
> sciences. (8)

Like Saussure,Troubetzkoy viewed

> the system of language as a social
> institution (which) constitutes a world
> of relations, functions, and values; the
> speech event, on the other hand, a world
> of empirical phenomena. (ibid 15)

But, unlike Hjelmslev, Troubetzkoy never divorced

language from its phonetic base. He pointed out that

> ...speech events and system of language
> presuppose one another. They are
> inseparably linked to each other and can
> be considered as two interrelated aspects
> of the same phenomenon 'language'. (ibid)

In practice, if not in theoretical statement, the

phonetic basis of Troubetzkoy's phonology is apparent.

Phonemic contrasts were classified primarily on the basis of phonetic articulatory criteria; Troubetzkoy's classification system served as the basis of the later development of the theory of distinctive features. He divided phonemic oppositions into three groups: those which show the presence vs. absence of a phonetic feature; those which are gradual, showing different degrees of the characteristic of the feature; and those which oppose one feature against another different feature, such as the different points of articulation. These are <u>phonetic</u> <u>features</u>, which play a functional distinctive role in the linguistic system. At the same time that he employed such universal phonetic categories, he stated that

> the articulatory movements and their
> corresponding phonations which occur in
> the different speech events, are
> infinitely varied, but the sound norms
> which make up the units of the significant
> aspect of the system of language are finite
> (enumerable) limited in their number. (8)

Since the sound norms are phonetically based, these norms form the basis for the phonetic categories which Troubetskoy uses. Certainly his classificatory system assumed such universal categories. Even a cursory perusal of Troubetzkoy's volume demonstrates that he was constantly concerned with the phonetic specification of his phonological units. He, more than many others, included phonetic grounds for phonological decisions.

For example;

> ...looking at the typical cases of
> monophonematic interpretation of
> consonant combinations, it is easily
> noticed that a gradual diminution of an
> articulatory complex is always involved.
> In the case of affricates, an occlusion
> is first widened, extended to a stricture,
> and finally completely suspended; in the
> case of aspirates the oral closure is
> exploded, the larynx, however, still
> remains for some time in the position it
> had during the oral occlusion, and this
> has as an acoustic consequence the
> prolongation of the aspiration...All these
> cases involve a uniform articulatory
> movement in the same direction...A sound
> combination such as st, on the other
> hand, can never be considered as
> monophonematic because it involves the
> gradual formation of subsequently dissolved
> occlusion.  A combination such as ks
> also cannot be considered as monophonematic
> because it requires two different
> articulatory movements.  (74)

Analyses such as the one cited leave no doubt as to
Troubetzkoy's reliance on phonetic reality.

Much of the approach of the other Prague School
linguists stems from this major work of Troubetzkoy's.
Certainly Jakobson's distinctive feature theory of
phonology shows a direct lineage.  And Jakobson is very
explicit regarding the important bearing that phonetic
facts have on linguistic phonemic structures.  Jakobson
and his student and collaborator Morris Halle
differentiated phonetics from phonemics, but they placed
as the crucial question

> the nature of the relationship between
> phonological entities and sound (Jakobson
> and Halle 1956, 8) (stating that) the
> immanent approach, which locates the
> distinctive features and their bundles
> within the speech sounds, be it on their
> motor, acoustical or auditory level, is
> the most appropriate premise for phonemic
> operations, although it has been repeatedly
> contested by outer approaches which in
> different ways divorce phonemes from
> concrete sounds. (8)

They criticized sharply Twaddell's view of phonemes

as "abstractional, fictitious units" (13), and the

"algebraic" view which "aims at the maximal estrangement

between phoneme and sound, or correspondingly, between

phonemics and phonetics". (15) They disagreed with

Hjelmslev's attempt to

> reduce language to its ultimate invariants,
> by means of a mere analysis of their distri-
> bution in the text and with no reference to
> their empirical correlates

which they believed "is condemned to failure". (ibid 15)

This criticism could apply equally to Harris's analysis of

simultaneous components which he called "primarily

distributional rather than phonetic." (Harris 1942, 183)

Harris, however, unlike Hjelmslev did consider "precise

phonetic data" as "relevant to phonemic discussion"

(Harris 1951, 47), but considered such data relevant "only

when phonemic distinctions are being established." (ibid)

Martinet is another structuralist successor of

Saussure who explicitly stated his acceptance of the

the close reliance of phonology on phonetics.

> The aim of phonological analysis is to
> identify the phonic elements of a language
> and to classify them according to their
> function in that language. (Martinet 1964,
> 53)

His position may be summarized by the following:

> When we speak of phonology as functional
> phonetics, and when we say that a linguistic
> description made on a phonological basis
> need not be more schematic and go less
> into details, we do not mean to blur the
> limits between the functional, phonological
> treatment and purely objective observation.
> What we mean is that phonology is to provide
> the frame in which all observable facts
> may find a place. (Martinet 1955, 21)

As has already been demonstrated, Saussure's work has had a profound influence on almost all of the modern schools of descriptive linguistics. Leonard Bloomfield, whose work has been the dominant force in American linguistics up until the last ten years, was certainly influenced by the Genevan linguist. Bloomfield, however, rejected the 'mentalism' of Saussure, which he considered unscientific and replaced it with a mechanistic behaviorism. Central to the idea of behaviorism is the conviction that a scientific study must be based on that which is overtly observable. The fact that the defects in the mechanistic view had become appparent long before Bloomfield had adopted this view is outside the scope of this paper. But what is of interest is the seeming contradiction between Bloomfield's acceptance of

behaviorism and his stated rejection of the importance of
phonetic data. He was also of the opinion that

> the physiologic and acoustic description
> of acts of speech belongs to other sciences
> than ours. (Bloomfield 1926, 153)

He contrasted phonetics which "gives us a purely
acoustic or physiologic description" revealing "the gross
acoustic features" of speech, with phonology which

> pays no heed to the acoustic nature of
> the phonemes, but merely accepts them
> as distinct units. (1933, 137)

Yet, Bloomfield's work is another example of an avowed
rejection of phonetic data with a practical reliance on
such data. He defined a linguistic form as "a phonetic
form which has a meaning". (ibid 138) While he believed
that a "record in terms of phonemes" should ignore "all
features that are not distinctive in the language" (ibid 85),
this in itself does not deny the phonetic character of those
features which are distinctive. This concurs with Saussure's
approach as well as that of Troubetzkoy, Jakobson, and
Martinet. Furthermore, Bloomfield stated that "any combin-
ation of phonemes that occurs in a language, is pronounce-
able in this language, and is a phonetic form." (emphasis
mine) (ibid 139) Pronounceable phonemes must be
manifestations of phonetic reality.

The only major group of linguists to overtly resist the
influence of Saussure has been the British school founded by

J. R. Firth.  Firth rejected the separation between 'langue'
and 'parole' (1957, 182), and whereas Saussure believed that
linguistics should deal with 'langue', Firth stressed the
"importance of the study of persons, even one at a time."
(ibid 183)  He believed that

> A context of situation for linguistic
> work brings into relation the following
> categories:  A.  The relevant features
> of participants:  persons, personalities.
> (i)  The verbal action of the participants
> (ii)  The nonverbal action of the participants.
> (ibid 182)

A linguistics which deals with 'parole' must place
great reliance on phonetics.

> The theory of exponents, linking the
> phonic data phonetically described with
> categories of phonology and grammar, is
> a central necessity of linguistic analysis
> at congruent levels.  (1962, vi).

In discussing the work of the British linguists, Firth
pointed out that

> Phonological invention and ingenuity
> without linguistic phonetics,...is most
> unusual in this country, and all the
> techniques of phonetics are prominently
> used... -- perception, transcription
> with notation and diagrams, supported
> by instrumental findings.  (ibid)

The reliance on phonetic reality shows that there is
not total disagreement with the followers of Saussure; the
theory of Jakobson and Halle, however, represents a search
for universal phonetic categories by means of which all
linguistic sounds may be described, while Firth's approach

echoed Hjelmslev's non-belief in a universal phonetic
theory:

> Every analysis of a particular 'language'
> must of necessity determine the values of
> the <u>ad</u> <u>hoc</u> categories to which traditional
> names are given....What is here being
> sketched is a <u>general linguistic theory</u>
> applicable to <u>particular linguistic</u>
> <u>descriptions</u>, not a <u>theory of universals</u>
> for <u>general linguistic description</u>.  (ibid 21)

From this approach follows the idea that the
phonological elements in any phonological description are
theoretical abstractions, which have no pronunciation.
(Carnochan 1962, 158)  Only by specifying the exponents of
the elements for each language, and for each term, of each
different system in that language is it possible to make the
transition from the phonological to the phonetic level.

Firth and his followers emphasize the phonetic basis
of linguistic analysis, and do not draw the distinction
between what is distinctive and what is non-distinctive
in phonemic terms.  Thus Robins stated that

> Distinctive in the context of phonemic
> analysis often means capable of differ-
> entiating one word from another...the
> implication being that phonetic
> differences not serving such a purpose are
> functionally and phonologically
> irrelevant.  This implication is
> unjustified.  (Robins 1957, 7)

Such a position differs greatly from that accepted by
most linguists since Baudoin de Courtenay differentiated
between the phoneme and the phone.  The widely accepted

view is that in all languages certain phonetic features play
no functional role, and that the linguist has the task to
distinguish what is functionally relevant from what is not.
This position does not necessarily imply that redundant
(non-functional) features are unimportant. It means rather
that a distinction be made.

Firth's disavowal of a theory of universals and his
insistence on the ad hoc categories to be set up in describ-
ing individual languages means that the phonological units
are viewed as totally abstract. This makes it impossible
to describe all languages in a similar manner, except on
the lowest phonetic level. While the phonological units
are provided with phonetic content by virtue of the expo-
nency relationship, the units themselves are devoid of
phonetic reality. The recognition that each language selects
only a limited number of universal features and organizes
them according to its own system is no justification for
the denial of the universality of the features themselves.
And in fact, while Firth stated that he does not propose

> an a priori system of general categories
> by means of which the facts of all
> languages may be stated (1957, 144)

he did state that

> The descriptions of pronunciation in
> phonetic terms at the phonetic level
> only do not form part of a given
> language system, since the categories
> of phonetics are inter-lingual,
> 'international'. (ibid 145) (emphasis mine)

It would appear that Hamp (1962) was correct in his assertion that the history of linguistics demonstrates the fact that all linguistic theories assume a definite relationship between phonology and phonetics.  Even Hjelmslev, according to Fischer-Jørgensen (1964), "has recently admitted that the elements are set up by considering the interplay between form and substance." (9)

This view has received renewed support in the most recent linguistic theory developed by Naom Chomsky.  His grammatical model is viewed

> as a device for pairing phonetically
> represented signals with semantic
> interpretations (1964, 52).

The phonological component of the grammar "converts a string of formatives with a specified syntactic structure into a phonetic representation.  (ibid 82).  He is critical of all linguists who deny the necessity or the existence of universal phonetic categories proposing that

> a general linguistic theory must incorporate
> a universal phonetic theory, with a fixed
> alphabet, as the condition of <u>phonetic
> specifiability</u>.  (ibid 86)

Furthermore he has pointed out that

> Analysis of actual practice shows no
> exceptions to the reliance on phonetic
> universals. (ibid 92-93)

This last view is reiterated by Trnka (1964) who has stated that

> present day linguists have ceased to
> regard their materials as an incoherent,
> structureless collection of physiological
> phychological and sociological data, and
> search to discover universal principles
> underlying particular data of their
> special fields of research, in the same
> way as physicists do in the area of
> physical phenomena.

The position accepted here agrees with Chomsky
(1964) that "the status of systematic phonetics...is
beyond dispute" and further agrees that

> there is room for much discussion as to
> what is the actual character of the
> universal phonetic theory that underlies
> all descriptive practice.  (93)

## C.  The Nature of a Universal Phonetic Theory

A universal phonetic theory may be simply an alphabet
such as was proposed by Lodwick, which attempts to enumerate
all the possible phones which exist in the totality of the
languages of the world.  This has been essentially the
approach of the International Phonetic Association although
extra symbols and diacritical marks "by means of which many
minute shades of sound may be represented" (IPA 1) are
utilized.  These symbols represent not composite phones,
but phonetic features.  While such an inventory of sound
segments constitutes one form of classification, it is a
trivial one, lacking generality and simplicity.  Each
symbol must be interpreted -- given phonetic specificity.
Since many of the symbols have similar properties, this

would lead to great redundancy. Furthermore, such a classification fails in the scientific aim of reducing the number of primitive concepts to a minimum.

A natural classification of objects is based on the relevant characteristics of the things under investigation and groups together objects which possess fundamental similarities. In such natural classifications the determining characteristics are associated, frequently, with other characteristics of which they are logically independent.

For example, one possible classification of speech sounds could be based on grouping together sounds based on the number of languages of the world in which they occur. One might find that the p, s, and a are found in 900 languages, t, b, n in 857 languages etc. If the first three sounds were found simultaneously in the same 900 languages it is conceivable that one might conclude that the existence of one implies the others, and certain predictions would result. But if the classification is based only on the fact that each one occurs in a total of 900 languages, such a classification tells us nothing but a trivial fact. If on the other hand, we classified speech sounds based on certain phonetic features which they shared in common, i.e. p, t, b, d, k, g are classed as 'stops' by virtue of the fact that in the production of all of them a complete closure of two articulators occurs, other characteristics

may be predicted. This would constitute a natural classifi-
cation. (Halle 1961) In other words, the concepts by means
of which we seek to establish a 'natural system' are defi-
nitely chosen with a view to attaining systematic and not
merely descriptive import. An inventory of all sounds is
merely descriptive.

> The devising of a classification is, to
> some extent, as practical a task as the
> identification of specimens, but at the
> same time it involves more speculation
> and theorizing (for) a natural system
> ...is one which enables us to make the
> maximum number of prophesies and deduc-
> tions. (Huxley 1940, 20)

Halle (1961, 1964) has pointed out in a number of
articles that, historically, speech sounds have been class-
ified as belonging to logically intersecting classes, since
many different sounds share common properties. In 1932
Jakobson suggested that the segments which constitute dis-
crete linguistic units be viewed not as indivisible units
but rather as 'complexes of features'. (1962, 635-6)
If the universal phonetic theory selects as its units these
properties, or features, rather than the composites of the
features, 'the maximum number of prophesies and deductions'
should result. Scientists constantly search for maximum
simplicity of the conceptual construction. This simplicity
is to be understood as the reduction in number of the
logically independent basic elements, i.e. concepts and
fundamental hypotheses.

> Even if no additional observation could be
> quoted in favor of a new theory...given a
> free choice between two theories, we should
> have to decide in favor of the new one (in
> which) the equations are...from the formal
> point of view, more complicated, but whose
> assumptions are, from the point of view of
> fundamental principles, much simpler.
> (Einstein and Infeld 252)

Martinet (1960) presented another argument in favor of
utilizing distinctive features as the primitive elements of
the phonetic theory.

> In principle there is no reason why each
> phoneme of a language should not be dis-
> tinguishable from all other phonemes by
> an articulation _sui generis_. But in fact
> no language is known where all phonemes
> show this degree of specificity...Let us
> consider the case of a language which
> possesses twelve consonantal phonemes.
> If each of them had a specific articula-
> tion speakers would have to keep twelve
> articulations distinct. But if six artic-
> ulations can be combined with one of two
> different actions of the same organ, the
> twelve phonemes will now require only
> eight articulations to be kept distinct,
> each of the first six always combining
> with one of the other two....In so far as
> such combinations are easy for the speaker
> to produce and the hearer to identify they
> should represent a real advantage for the
> system: a given number of phonemes will
> thus require fewer articulations to be
> kept distinct. (195-196)

Reducing the alphabet of a universal phonetic theory
to a relatively small set of universal features or prop-
erties of speech sounds tends toward the desired simplicity.

1. <u>Physiological</u> <u>or</u> <u>Acoustic</u> <u>Features</u>?

One may accept as valid the proposals that a Universal

Phonetic Theory should select as its basic elements the
phonetic properties or features which form all speech sounds
without accepting the particular fourteen or fifteen fea-
tures which have been selected by Jakobson and others.
Since the speech act is a complex triplet, wherein articula-
tion and perception are bridged by acoustics, any stage may
be singled out for description. The chosen stage will have
definite bearing on the selection of features in the theory.
It is intuitively appealing to assume that articulatory and
acoustic descriptions must have some correlation with each
other. However, it is well known that such correlations as
do exist are neither simple nor unique. That is, given the
acoustic output it is impossible to predict uniquely the
geometric configuration of the vocal tract which produced
it. But you can tell these apart by the relative level of
the formants. There are also features present in the
acoustic output which are not perceived by the hearer. It
has also been pointed out that the acoustic signals are
seldom invariant with respect to different tokens of a
phoneme perceived as identical. The tripartite nature of
the speech process has resulted in differences of opinion,
historically, as to which aspect of the speech process (if
any) is best suited by itself for the description of speech
sounds.

The selection of concepts as fundamental is not

unambigously determined by their suitability to form a basis
for the derivation of observable facts.  Some element of
contingency is introduced by the somehow fortuitous sequence
of experimentation and observation.  This was emphasized by
James Bryant Conant (1955):

> It seems clear that the development of
> our modern scientific ideas might have
> taken a somewhat different course, if
> the chronological sequence of certain
> experimental findings had been different.
> And to some degree, at least, this
> chronology can be regarded as purely
> accidental.  (56)

There are fashions in science, and fashions in linguis-
tics, and a climate of opinion conditioned by subconscious
motives may be responsible to some extent for the specific
character of the basic concepts.

While one stage of the speech act may be selected to
provide the framework for phonetic description, the features
which are chosen as the primary units should provide for
the simplest and most revealing connections with all the
stages.  Such was Troubetzkoy's assertion:

> Either the purely physical, acoustic
> aspect, or the physiological, articu-
> latory aspect of the flow of sounds
> can be studied, depending on whether
> the object of study is the constitution
> or the production of sounds.  However,
> both aspects should be studied...the
> study of the nature and the production
> of speech sounds constitutes not two
> separate but one single task of phonetics.
> (13)

The goal of linguistic theory is to explain and predict the ability of speakers to both speak and to understand, to be simultaneously speakers and hearers. The features specified must therefore allow interpretation of all stages. To the extent that the theory fails to provide this, it fails to reveal the generalities sought.

In theory we are free to select the simplest number of fundamental concepts and the relations between them. Our freedom is not, however,

> like the freedom of a fiction writer, but
> rather like that of a person who has to solve
> a cleverly designed word puzzle. He may
> suggest any word as a solution, but there is
> probably only one which really solves the
> puzzle in all its parts. (Plank 1959, 140)

Malmberg has summarized some of the problems involved:

> ..the acoustico-phonetic analysis of the
> speech wave gives us a fairly exact physical
> description of the kind of stimuli which
> reach our hearing mechanism. Even the most
> complex speech-wave may be exhaustively
> described in terms of frequency, amplitude,
> and time. But such a description does not
> tell us anything about how these stimuli are
> transformed into auditory reactions, nor --
> and still less -- into perceived speech
> patterns. In a corresponding way, the
> physiological analysis of the speech mechanism
> may give a picture of the procedures used by
> man in order to produce the sounds in
> accordance with the social norm...A sound is
> an acoustic phenomenon and cannot be described
> in terms of tongue positions and lip rounding
> but must be described in terms of acoustic
> variables...But on the other hand, the shape
> of our speaking mechanism reduces considerably
> our possibilities to vary the production of
> sounds...And as the differences between

> people's speaking apparatusses are relatively
> small, articulatory variation is slight and
> ...the sounds used in a language are produced
> in a way which is fairly constant from one
> individual to another. (Malmberg 1963, 64-65)

The position adopted here is that the articulatory, or neurophysiological stage of the speech act is the one to solve the puzzle. Speech is basically a physiological process. This process produces the sounds, not vice versa. While one may uniquely predict the acoustic output given the shape of the vocal tract, the opposite is not the case. It is the physiological apparatus of man which is universal, and which constitutes the constraints imposed on combinations of sound features. As Ladefoged (1965) has pointed out in criticism of the Jakobson-Halle distinctive features, these features are inadequate because they generate too many phonetic categories. The reason for this is because they are based on auditory/acoustic criteria rather than physiological, which results in the difficulty of specifying the impossible combinations.

As has already been noted, this is not a universal view. Many factors have contributed to the choice made by different linguists throughout history.

The earliest descriptions of speech sounds made by the Hindu grammarians around the 3rd century BC were based on articulatory features, i.e. the positions and actions of the organs of speech. Succeeding descriptions up until the

development of the field of acoustics in the 19th century remained basically articulatory. With the work of Willis and Helmholtz and Bell, among others, in the 19th century, acoustic descriptions of speech sounds were attempted. However, it was not until the development of the sound spectrograph in the 1940's that full scale investigations of the acoustics of speech sounds were launched. By and large, with the exception of the last twenty years, the history of phonological theory is the history of articulatory specifications. In particular it can be noted that the phonetic descriptions employed by Saussure, Bloomfield, Sapir, Firth, and their followers up until the 1950's are articulatory. These descriptions were based on the shapes and positions of the organs of speech and are often highly impressionistic, not supported by experimental verification.

A break with the earlier tradition occurred with the publication of _Preliminaries to Speech Analysis_ by Jakobson, Fant, and Halle, and _Fundamentals of Language_ by Jakobson and Halle. The distinctive features 'the ultimate discrete components of language' are described primarily in acoustic terms. Jakobson and Halle (1956) singled out the auditory experience as

> the only aspect of the encoded message actually shared by the sender and the receiver...Since articulation is to acoustic phenomenon as means to effect, the classification of motor data must be made with reference to acoustic patterns. (34-35)

Halle (1956) reiterated this position:

> Speech evidently is a physical phenomenon, and the terms in which we describe it must...be translatable into the language of physics; e.g. into frequency, amplitude, phase relations of sine waves. (90)

This was a position apparently shared by Saussure:

> Many phonologists limit themselves almost exclusively to the phonational act, i.e. the production of sound by the vocal organs (larynx, mouth etc.) and neglect the auditory side. Their method is wrong. Not only does the auditory impression come to us just as directly as the image of the moving vocal organs, but it is also the basis of any theory. Auditory impressions exist unconsciously before phonological units are studied.....Even if all the movements made by the mouth and the larynx in pronouncing a chain of sounds could be photographed, the observer would still be unable to single out the subdivisions in the series of articulatory movements. (38)

But one may question a number of the assumptions. Since science is concerned with explaining phenomena, with finding causes which produce certain effects, the very reason that is presented by Jakobson and Halle for singling out the acoustic stage -- i.e. articulation is the cause, acoustic output the effect -- should lead to the opposite

conclusion.

Secondly, as to Saussure's position, he was discussing the segmentation of the utterance into discrete units. The point at issue here is not the 'discovery' of linguistic units but their specification. In this regard he stated:

> Delimitation of the sounds of the spoken chain can be based only on auditory impressions; but description of these sounds is an entirely different process. Description can be carried out only on the basis of the articulatory act. (38-39)

Thirdly, it is of interest to note that although Jakobson considers the perceptual aspect as the most important and believes that the acoustic stage is closest to perception, it was pointed out by Fischer-Jørgensen (1958) that

> ...most of the features seem to have been established on an articulatory-perceptual basis, and therefore the acoustic descriptions are often somewhat artificial. (476)

Another argument against the Jakobson-Halle position was raised by Lotz (1950). He took issue with the view expressed that the auditory aspect is the only aspect shared by both speaker and hearer.

> Since every member of a speech community can act as both speaker and as listener...(he) thus experiences the entire speech process. ...(It is possible) that the brain singles out one of the phases, e.g., articulation, and refers the other phases to this kinaesthetic phase. (712)

This is essentially the position adopted by Haskins

Laboratories.  They indicated that

> the relation between phoneme and articula-
> tion is more nearly one-to-one than is the
> relation between phoneme and acoustic
> signal...when articulation and sound wave
> go separate ways...the perception always
> goes with articulation.  (Liberman et al.
> 1962, 7-8)

This view echoes the one adopted by Paget in 1923:

> ...in identifying...particular consonant
> sounds, and probably also in identifying
> all speech sounds, the ear is primarily
> concerned in recognizing where and how
> the closure (or release) is made in the
> vocal cavity, rather than in identifying
> the actual resonance changes themselves
> ...human speech appears to be essentially
> a branch of human gesture, which the ear
> has learnt to identify...by means of its
> secondary effects in modifying the
> resonances produced by the passage of air
> by or through the gesticulating members
> of the vocal cavity.  (1923, 760)

In a later paper Halle presented what could be

interpreted as an argument against the acoustic basis of

phonetic features.

> (The fact that ) the assignment of phonetic
> interpretations to phonemic matrices is
> uniform for all languages reflects the
> fact that the articulatory apparatus of
> man is the same everywhere, that men
> everywhere are capable of controlling the
> same few aspects of their vocal tract
> behavior.  The phonetic features represent,
> therefore, the capacities of man to produce
> speech sounds and constitute, in this sense,
> the universal phonetic framework of language.
> (1964, 333)

Since it is this articulatory apparatus which is universal, it follows that the universal phonetic features should be based on physiological parameters.

Other reasons have been suggested for selecting the physiological stage of the speech act. Martinet based his reliance on the articulatory stage because he believed it revealed the causes of historical change.

> We shall identify the relevant phonic
> features and describe the various types
> of phonological units by reference to
> the way in which they are produced by
> the 'organs of speech'. We could utilize
> for the same purpose the sound waves
> produced by the action of these organs.
> But articulatory or motor phonetics...
> gives us a clearer insight into the
> casuality of phonetic changes. (1964, 47)

A detailed spectrographic and cineradiological study of dynamic aspects of vowel articulation by Bjorn Lindblom (1965) revealed that

> the acoustico-phonetic experimentation
> has demonstrated that the neat and
> simple organization of data at the
> acoustic level cannot be achieved unless
> we turn our attention to the preceding
> stages. (93)

Ladefoged (1958) suggested that certain aspects of speech can be described more simply in articulatory terms, rather than in acoustic terms. An example of this fact is that whereas

> stress can be associated with a pulse of
> muscular activity...analysis...by means
> of the sonagraph and other acoustic
> instruments does not reveal any acoustic
> features which are in a one-to-one
> relationship with the perceived stress.
> (48)

Ladefoged (1961) also pointed out that while the

acoustic quality of most vowel sounds "can be specified by

stating the frequencies of their first two or three formants"

this is not true of all vowels, particularly of the 'close'

or 'back' vowels. (82)

> It appears that no precise statements
> about the acoustic correlates of phonetic
> quality can be made....It is the relative
> and not the absolute values of the formant
> frequencies which convey linguistic in-
> formation. (90, 91)

The conviction that the articulatory facts furnish

sufficient data for discovering the relevant phonetic pro-

perties was stated by Delattre (1958):

> s'il existe un 'invariant' qui permette
> de distinguer un lieu d'articulation
> consonantique d'un autre, il est plutot
> dans le geste articulaire que dans le
> trait acoustique: la forme acoustique de
> la parole serait percue, non directement,
> mais indirectement par référence au geste
> articulatoire qui est le même pour plusieurs
> valeurs acoustiques différentes. (228)

It must be stated that the position adopted here does

not necessarily agree with all the reasons which have been

put forth for singling out the physiological stage of the

speech act as basic to any description.  For example,

Stetson (1927), based his argument on absurd assumptions:

> This assumption that speech is primarily
> a series of sounds is to be seriously
> questioned....The speech of the deaf and
> the 'lip-reading' show that sound is not
> essential to speech, that the process
> can occur without it.  (18)

What is maintained is simply that it is the physiologi-

cal processes which result in the sounds which are perceived

and that the basic physiology of the human being provides

the framework for the finite set of phonetic features which

combine to form all speech sounds.  The increase of acoustic

research, and the fact that speech can be synthesized by

acoustic parameters more easily than by articulatory para-

meters are not sufficient reasons for singling out the

acoustic stage of the speech act.  Particularly since

> The search for acoustic cues that would
> show a reasonable degree of invariance
> with respect to perception has a long
> and largely unrewarding history...
> (Liberman et al. 1965, 2.10)

The physiological stage may be further divided.

Recently the Haskins group has suggested that

> the simple correspondence with phoneme
> perception is not to be found in the
> conventional conceptions and descrip-
> tions of articulatory phonetics, which
> are concerned largely with the changing
> shapes of the vocal tract, but rather
> in the motor commands that actuate the
> articulators...the neural commands to
> the articulators will...provide the
> simplest relationship to phoneme per-
> ception.  (Liberman et al. 1962, 8)

This interesting hypothesis obviously requires experi-

mental verification or rejection.  It is to this question

that the research described below was directed.

D. <u>The Role of Physical Phonetics in the Verification of</u>
<u>Phonological Units</u>

The problem of selecting the features in a
Universal Phonetic Theory is not the same as the problem of
verifying the theory.  Once the features are chosen and
classified they must be provided with empirical content by
being related to the phenomena of physical phonetics.

It seems that there has been considerable agree-
ment among linguists that physical phonetics "the science
of the sounds of parole" should be excluded from phonolog-
ical theory.  Chomsky (1964), for example, does not question
the status of physical phonetics (92) but sees no reason
to consider it.  Similarly Saumjan (1964) believes that

> the difference between physical and
> systematic phonetics is clear and
> (therefore) need not be commented
> upon. (979)

The lack of consideration for physical phonetics
leaves open the question of what relationship, if any,
exists between physical phonetics and systematic phonetics.
Chomsky's model (1964) includes as the final level of a
grammar the level of systematic phonetics. (87)  The units
of this level are represented by a universal phonetic
alphabet which is part of a universal phonetic theory.
That is the end of the line.  A counterposition is proposed
here.  The total exclusion of physical phonetics is as
impossible as the exclusion of systematic phonetics.

That it need not be included in any specific grammar is not the point. The data of physical phonetics must be the starting point and the end point of any theory of universal phonetics.

A phonological theory, which includes a universal phonetic theory, consists of a set of hypotheses about the sound system of 'langue'. Similarly, the phonology of a particular language can be conceived of as an abstract model. But in the words of Bertrand Russell, such a model must be interpreted, and "the problem of interpretation is the problem of the insertion of something definite." An adequate empirical interpretation turns a theoretical system into a testable theory. The hypothesis whose constituent terms have been interpreted becomes capable of test by reference to observable phenomena. Only the data of physical phonetics are observable phenomena.

Since linguistics is an empirical science the criteria used must be those accepted by the scientific community as a whole. This requires that the claims made be, in principle, capable of test; that the concepts used in the theory be definite and precise. It is not a mere collection of miscellaneous items of information, but a well-connected account of the facts which is sought. These are descriptions, explanations and predictions which are as adequate and accurate as possible in the given context of research.

While the very essence of scientific explanation is the
analysis of more complex phenomena into simpler ones, it is
necessary to guarantee that the simpler ones are sufficient
to fit the empirical evidence.

> The fundamental principle here is
> that the justification for a physical
> concept lies exclusively in its clear
> and unambiguous relation to facts
> that can be experienced.
> (Einstein 1934, 49)

The units and concepts of neither systematic phonemics
nor systematic phonetics constitute the physical observable
phenomena of speech sounds.  Both are abstractions.  If the
final output of a grammar is a phonetic matrix "in which
columns stand for successive segments (phones) and rows
define phonetic distinctive features" or if the final phono-
logical units of a grammar are represented by more tradi-
tional phonemes, both the distinctive features and the
phonemes must be provided with empirical content.  This can
be accomplished only by relating these concepts by means of
correspondence rules to the empirical phenomena of physical
phonetics.  The units of each grammar need not have immedi-
ate reference to physical phonetics, but the alphabet in
which they are written, provided by a universal phonetic
theory, must have such a connection.  Furthermore, once the
units of the universal phonetic alphabet have been selected,
they can only be verified by experimental tests conducted
on specific languages.  Physical phonetics provide the

means by which the ultimate phonological units of a grammar may be tested. For example, suppose that a phonological description of a specific language opposes one class of sounds to another by virtue of the first being 'tense' and the second 'lax', and that the feature "tense" is specified by the Universal Phonetic Theory as meaning greater amount of muscle action. If experiments using electromyography show that there is either greater muscle action in the 'lax' sounds for all speakers or demonstrate that for some speakers the 'lax' sounds show greater muscle activity and for others the 'tense' sounds show greater muscle activity, the selection of such a feature as distinctive would prove to have been incorrect. Only in the event that certain definite correspondences hold between the original and the model can one speak of the model as verified. As long as the interpretation of the linguistic model has not been investigated, the model remains a pure fiction. Indeed, the deductively obtained proofs, no matter how logically irreproachable they may be, do not as yet tell anything about the properties of the real language which the model describes.

As stated by Eli Fischer-Jørgensen (1958):

> ...the chief objective of linguistics
> is the abstract functional system...
> but the units of this abstract system
> can only be identified if the 'substance'
> is taken into account. Moreover, once
> the system is established, the linguist
> will be interested in its actualization
> in the speech act....This means that
> the study of speech sounds must be

considered as part of linguistics. (424)

It is not suggested that 'phonemes' or distinctive features can be found by merely examining the "mechanical record of the gross acoustic features, such as is produced in the phonetics laboratory" (Bloomfield 1933, 85).  No procedures of any kind can lead directly from the phenomena of physical phonetics, which are semi-continuous phenomena, to the discrete primitive linguistic units which are selected and related in the theory.  There is no disagreement with Sapir's warning that

> Mechanical and other detached methods
> of studying the phonetic elements of
> speech are, of course, of considerable
> value, but they have sometimes the
> undesirable effect of obscuring the
> essential facts of speech-sound psy-
> chology.  Too often an undue importance
> is attached to minute sound discrimina-
> tions as such; and too often phoneticians
> do not realize that it is not enough to
> know that a certain sound occurs in a
> language, but that one must ascertain
> if the sound is a typical form or one
> of the points in its sound pattern, or
> is merely a variant of such a form.
> (Sapir 1925, 36)

The history of scientific theory has shown that in

> the establishing of principles which are
> to serve as the starting point of deduc-
> tions...(there is) no method capable of
> being learned and systematically applied
> so that it leads to the goal....Knowledge
> cannot spring from experience alone.
> (Einstein 1934, 7)

The sounds of 'parole' -- the physical raw data -- serve as the starting point. One then proceeds to the generalizations and hypotheses of the phonetic theory. These hypotheses are then confirmed or contradicted by reference once more to the observational data. The units of the phonetic theory are abstractions which can only be validated by reference to the raw data of physical phonetics.

> Structural analysis can inform us about oppositions, distributions, contrasts, and distributional limitations...Instrumental analysis can discover the physical facts corresponding to the linguistic realities. (Malmberg 1963, 98)

Or as Siertsema (1955) has suggested:

> It is right that _phonetic_ qualities should be emphasized. That language is independent of individual sounds is quite true. But to be independent of something is one thing, to have nothing to do with it is another...To fathom the nature of language, to penetrate into the secrets of its foundations and of the structure of the building itself, we must study it in its natural manifestation: _speech_. (10)

Ladefoged (1960) has pointed out that the disregard for the facts of physical phonetics has resulted in invalid linguistic descriptions and that

> This traditional cavalier treatment of physiological facts both sets us apart from other scientists and hampers our work as linguists. (387)

In the same article he stated that

> A phonetic description can be considered
> to be adequate only if it has the same
> meaning for all who use it.  (ibid 388)

Once the features of the universal phonetic theory are chosen and classified, only by virtue of their being provided with rigorous physical specifications are they capable of being tested.  The phonetic specification, by means of which the abstract features are connected with reality involves 1) the selection of proper physiological parameters and 2) statements of the values for these parameters.

The fact that all instrumental and experimental work has shown that no two utterances are ever physically identical shows the immense complexity of the phenomena with which linguists deal.  But the development of a logically uniform system out of the chaotic diversity of the speech phenomena proceeds in linguistics in the same way as it does in other sciences.  Linguists are compelled to abstract certain necessary parameters from the totality of collected or observed data, and reject others as contingent.  Despite the great variation each time the "same" utterance is pronounced by a single speaker, or many speakers, "...the relations that obtain between the elements in the two patterns are the same." (Sapir)  The realization of universal phonetic units is no more the same from language to language in an absolute sense than from individual to individual or from utterance to utterance.  Linguists seek

to discover amidst the complexity of change and transforma-
tions the relationships that remain effectively constant.
They attempt to show that there are necessary relations
between articulatory phenomena, sound, and linguistic units
at a given time and those at other times. These relations
constitute the same kind of causal laws as are sought in
other empirical sciences. In other words linguists must
abstract certain parameters from the mass of data which are
collected. Whether a particular abstraction is valid de-
pends on the extent to which those facts that it ignores do
in fact produce negligible effects in the problems of
interest.

The validation of the theoretical linguistic units is
not a simple process. It is possible that the correct
features have been abstracted, but that the interpretive
rules are incorrect.

The validity of the features can be tested in two
ways: 1) by synthesis and 2) by analysis.

In the first method rules are stated specifying the
values of the parameters. These can then be fed into a
machine which produces as its output a sequence of speech
sounds related as specified to the parameters at the input.
If the synthesized speech is indistinguishable from real
speech, we can conclude a) we have selected the proper
parameters, and b) we have assigned the proper values to
these parameters. If the results can be distinguished from

real speech we must conclude that either incorrect parameters were selected, improper values were assigned, or both.

The second method requires that more data be collected, the results of which are compared with the hypothesized parameters and values assigned. If there is a match, we may assume for the time being that our hypotheses are not incorrect. But by this method we are unable to determine whether or not we have selected the proper parameters. We can only determine whether the values assigned are correct.

For this reason, it has been suggested that analysis is necessary but not sufficient for precise description of speech sounds. (Cooper 1962) Unfortunately, there are times in scientific research when certain hypotheses cannot be definitively tested by synthetic means. At the present time we have no black box into which we can feed, as input, rules specifying physiological parameters and receive as output synthesized speech. But this problem is not unique to linguistics and phonetics. And although acoustic synthesis has been accomplished with a high degree of success, for the reasons given above we cannot support the position that this justifies the choice of acoustic rather than physiological specification of phonetic features. That would be analogous to the story of the man who lost a quarter in a dark alley and searched for it under the street light because he could see more easily.

Rather it is our contention that further experimental work must be carried out in the attempt to provide testable, precise specifications of physiological parameters. With the advent of new instruments and techniques in the phonetics laboratory such a specification is no longer out of the question. We no longer have to depend on the sharp ear of the phonetician who in the past was relied on to specify speech sounds, distinguishing the various sounds of speech and correlating these with the motions of the speech organs so far as he was able to judge or to observe these.

In 1856, Samuel Haldeman pointed out that phonetic specifications which depended on the 'good ear' of the phonetician were subject to question.

> ...when linguists commit grave
> errors in the uses of speech organs
> which can be seen and felt, in
> addition to the sounds being heard,
> we may well doubt the analysis of
> sounds formed out of sight, in the
> depths of the 'fauces'. (35)

In the place of the 'good' or 'bad' ear of the phonetician is a battery of equipment such as the electro-myograph which measures the electrical activity of various muscles during the speech process, the cineradiograph which yields X-ray moving pictures of the speech organs in action, the camera for still or high speech photographs, pressure and air flow measuring devices, the palatograph which indicates the relationship between the tongue and the roof of the mouth, and other laboratory instruments. The various

shapes of the cavities, the mouth openings, tongue positions,
lip positions, air pressures, muscle activity, can now, by
means of such instruments, be more or less measured and re-
duced to a set of parametric rules consituting an objective
interpretation of the phonetic alphabet required by a gram-
mar of a language.

The remaining chapters deal with a specific research
experiment employing electromyography conducted towards
this objective.

Bacon once stated that 'the experiment is a question
asked of nature to make her speak.' This thesis deals with
the questions asked and the answers which were received.

CHAPTER II

ELECTROMYOGRAPHY IN SPEECH RESEARCH

A. Introduction

For many centuries speech sounds have been described
in terms of the positions and shapes of the organs of speech.
Until recently, however, little attention has been paid to
the means by which these positions and shapes are effected,
i.e. the neurological innervation of the muscles and the
muscle activity. This was due in large measure to the
technical difficulties which were present. Since the 18th
century, when Galvani discovered that muscles will contract
when stimulated electrically (Foley 1953), physiologists and
anatomists have attempted to study muscle functions by
artificial stimulation. The utilization of Galvani's
additional revelation that all contracting muscles produce
an electrical current or voltage was postponed until the
twentieth century when techniques were finally developed
for detecting and recording the minute electrical discharges.
The techniques of electromyography was utilized for the
first time a little over thirty years ago by such neuro-
physiologists as Adrian and Bronk, Denny-Brown, Buchthal
and others. Electromyography deals with electrical

potentials produced by muscle. Its use now makes possible the analysis and description of the previously neglected early stage of the speech act. The engagement of the muscles is directed by the central nervous system through centrally originating innervation patterns. Thus, the study of muscular behavior enables one to gain some insight into the behavior patterns of the central nervous system.

Other methods which have been used to determine the muscle activity involved in speech production, such as X-ray motion pictures, clinical observation, and anatomical investigation can provide only indirect information. Van Riper and Irwin (1958) state, for example:

> Actually, primarily because of technical reasons, we do not have completely satis- factory evidence concerning the relative activity of specific muscles in the pro- duction of English speech sounds. The picture of muscular activity that we shall present simply represents our attempt to piece together a story on the basis of anatomical data, clinical experience, and the somewhat sketchy experimental findings that we have at hand. (387)

The older methods attempted to reveal only what a muscle might do, and which muscles may be involved in the production of different speech sounds. Electromyography is unique in that it can reveal when a muscle is active, how active it is, and reveal the coordination of different muscles involved in any one gesture. In 1876, Duchenne pointed out:

> Formerly the action of the face was concluded
> from observation and induction. It was well
> understood that the movement of the face, just
> as the movements of the arm or any other part,
> was due to muscles, but the action of the
> facial muscles was deduced either from the
> wrinkles and skin folds which are produced by
> repeated contractions, or from the form and
> direction of the insertions of muscular fibers.
> These observations did not reflect the true
> state of affairs and could not do so....Because
> the a priori and the a posteriori deductions based
> on observations and on anatomy were fruitless,
> it was necessary to proceed differently and
> use the experimental method. (573)

Almost one hundred years have elapsed since Duchenne

reached those conclusions which are as correct today as they

were then. Fortunately, modern instrumental techniques

permit an objective investigation of the muscle actions

involved in speech.

B. The Basis of Electromyography

1. The Motor Unit

A knowledge of the structural and functional units in

striated muscles is necessary for an understanding of elec-

tromyography. A muscle can be defined as a tissue of cells

which enables an organism and its parts to move. Physiolog-

ically, a muscle is composed of motor units, a term coined by

Liddell and Sherrington (1925). A motor unit is defined by

them as a motor cell, its axon process, and the group of

muscle fibers innervated by this one nerve cell. Figure 1

illustrates in schematic fashion the structure of the motor

unit, and the path of an order for muscular action.

The bunches of fibers which make up the motor unit may be striated or banded; the striations indicate that they are composed of a chain of shorter sections. The number of muscle fibers in a motor unit varies widely from muscle to muscle, and even within one muscle. (Krnjevic and Miledi 1958; Dutta and Basmajian 1960; Buchthal 1959; Buchthal, Guld, and Rosenfalck 1957 et alia). A survey of the literature reveals that there has been no estimate of the number of fibers in a motor unit in the muscles of the tongue and lips.
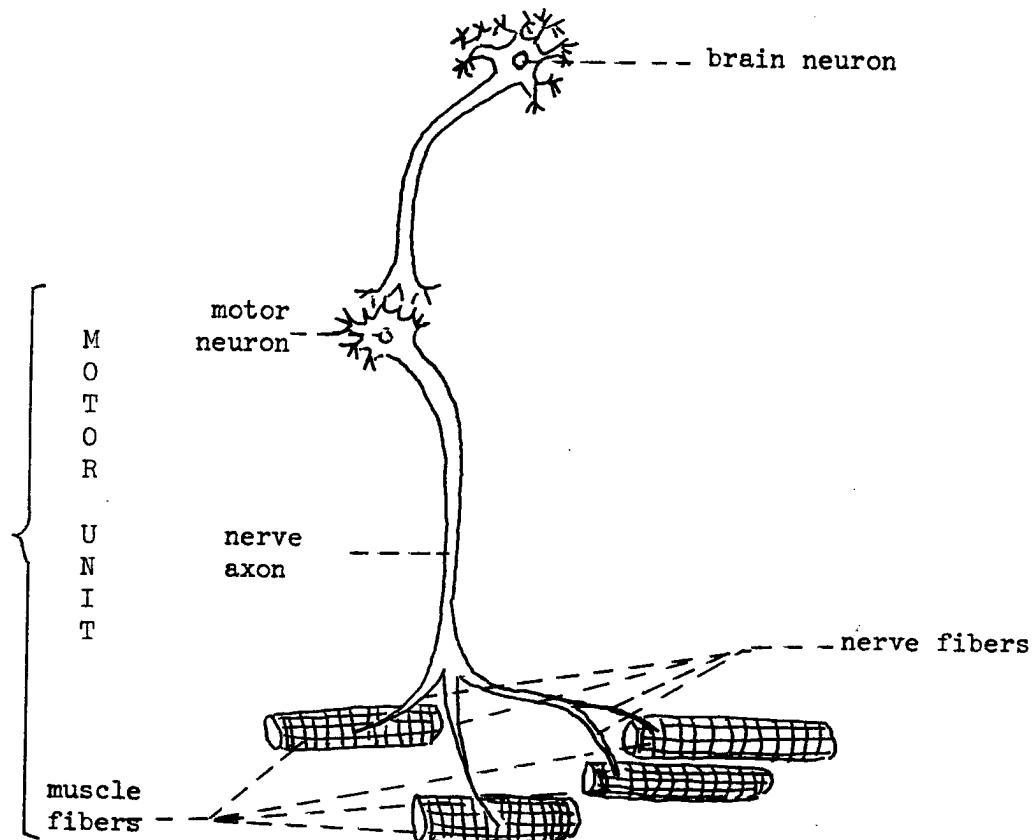
Figure 1. Schematic diagram of a motor unit.

Faaborg-Anderson (1957) has shown that in the muscles in the
larynx there are from 116 (in the cricoarytenoideus posterior
muscle) to 248 (in the arytenoideus transversus muscle). In
general, as muscles get larger, the number of fibers per
motor unit increases; limb muscles have from 400 to 1700
fibers per motor unit (Buchthal 1960). Presumably the small
fast-acting muscles which are responsible for articulatory
movements are more similar in this respect to the muscles of
the larynx. Within the bundles the fibers are interwoven to
a great degree, with many fibers overlapping others.
(Buchthal and Lindhard 1939).

## 2. The Individual Muscle Fiber

The structural unit of contraction is the individual
muscle cell or fiber. In small muscles a muscle fiber is
usually only a little more than 10 microns (a hundredth of
a millimeter) in diameter, although it may be several centi-
meters in length. There is considerable variation in the
shape of the muscle fibers. Those that are cylindrical in
shape are always comparatively short. There are also long
fibers which are flagelliform or laneolate. Spindle shaped
fibers are thickest in the center with long pointed ends.

Even within the same muscle, fibers vary in length.
In certain muscles the fibers are shorter than the bundle,
with an average length more than half the length of the
bundle so that the thin fiber-ends overlap for some distance.

(Buchthal and Lindhard 1939)

According to Haines (1932, 1934) a muscle fiber will decrease its resting length about 57% on contracting. The amount a whole muscle can contract is dependent on the maximum contraction of its contractile units, i.e. its individual fibers. (Basmajian 1961) This is illustrated in Figure 2.
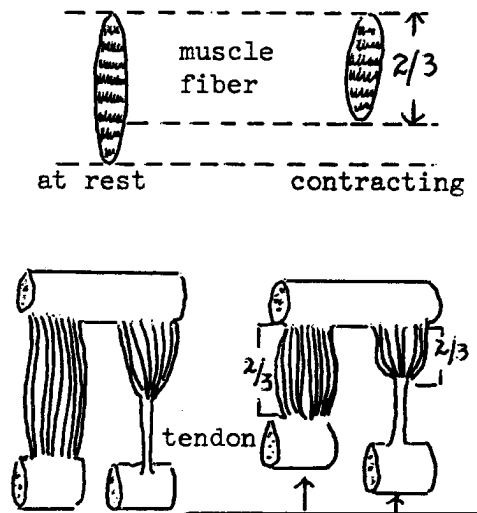


Figure 2. Diagram illustrating the dependency that whole muscle contraction has on individual fiber, which is the structural unit of contraction.
(After Basmajian 1960)

3. <u>Frequency Behavior of Individual Motor Units</u>

All the individual muscle fibers in a motor unit contract almost simultaneously when that unit receives a stimulus from the motor nerve.  Each contraction lasts for a few milliseconds.  A contraction results in an increase of tension at each end of the fiber, which may or may not cause actual shortening.  Then the contraction ceases, certain chemical changes occur restoring the original conditions, and the group of fibers is ready to contract in response to another neural impulse.

Adrian and Bronk (1929) were the first to study the frequency behavior of the individual motor units during voluntary contractions.  Their work was followed by other similar investigations.  (Kugelberg and Skoglund 1946) Individual motor units may contract in response to impulses arriving at rates of from 5 to about 50 per second.  An investigation of the action of the respiratory muscles in speech (Ladefoged 1958; Draper, Ladefoged and Whitteridge 1959; 1960) showed that the shortest time between contractions was about one forty-fifth of a second.  Faaborg-Andersen (1957, 1965) reports a similar figure in his studies of the muscles of the larynx.  Much higher figures have been claimed for the vocalis muscle by Husson -- up to 500 per second. (1955)  This is now generally discredited (Van den Berg 1958; Rubin 1960; Faaborg-Andersen 1965).

The frequency range of 3 to 40 or 50 per second is corroborated by the findings of Katsuki (1950) and the work of Sawashima, Sato, Funasaka and Totsuka (1958).

The twitch time, or frequency of firing, varies from muscle to muscle. Great precision is required by muscles responsible for skilled movements, e.g. eye, tongue, lip muscles. The innervation ratio, i.e. the number of fibers per single neuron, is low in such muscle, and the twitch time fast. (Dr. G. Moore, private conversation)

The response of a muscle fiber to an arriving impulse is an invariant, "all or none" type of response.

In order to keep the entire muscle from responding in this fashion, not all the motor units are stimulated at once. Muscle action will increase as the load increases. Variations in the degree of muscle activity are achieved in two ways. In the first place, an increase in the strength of contraction can be produced by increasing the rate at which the individual motor units are contracting, since the individuals twitches are summed. Secondly, there can be an increase in the number of motor units in the muscle which are active. It has been shown (Bigland and Lippold 1954) that the impulse rate of the individual active motor units is a good measure of the force being produced at low levels of muscle action; but at higher levels the degree of recruitment of additional motor units becomes a more important factor. In reference to this point, Kugelberg and Skoglund

(1946) give the following summary of their investigations:

> The initial frequencies of the motor units
> associated with slight degrees of voluntary
> contraction range for the most part between
> 5 and 10 per sec., the frequency of the
> unit discharge increases with increasing
> contraction up to a maximum of about 30-50
> per sec., the initial frequency for each
> new unit is, as a rule, lower than for those
> already involved, but with further increase
> of the contraction the new unit soon attains
> the same maximum frequency. (119)

The process of matching the response of a muscle to a specific load involves the feedback mechanism without which we would expend as much energy in lifting a spoon as we would in raising a heavy stone. Within all muscles there are specific sensory organs that provide information about length and tension to the nervous system, the significance of which will be discussed in Chapter 4.

4. Motor Unit Potential

The firing of a muscle fiber, producing the contraction, begins at a point where the associated motor nerve is joined to the outer membrane of the muscle fiber. An electrical potential difference, called the resting potential, exists between the interior and the extracellular environment of a non-innervated muscle cell. When a nerve impulse reaches the neuromuscular junction (or motor end-plate) a chemical reaction is initiated whereby the properties of the muscle cell's outer membrane are changed so that the cell releases

its pent-up electrical charge and the fiber contracts. The change in membrane potential which results from a nerve impulse is called an _action_ _potential_.

An electrode placed close to an active motor unit will register the potentials which are being conducted through the surrounding tissue with reference to a second electrode further away from the source of the potentials. This is the main process involved in electromyography.

The action potentials picked up by an electrode represent at least the sum of the action potentials of some of the individual muscle fibers of a single motor unit. However, it has been shown (Buchthal 1960) that the so-called motor unit potential does not originate from all the fibers of the motor unit; only the one or two groups of fibers which are situated closest to the electrode contribute to the recorded motor unit potential.

A number of factors contribute to the amplitude of the motor unit potential recorded by an electrode. First, the amplitude of the recorded spike decreases as the distance increases between the active motor unit and an electrode placed in the same muscle. (Buchthal, Guld and Rosenfalck, 1957b). Second, it has been demonstrated (Weddell, Feinstein and Pattle 1944) that there is a discontinuity in the rate of decrease of the amplitude of the recorded spike when a muscle boundary or septum intervenes between the motor unit and the electrode; in these circumstances the potentials

recorded are an order of magnitude smaller.

Observations made by Ladefoged (1958) have confirmed both of these points. In several years' work on the action of the respiratory muscles in speech it was possible on only very few occasions to place an electrode so that valid records were obtained from both the internal and external intercostals. Usually large spikes from only one or the other of these two muscles were recorded although they are very close to one another and their combined thickness is less than 5 mm.

In other experiments conducted in the UCLA phonetics laboratory, the signals recorded on a surface electrode and on a needle electrode inserted through the surface electrode into the muscle below were compared. The surface electrode was varnished so that the uninsulated portion in contact with the skin was comparable to the exposed area of the needle electrode. A scale was attached to the surface electrode permitting the measurement of the distance between the point of the needle and the skin. In one such experiment, the output of both electrodes was recorded, while the needle was pushed slowly into the zygomaticus major muscle 23 mm. up from the right corner of the lips and 26 mm. to the right of the midline. The depth of the needle was adjusted by millimeter steps both as it was pushed in and as it was later withdrawn. After adjustment at each step the

subject was instructed to raise her upper lip in a sneer-like gesture, thus contracting the zygomaticus muscle. Figure 3 shows the ratio between the size of the spikes recorded by the needle electrode in comparison with the surface electrode for each position of the needle. Each point represents the mean of the ratio for the ten largest spikes in each position which could be identified on both records. The largest spikes recorded by the surface electrode were always between 500 and 550 microvolts. The spikes recorded by the needle electrode were about the same size (or slightly less) when the point of the needle electrode was enclosed within the surface electrode. But they increased to more than three times this value when the needle was closest to where we might presume the fibers of this muscle to be. Our experiment thus corroborates the findings that the amplitude of the spikes vary inversely with an increase of distance from the active fibers. Figure 4 portrays the apparatus which was used in obtaining the data of Figure 3.
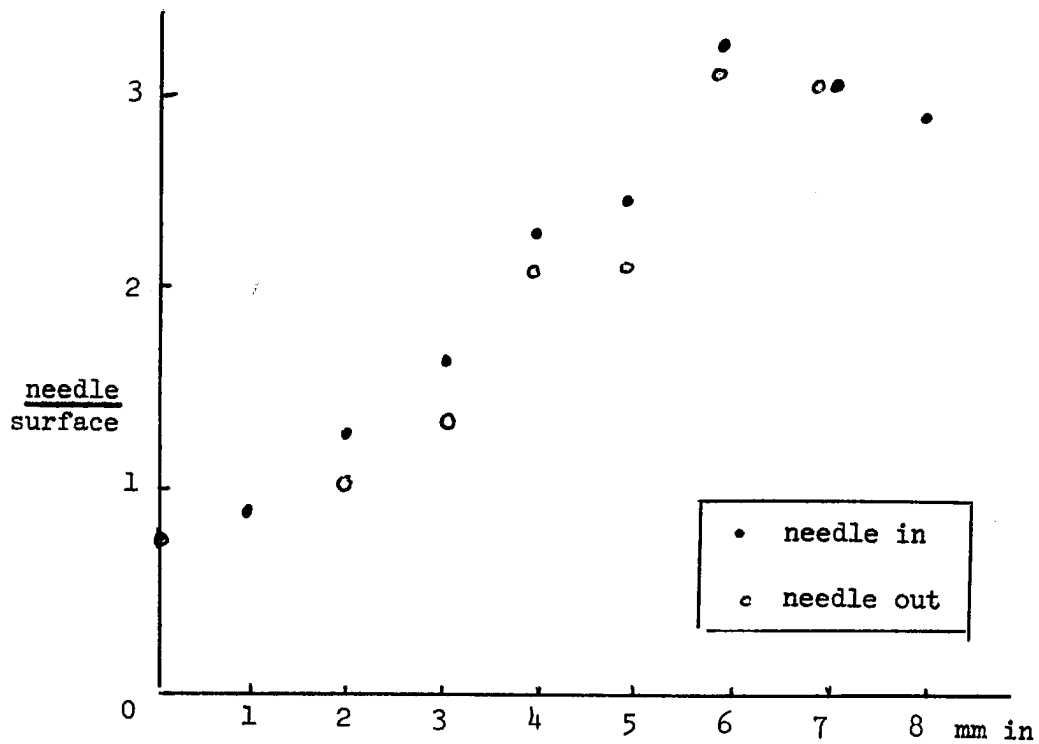
Figure 3. Ratio between size of spikes recorded by needle electrode in comparison with surface electrode for each position of needle.
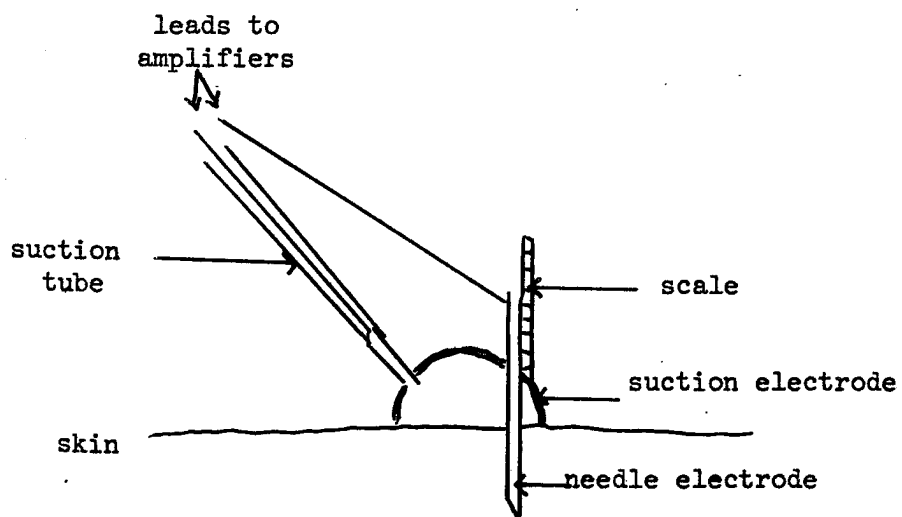


Figure 4. Apparatus used in obtaining data.

The largest spikes recorded in the experiment discussed above were about 2 millivolts peak to peak.

Besides the two factors already discussed which affect the amplitude of the recorded action potential -- the distance between the recording electrode and the active motor unit; and the interference caused by septa between muscles -- there are other factors which are less important from the point of view of most experiments as they may be considered to be constants. It has already been noted that the number of fibers in a motor unit differs from muscle to muscle. Other things being equal, the greater the number of fibers per motor unit, the larger the spike. Finally, it has been shown (Bauwens, 1950; Buchthal, Guld and Rosenfalck 1957a; Petersen and Kugelberg 1949) that the size and type of recording electrode affects the duration and amplitude of the recorded action potential. In the experiments cited above the largest spikes obtained were recorded with an insulated needle electrode with an exposed area too small to measure. These spikes were about 7 millivolts from peak to peak.

Research started a few decades ago revealed that when a muscle contracts the contraction begins with the units giving small amplitude potentials, followed by others with larger spikes. (Smith 1934; Hoefer and Putnam 1939; Kugelberg and Skoglund 1946; Bauwens 1948 et alia) This is called the normal pattern of recruitment. (Norris and Gasteiger 1955)

The reasons for this pattern are given in the discussion on frequency. (Cf. p. 3-8)

According to Wedell, Feinstein and Pattle (1944) no electric activity occurs in a completely relaxed muscle. However, it must be noted that complete relaxation is impossible for certain facial muscles. Carlsöö (1952) stated that even when the mandible is in habitual rest position a certain amount of activity is necessary to counteract the force of gravity. (78) In comparison with the activity during movement, however, it is faint and very rarely registrable. Basmajian (1961) upholds the view that "in no normal muscle at complete rest has there been any sign of neuro-muscular activity.." (43). Faaborg-Andersen (1965) points out that while there are two different kinds of electrical activity in the vibrating vocal muscle -- one, active, representing the action potentials of the muscle, and the second, passive -- the latter is usually caused by mechanical movements of the electrodes and must be considered an artifact. (13-14)

Given the knowledge that relaxed muscles show no sign of electrical discharges, and that increased muscle activity shows both an increase in frequency of spikes generated plus a greater amplitude of new spikes, it is possible to compare the muscle activity associated with different speech sounds using the techniques of electromyography.

C. <u>Electromyographic Technique</u>

1. <u>Electrodes</u>

Two main types of electrodes have been used to record the motor unit potentials: surface electrodes and needle electrodes. The efficiency and pick-up range of the electrodes have been studied and investigated by Smith (1934), Lindsley (1935), Denslow and Hasset (1943), Cuthbert and Denslow (1945), Wedell, Feinstein and Pattle (1944), Bauwens (1948) gives a summary of the properties of the two types of electrodes:

> The former (surface electrode) records at the level of the skin the integrated potentials caused by the electrical disturbances in a large...muscle mass...This method is useful...when collective effects are investigated. The second method (needle electrodes) ...obtains samples of electrical disturbances in a very restricted volume of the tissues.(136)

The insertion of needle electrodes is essential when studying muscles which do not lie immediately below the skin, such as the internal intercostals or some of the muscles of the larynx. But needles are inconvenient in very flexible moving structures such as the tongue and unnecessary when studying muscles which are immediately subcutaneous such as the orbicularis oris. In research on speech, the uninsulated area of a needle electrode should be larger than in many other studies of muscular action, so as to be sure of sampling sufficient motor units for an adequate specification of the rapid movements.

Duchenne considered himself fortunate in finding a subject advanced in years who suffered with facial anesthesia which permitted him to stimulate the muscles without producing pain. He wished to avoid the "painful responses (which) could be accused of acting on the muscles and interfering with the precision interpreted in their contraction." (1867, 576) Fortunately, today a very efficient type of surface electrode for use in electromyographic studies of speech has been devised by members of the Haskins Laboratories (Harris, Rosov, Cooper, Lysaught 1964). It consists of a hollow silver bead cut in half and connected to a suction pump; maintenance of a negative pressure will enable it to adhere firmly even to rapidly moving structures such as the lips and tongue.

## 2. Apparatus

Since muscle action potentials can be less than 50 microvolts, they must be greatly amplified before they can be recorded. For this purpose one can use a cathode ray oscilloscope which ha' an amplifier with a gain of $10^6$ (making a signal a million times bigger) and a display sensitivity of 200 microvolts/cm. This permits both the amplification necessary and the deflection on the oscilloscope screen which can be viewed and monitored during the recording of the electromyographic signals. It should also be noted that since the bulk of the frequency components in

electromyographic signals are in the audible range, one can listen to the action potentials over a loud speaker. The noise level of the oscilloscope should be below 10 micro-volts.

A two-channel oscilloscope can be used either for recording from two electrodes simultaneously or, sometimes more important for speech research, to view the audio signal together with the electromyographic signal. If it is desired to record from more than two electrodes at a time, more channels can be added.

Extraneous electrical noise can present definite problems because of the small amplitude of the incoming electromyographic signal. Since the major source of interference is 60 cycle line noise, much of it can be eliminated or at least minimized by adequate shielding and the proper grounding of the subject. In addition, one can use differential amplifiers which amplify only the difference between the signals on the leads coming from the active and reference electrodes, and which reject the noise signal which is common to both leads.

Calibration is accomplished by introducing into the oscilloscope circuit a known signal suitable for comparison with the bioelectric activity to be measured. Calibration signals consisting of a periodic changing voltage of known amplitude can be used.

It is necessary to have a permanent record of the electromyogram and the audio signal because of the necessity of checking whether the electromyographic records are artifact free. It is not possible to do this during the course of the experiment since the oscilloscope display is too transitory to permit a detailed examination.

The audio signal and the electromyographic signal can be recorded (after amplification though the oscilloscope) on multi-channel tape recorders. An added advantage of recording these signals on tape is that this acts as a high-pass filter and gets rid of artifacts due to movements of the electrode. Hayes (1960) has shown that the spectra of potentials from the lips may be considerably affected by electrode movements during rapid speech. The EKG low frequency (electrical signals arising from the heart beat) are also considerably reduced by the recording on tape. The tape recorders used should have a frequency response of $\pm$ 2 db from 40 to 10,000 cps.

The recorded information can then be played back at any later time, and then reproduced and displayed by an appropriate device. It is important that this device have a high enough frequency response to show the high frequency components of the electromyographic signal. An ordinary ink writer is not suitable for insuring that records are free from irregular bursts of noise or other artifacts.

The Oscillomink, with a frequency range from about 0 to 1000 cps. is suitable for this purpose. This is a 4-channel ink writer which enables one to record the audio signal and the electromyographic signal. One may use the other channels to record the electromyographic signal after it has been rectified and integrated and/or after all the action potential spikes over a certain amplitude have been converted into pulses. Alternatively one can display up to three simultaneous electromyographic signals plus the audio signal.

Another way of making a permanent visual record which is equally satisfactory is to photograph the cathode ray oscilloscope.

### 3. Quantification of Electromyographic Records

The literature concerning electromyography presents varying and opposing opinions regarding methods for interpreting and evaluating the data collected. It is a commonplace notion in science that all findings are enhanced by the quantification of data. Basmajian, however, believes that at present the most reliable evaluation of electromyographic records is done by a trained observer's visual evaluation. He assigns arbitrary units to different amounts of muscle activity, determined by mere visual examination (Basmajian, 1962). The variable factors in such evaluation proceedings are enormous. Obviously instrumental quantification of the electromyographic signals will lead to more

reliable conclusions.

One way of quantifying a signal such as the electrical activity recorded from a muscle is to measure the average activity over a period of time. In the case of speech events the muscles may be producing as many as five or six gestures in a second, and the interval between consecutive observable action potential spikes in the comparatively inactive periods between gestures may be of the order of one-twentieth of a second. If we averaged the amount of activity over a comparatively long period, e.g. one second, we would not have a record which reflected the different discrete muscular events. If, on the other hand, we made a series of averages over too short a period, e.g. one-hundredth of a second, our averages would be overly influenced by the irrelevant fact of whether an action potential was in the sample or not.

One's goal in averaging any time-varying phenomenon is to arrive at an average which reflects the gross variations in time which are characteristic of the phenomenon but which does not show the smaller variations which may be considered as random because they do not concern the events being studied. The measurement of speech power, which has been discussed by Fant (1959) and by Peterson and McKinney (1961-62), presents similar problems to those which we have to consider here.

In order to average and still show the variations in time which are of interest one may use an active RC (resistor-condensor) circuit to produce a kind of running average curve, in which each point indicates the sum of the energy at that instant and a proportion of the energy which occurred at previous instants. The proportion is determined by the time constant.

The problem in averaging electromyographic activity in speech is to set the time constant relatively long compared to the duration of each spike and the time interval between spikes, but short in relation to the number of times per second the muscle activity changes in the production of a speech sound.

With the above in mind, one can attempt to evaluate the different averaging methods used by workers in electro-myography. One method is to first rectify the inverted forms of the spikes, and then add the total amount of elec- trical activity producing an average 'integrated' curve. (Close 1964) This 'true' integration method actually pro- duces a summation curve each point on which indicates the total amount of electrical activity accumulated up to and including that instant. The total activity (the end point on the curve) can also be found by using a planimeter to measure the area of the envelope under the curve of an RC integrated signal. (Lippold 1952; Bergstrom 1959). While

such procedures are usually inadequate to quantify the chang-
ing muscular events which occur in speech, there are certain
areas of speech research where it may be helpful.  An exam-
ple is the comparison of the total amount of muscle activity
in 'tense' and 'lax' syllables. (Kim 1965)

Various types of integrating circuits have been sug-
gested.  For instance, Rosenfalck (1960) discusses the ad-
vantages of an RLC (resistance -- inductance -- capacitance)
circuit over an RC circuit for this integration procedure.
That integration of the action potentials is a significant
method was shown by Bigland and Lippold (1954).  They
demonstrated that integrated potentials vary directly with
the strength of muscle contraction.  Figure 5 demonstrates
this fact.

Another method of quantifying the electromyographic
signal is to count the recorded spikes.  A simple way of
going this is to turn all recorded spikes over a certain
voltage into identical pulses.  One may then count the
total number of pulses for one utterance, or the average
number per unit time.  These two methods correspond to the
summation type of integration and the RC integration
described above.

Bergstrom (1959) counted the number of motor impulses
irrespective of size.  This number was then compared to the
integrated electrical activity which was quantified by

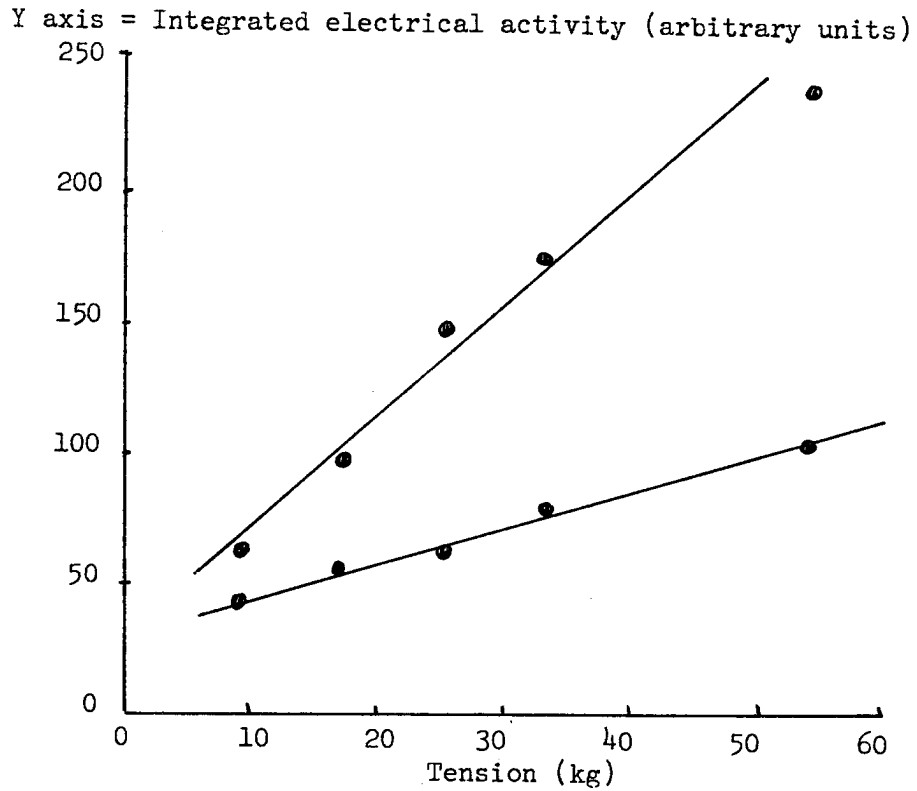Y axis = Integrated electrical activity (arbitrary units)



Figure 5. The relation between integrated electrical
activity (via surface electrodes) and tension
in the human calf muscles. Shortening at constant
velocity (upper) and lengthening (lower).
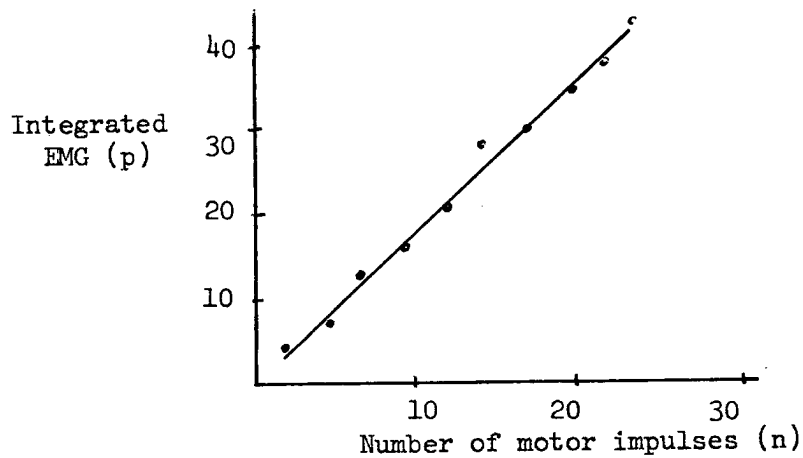(From Bigland & Lippold 1954)



Figure 6. The relation between the number of motor unit
spikes (n) and the integrated area of the
EMG (p). (From Bergstrom 1959)

means of a planimeter. A linear relation was found to exist between the integrated activity and the number of motor impulses, where the maximum rate of occurrence of spikes was no more than 500 cps. Figure 6 shows this relationship.

Close (1960, 1964) strongly supports the method of spike counting. While he also states that there is a definite correlation between the total electrical activity for a given interval, and the total number of action potential spikes for that same period, he argues that spike counting is preferable to integrating since the motor unit conforms to the all-or-none law.

The findings of Buchthal and his colleagues (1956, 1957, 1959, 1960) would appear to support this procedure. As was mentioned, he concludes that the determining factor influencing the voltage of the motor unit potential is the distance of the recording electrode from the active spike source (Buchthal 1960). This being so, spike-counting should be the better method of quantifying the data. The integrated signal may be largely determined by irrelevant factors. Spikes with greater amplitude would contribute more and would indicate greater muscle activity than spikes with lesser amplitude. Yet, if this greater amplitude represents mainly distance from the electrode, the amount of activity of the motor units may be equal. On some occasions, using surface electrodes on the lips, spikes have

been recorded with very large amplitudes even in the interval between utterances when the subject was not moving her lips. These spikes contribute a significant amount to the integrated record but they hardly affect the action potential counts.

Unfortunately, counting action potentials presents a number of problems. Motor units overlap; the amplitude of larger spikes may be the result of superimposition of action potentials from a number of motor units. Using needle electrodes it is usually possible to separate out the action potentials of individual motor units by their individual shape, constant size and frequency. But Rosenfalck (1960) suggests that counting the number of action potentials must be limited to data which shows little muscle activity and in which single motor units can be discriminated.

The problem is further complicated when one uses surface electrodes instead of needle electrodes. While it is difficult enough to distinguish single motor unit potentials when needles are used, from the surface the firing of many more motor units is recorded, and the varying amplitude of the spikes can be the result of both differences in distance from the electrode and the superimposition of different action potentials. (Hayes 1960; Basmajian 1962; Close 1964; Tulley 1953). Consequently it is difficult to be certain how many discrete motor units are represented.

In summary, there are both advantages and disadvantages to spike counting as opposed to RC integration of the rectified signal. Spike counting allows one to disregard chance effects due to distance from the electrode. Thus, by this method, only electromyographic activity is measured and signals originating from varying electrical noise or movements of the electrode are omitted. But the count may not be reliable due to the superimposition of action potentials.

One other method of quantifying muscular activity from electromyographic records has been used. It has been claimed that the activity of a single motor unit is a good indication of the activity of the muscle as a whole (Close 1964). On this basis the impulse rate, defined as the reciprocal of the interval between single motor unit spikes, has been used to represent the variations in the activity of the internal intercostal muscles in speech (Ladefoged 1958). It is now believed that this is not the most appropriate way of quantifying electromyographic activity in speech for several reasons: single motor units are seldom unambigously recorded, except when using small needle electrodes; the interval between spikes is usually too long in comparison with the individual movements of speech; and Bigland and Lippold (1954) have shown that the impulse rate is proportional to the work being done by the muscle only at low efforts.

One of the difficulties in using electromyographic techniques in speech research is due to the random variation in the myographic signals when the same utterance is repeated. Since one aim of the research is to compare the muscle activity of many different speech sounds, it is necessary that twenty or more tokens of the same utterance be averaged in some way. This can be done by taking the same reference point in each token of the same utterance, and then sampling the signal at a number of pre-selected points. The measurement taken at the sampling points can be the height of the RC integrated curve, the number of spikes which occur between designated time intervals etc. The measures recorded at these points for all the utterance tokens may then be averaged.

Averaging all these values is an enormously time-consuming task when it is done by hand. There exists, therefore, an urgent need for better methods of measuring, quantizing, and analyzing the information which is collected. The reduction and analysis of EMG data is a task well suited for the electronic digital computer. The characteristics of electromyographic signals, like other bioelectric impulses, are analog or continuous in nature. The computer can measure and quantize these analog signals into digital or discrete form not only more rapidly but more accurately than can be done by hand. The computer can also sum the

accumulated data, and average these sums.

The procedure for automating the collection and reduction of EMG data as proposed by Haskins Laboratories uses a DDP-24 computer. (Music et al. 1965; Sholes 1965)  Their processing involves three different phases; data collecting, editing, and data reduction.  According to their outlined method, the EMG data are stroked at 5 msec intervals, beginning at a time determined during the editing phase.  They believe that the determination of the reference time should be made by the investigator rather than the machine.  Their program produces sums or sums of squares as desired.

The LINC, a small, general-purpose digital computer, was used in the research discussed in Chapter 5.  The principal output of this computer is an oscilloscope display which may be viewed directly or photographed.  The computer program specifically written for the automatic reduction of the EMG data will be discussed below.

D. Electromyographic Studies of Speech

Electromyography has been surprisingly little used as a technique for investigating muscular gestures of any kind.  By far the greatest use of this technique has been in clinically oriented studies.  There is still a great deal of work to be done before it can be considered a fully developed tool which can easily be used by research workers studying the degree of involvement of different muscles

in specific actions.

A survey of some electromyographic research on speech
has been given by Cooper (1965). Some qualitative data is
available on the involvement of the respiratory muscles in
speech. Stetson (1951) used electromyographic techniques,
but, as has been pointed out by Ladefoged (1958), his work
is somewhat unreliable in this respect. Hoshiko (1960) used
surface electrodes, as did Stetson, in studying the respira-
tory muscles, but was more thorough in his survey. Campbell
(1958) was primarily concerned with the mechanics of breath-
ing although he does consider speech and singing. The rela-
tion between subglottal pressure, volume of air in the lungs,
and electromyographic activity of the respiratory muscles
in speech was reported in a series of studies summarized in
Ladefoged(1962).

The larynx has been more extensively studied. A recent
survey by Faaborg-Anderson (1964,1965) discusses electro-
myographic studies of both the intrinsic and extrinsic
muscles.

The palate has been examined by Fritzell (1963) and
others; a partial summary is given in Basmajian (1962).

Basmajian remarks that

> Until 1958, electromyography of the mouth
> and pharynx was virtually an unexplored
> frontier, and even now the tongue -- though
> it is an obvious and accessible muscular
> mass -- has not been adequately explored.
> Indeed, I know of no systematic studies

> that have been done on the functions
> of the intrinsic or extrinsic muscles
> of the tongue. Furthermore, the
> easily accessible musculature of the
> floor of the mouth (i.e. mylohoid,
> etc.) also has been badly neglected.
> (1962, 193)

He adds that the same situation holds in relation to the facial muscles. (213)

Recently, members of the Haskins Laboratories have started to remedy this defect. MacNeilage (1963) has reported data on the action of the lips; and MacNeilage and Sholes (1964) have published data on the electromyographic activity recorded from electrodes at 13 locations spaced evenly along the dorsal surface of the tongue. They concluded that "for the most of the vowels, a muscle or a small number of muscles could be isolated as primarily responsible for the tongue movement." They also note, however, that "the interpretations given, and the relative emphasis put on different events have, in many cases, not been the only possible ones." It seems reasonable to consider that their statements concerning the activity of the individual tongue muscles be viewed with caution.

A preliminary study was conducted by Elizabeth Dunstan to ascertain whether one could determine the actual positions of certain tongue muscles using electromyographic techniques. (1965) Tentative conclusions were reached concerning the genioglossus, the geniohyoideus, the

the mylohyoideus, the hyoglossus, the styloglossus, the
glossopharyngeus, and the palatoglossus. While the findings
are tentative, it seems clear that electromyography can be
used to locate the tongue muscles as well as the face muscles
(see Chapter 4). The location of the muscles used in speech
production must be the first step in any thorough study of
muscle activity.

## E. Statement of the Problem and Research Objectives

The general objective of the present study was to
establish, if possible, correlations between the activity
of particular muscles and the production of particular
speech sounds. Underlying the approach was the assumption
that the sounds of speech which are produced by neuro-
muscular events, must at some point be equivalent to the
units of phonology. It is obvious that speech involves the
generation of new utterances by the rearrangement of a
comparatively limited number of stored items. But nobody
knows the size or nature of the units at the neuro-
physiological level. The probability has been suggested
that "spoken language is so organized that it is produced
by putting together simple combinations of component
gestures, and that some of these component gestures...are
themselves quite simple".(Cooper 1965, 166) Using electro-
myographic techniques, this hypotheses can be confirmed,
discarded, or developed.

Lindblom (1963; forthcoming) and Ohman (1964; forthcoming) have shown that it is possible, in some circumstances, to predict or generate the acoustic output and the shape of the vocal tract from knowledge of certain idealized "target" positions for the different speech sounds and to establish mathematical functions specifying the degree of coarticulation or overlap between successive sounds. Whether this is possible on the neuro-physiological level can be partially determined by the use of electromyographic research. Preliminary studies of the activity of the orbicularis oris in the two phrases "I'll see you tomorrow" and "I'll see Sue tomorrow" indicate that the activity associated with the vowel in the underlined words is different in the two cases. This was corroborated by more extensive study of the same vowel /u/ in the utterances /bud/ /dud/ /dub/ /pud/ /dup/ /bub/ and /pup/ (See Chapter 4). If the electromyographic activity is different, it means that the muscles actually receive different instructions. Any 'coarticulation' must be due to overlap in the instructions at a higher level; or the neuro-physiological unit is not the individual speech sound, but something larger, perhaps more of the size of the syllable. This latter position would contradict the basic tenets of most linguistic theories. The 'physchological reality of the phoneme' must have its counterpart in the neuro-muscular commands which

are associated with different speech sounds, or the phoneme is indeed 'fictional'.

The present study, therefore, sought to determine the relationship between the neuro-muscular reality of the phoneme and its 'psychological reality'. It attempted to determine by means of electromyography: 1) the muscular activity of one facial muscle (in terms of timing, duration and force of muscular contraction) involved in the production of 12 vocalic and 3 consonantal phonemes of American English; 2) whether the same phoneme in different contexts could be characterized by a certain invariance of muscular action; 3) how different phonemic contexts effect the muscular activity involved in the production of phonemes; 4) whether the myographic activity of different phonemes, which have been grouped together by virtue of their sharing a common property, was sufficiently constant to justify this classification.

Hopefully, electromyography will prove itself to be an invaluable tool for research linguists seeking answers to such questions.

# CHAPTER III

# THE MUSCULATURE OF THE FACE

## A. Introduction

There has been relatively little investigation of the
role performed by the face muscles in speech production.
In the 19th century the interest in those muscles primarily
concerned their function in the display of human emotions.
Even today, the anatomy books designate the facial muscles
as 'the muscles of expression'. Thus one finds in both
Gray and Cunningham that the specified function of the
riserius muscle is to produce a grin, while the depressor
labii inferioris is specified as the muscle used to show
'irony'. (Gray's Anatomy 1954; Cunningham 1951) While
such an approach may provide inadvertant support for the
'pooh-pooh' theory of language origin, it is of little help
to linguists and phoneticians who are concerned with the
specification of speech sounds.

Charles Bell was not unaware that facial muscles were
related to speech production.

> The organization necessary to speech, the
> great instrument of human thought, is
> widely dispersed: that is, for the utter-
> ance of a sound there must conform a motion
> of the lungs or chest, an adjustment of the
> larynx and pharynx, and a fine modulation of
> the lips. It is more directly from the

> motions of the tongue and of the lips
> that articulate sounds proceed; and the
> connexion of the numerous muscles brought
> into operation in these actions, is con-
> genial with the awakening intellect.  Long
> before a child is taught to speak, we may
> see an imperfect agitation of the lips and
> cheeks...(Bell 1888, 104)

Yet, Bell wrote his whole volume describing the muscles which are used to express 'laughter, weeping, grief, pain, fear, terror, despair, admiration, rage, remorse etc.' with no mention of how these muscles are used in "speech (which) is instinctively associated in our thoughts with the most exalted endowments of man, moral and intellectual." (ibid 105)

Similarly, Charles Darwin traced the development of the muscles expressing emotions in man and animals. (Darwin 1886)

G. B. Duchenne, the acknowledged father of electro-physiology, studied the movements of the facial muscles extensively by stimulating the muscles through the skin by electric currents.  But he, too, was concerned with them only as the 'muscles of expression'.  He described the "grand zygomatique, muscle de la joie", "triangulaire des levres, muscle de la tristesse et complementaire des passions agressives" (1876) and all the other facial muscles in similar fashion.

The research conducted in more recent times has either ignored the facial muscles completely, or has been concerned

with pathological medical problems and orthodontics.
(Kugelberg 1952; DePalma et al 1958; Meyers 1956; Tulley
1953; Carlsöö 1952 etc.) Basmajian (1962) has pointed out
that

> Systematic electromyography of the muscles
> of expression has been neglected...To my
> knowledge no organized study of normal
> function has been done in this field.
> (1962, 213)

In order to specify which muscles of the face are
involved, and the extent of their involvement in the produc-
tion of different speech sounds, extensive research must
be conducted.  Electromyographic techniques now makes this
possible.  But, while the EMG patterns reveal measurements
of muscle potentials, prior knowledge of which muscles are
involved, their location, mechanical function, and size is
necessary before any inferences may be made.  The starting
point for such research can be the knowledge of the facial
muscles based on the existing literature.  The summary
which follows relied to a large extent on this literature
coupled with personal dissection of the facial muscles of
four human cadavers.

## B. The Anatomy of Facial Muscles

The facial muscles are striated, voluntary muscles.
The term 'voluntary' refers to the fact that these muscles
can be controlled by the 'will' whether consciously or
unconsciously.  Like many other muscles of the body they

are bilaterally symmetrical. Except for the orbicularis oris, which is a continuous oval, each muscle is one of a pair which includes a muscle on the right side of the face, and a corresponding muscle on the left side. However, it should be noted that pairs of symmetrically situated muscles in the same body differ in structure considerably. (Buchthal and Lindhard 1939, 5) This must be considered in experimental work.

Every muscle has at least one nerve of supply which conveys motor impulses to it causing it to contract or relax and carries sensory impulses from it informing the central nervous system about its state of contraction. The network of the seventh cranial or facial nerve is the most important for the muscles of the face.

## 1. Attachments of Facial Muscles

Each muscle usually has two attachments, one at each end. The attachment that remains relatively fixed during muscle contraction is called the origin, while the attachment that moves is called the insertion. Both the origin and the insertion may be bones, membranes attached to bones, or other muscles. Most of the facial muscles involved in speech originate from bones and insert into muscles of the lips. Figures 7 and 8 illustrate the areas of muscle attachments. Both origins and insertions are shown where they are visible.

Temporalis

Levator
labii sup.

Levator
anguli oris

Zygomaticus
(minor)

Zygomaticus
(major)

Masseter

Temporalis

Buccinator

A = Os frontale
B = Os zygomaticum
C = Maxilla
D = Mandibula

Orbicularis oris

Mentalis

Depressor labii inf.
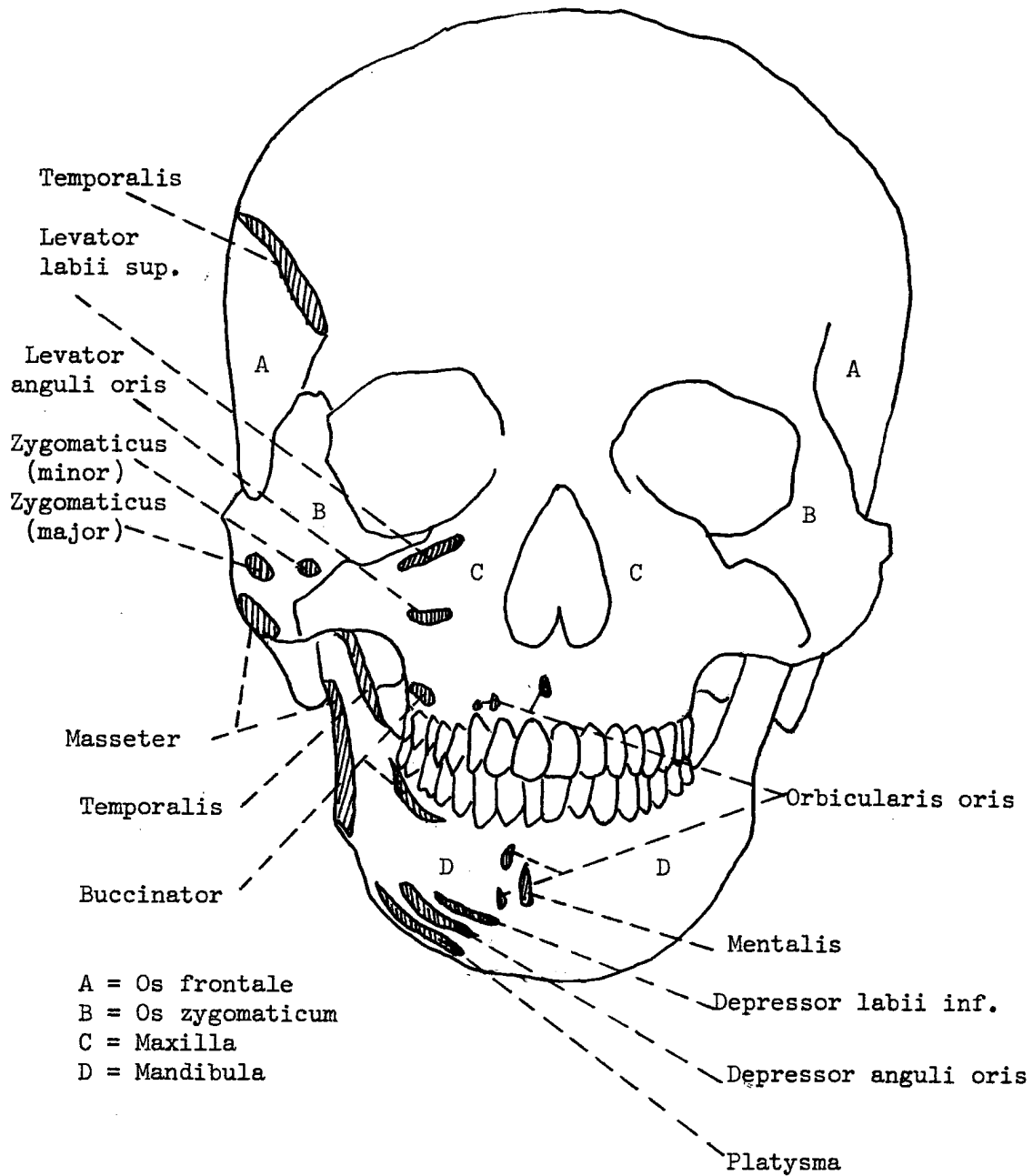
Depressor anguli oris

Platysma

Figure 7.   The skull from the front.   On the
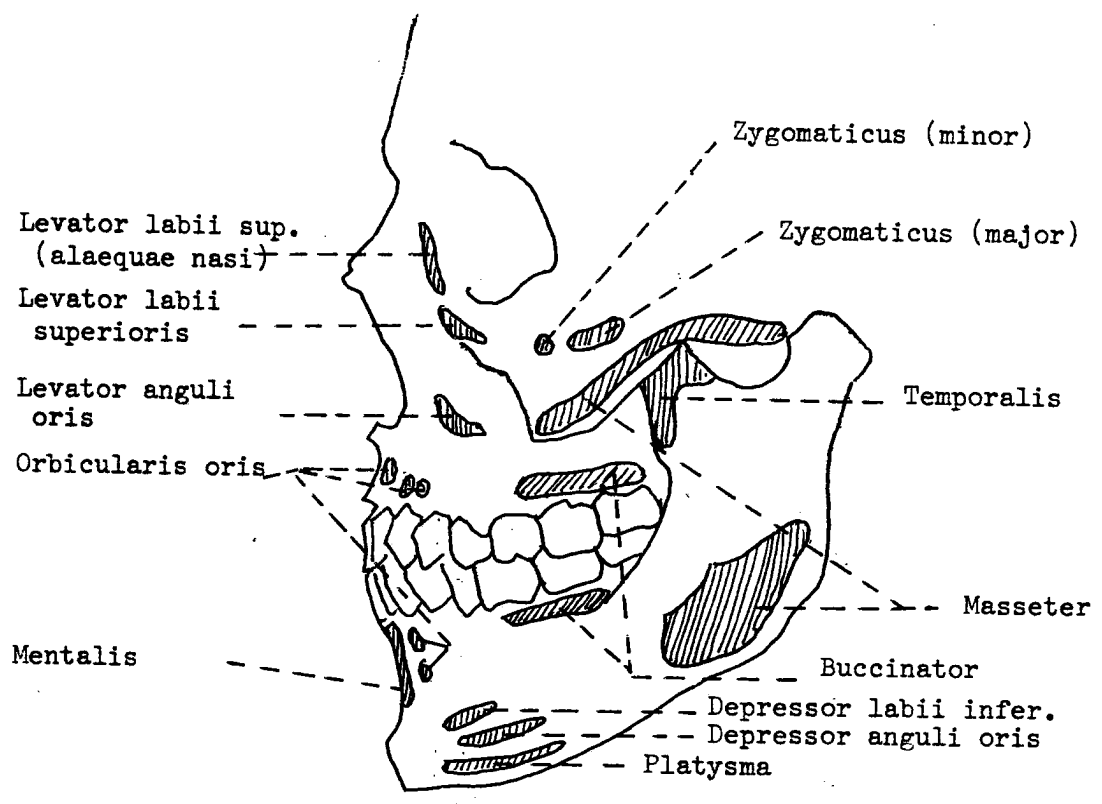right, areas of muscle attachment
are shaded. (After Pernkopf 1963)

Figure 8.  Left lateral view of skull.  Areas of
muscle attachments are shaded.

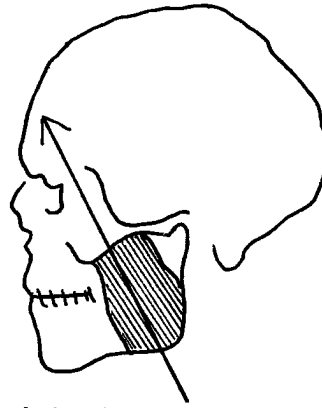## 2. The Function of the Muscles

Muscle function refers to the mechanical behavior of the tissue and the results of that behavior. The basic mechanical process involved in all muscle action is the contraction of many bound muscle cells, or fibers. The ability to contract is a direct consequence of the characteristic elastic property of the muscle. (Buchthal 1939, 73)

Duchenne (1867) suggested that a large number of muscles combine to create "the precise mechanism of muscular function". (xix) So interrelated are muscles that one contraction often involves many others. It has been demonstrated that the height of opening for the front vowels is controlled by the position of the jaw. (Fromkin 1964) Three major muscles are involved in raising the mandible: the masseter, the temporalis, and the internal pterygoid. As these muscles contract, the mandible is pulled up firmly against the maxilla (upper jaw). Figure 9 shows the directions of the pulls of these muscles as determined by Carlsöö. Historically, the mechanical behavior of muscles was determined by anatomists working on cadavers. The inherent difficulties of this procedure were pointed out by Duchenne:
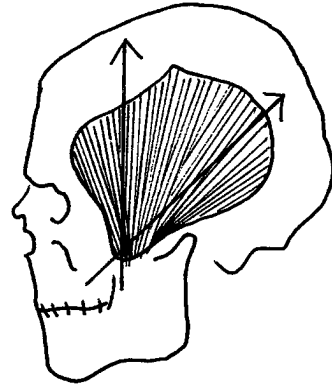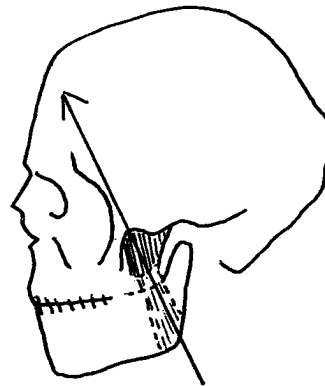
Temporalis muscle

Anterior portion of
Masseter muscle
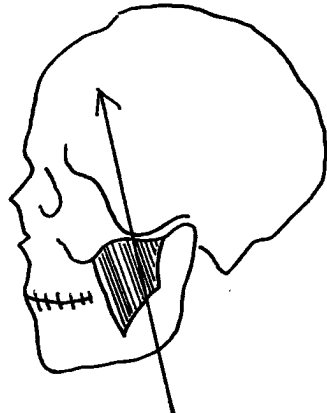
Posterior portion of
Masseter muscle

Pterygoideus
Internus muscle

Figure 9.  Left lateral views of skull showing
the muscles involved in raising the
jaw, and the direction of their
pulls. (After Carlsoo 1952)

> When I discovered that the results of my
> electrophysiologic experiments were not
> in agreement with results deduced by
> earlier investigators from their mechanical
> experiments on the cadaver, I could see
> that the laws which appeared most exact and
> based on these experiments were a cause of
> inevitable errors committed by most eminent
> observers. (Duchenne 1867, xviii)

Furthermore, as was pointed out by Buchthal, to fully understand the function of any organ, one must understand its structure.

> The shape of the contractive elements
> themselves and their arrangement in the
> muscle will influence profoundly the
> mechanical behavior of the tissue.
> (Buchthal 1939, 4)

The descriptions of the facial muscles which follow, however, will, as was stated above, be based on the existing literature. (cf. bibliography)  Any specification of a muscle's role in the production of particular speech sounds should be regarded as highly tentative.  Definitive conclusions can only be made after further research has been conducted.

## C. The Individual Muscles of the Face

Unless otherwise specified, the muscles of the left side have been shown throughout.  The illustrations are based on these in Pernkoff (1963), Quiring (1960), Gray (1959); the page references refer to Gray (1959) and Cunningham (1951). Other books of anatomy were consulted, however.  The Latin names according to Gray's Anatomy have

been employed. The anatomical terms "superior" and "inferior"
mean 'higher' and 'lower' respectively. "Anterior" and
"posterior" are 'front' (toward the surface of the face) and
'back' (away from the surface of the face). "Lateral" refers
to muscles towards the left or right sides, while "medial"
refers to those towards the middle plane of the body.

The definitions of other anatomical terms may be found
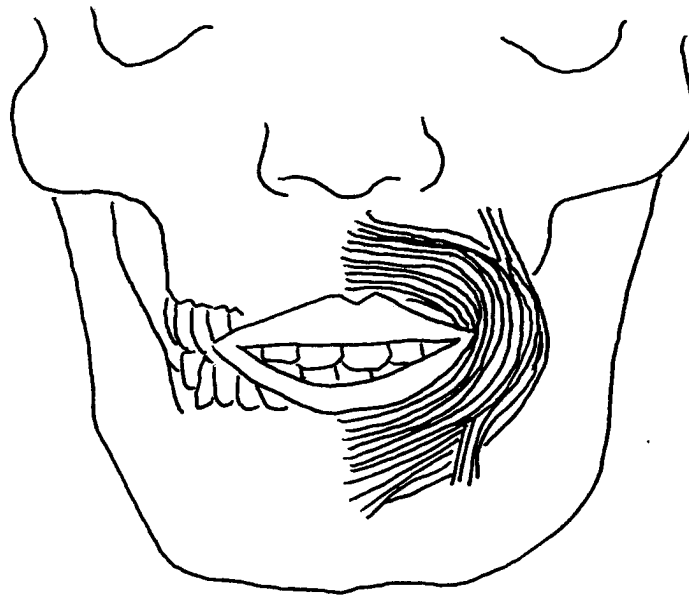in the glossary.

1. <u>Orbicularis</u> <u>Oris</u> <u>Muscle</u>

**Figure 10.** **The orbicularis oris**
**(after Quiring 1960)**

Origin and insertion: The orbicularis is a sphincter muscle formed by various facial muscles converging on he mouth, and by its own proper fibers. The deep stratum derived from the buccinator decussates at the angle of the mouth (angulus oris), the fibers from the maxilla (upper jaw) passing to the lower lip, and these from the mandible to the upper lip. Upper and lower buccinator fibers pass across the lips without decussation. More superfically the levator anguli oris and the depressor anguli oris fibers cross at the angle of the mouth, those from the levator to the lower lip and those from the depressor to the upper.

The upper fibers insert near the median line. Fibers from the levator labii superioris, the zygematicus, and the depressor labii inferioris intermingle with the transverse fibers. The proper fibers of the lips run obliquely under the skin surface to the mucous membrane. A lateral band of proper fibers arises from the alveolar border of the maxilla opposite the lateral incisors and arches laterally to continue with the fibers at the mouth angle. A medial band connects the upper lip with the nasal septum.

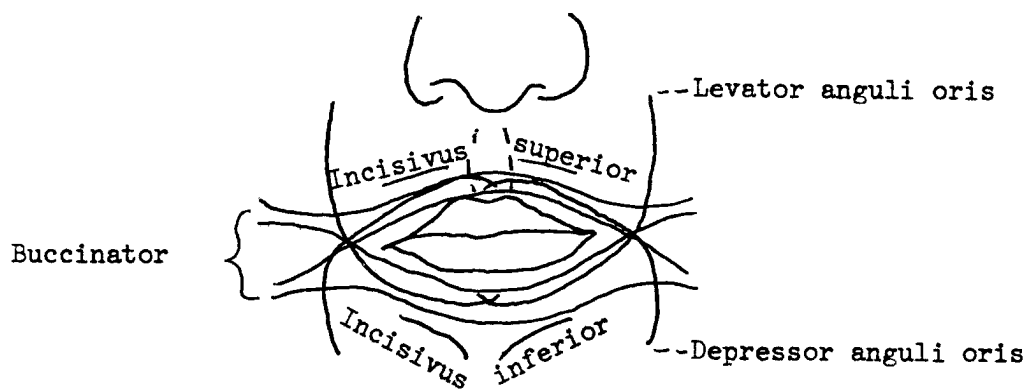Figure 11 illustrates the arrangement of the fibers.

Figure 11. A schematic diagram showing the
arrangement of the fibers of the
orbicularis oris. (after Gray
1959)

Location: around the rima oris (mouth opening), just

beneath the skin.

Shape: a circular flat band

Nerve: The lower zyg natic, buccal and mandibular branches

of the facial nerve (7th cranial).

Function: Compression, contraction and protrusion of lips.

Raises lower lip up, and upper lip is lowered. The compres-

sor fibers, not recognized as separate muscles by most

anatomists, run through the lips from outside to inside

(front to back) and flatten or compress the lips. The

orbicularis contracts during the articulation of bilabials

and rounded vowels, e.g. [b, p, u].

(Gray 419; Cunningham 424-427)

2. The Superior and Inferior Incisive Muscles

Location: Deep among the fibers of the orbicularis oris,
approximately 1/4 to 1/2 inch above the angulus oris, behind
the levator labii superioris.  The fibers of the superior
muscles run downward and outward, while the inferior fibers
run upward and outward.

Shape: thin, flat nearly triangular band.

Origin: from the external surface of the alveolar border
of the maxilla just internal to the canine teeth (superior);
from the external surface of the mandible, just below the
inferior incisives.

Insertion: into the fibers of the orbicularis oris near
the angulus oris. (cf. Figure 11)

Function: As they contract, they draw the corners of the
mouth toward the center of the face and up or down depending
upon which set is doing the pulling.

3. The Zygomaticus (major)

Location: About 1/4 to 1/2 inch external to the levator
labii superioris.  The most external and longest band of
muscular fibers in the infraorbital region.  The direction
of its fibers is downward.

Shape: a flat band.

Origin: from the zygomatic portion of the zygomatic arch.

Insertion: into the angle of the mouth, mingling with
the orbicularis oris, the levator anguli oris, and the

depressor anguli oris.

Nerve: the zygomatic and buccal branches of the facial
nerve.

Function: it draws the angle of the mouth backward and
upward. It is probably involved in the articulation of the
spread vowels, e.g. [i], together with the other muscles
which pull the corners of the mouth lateralward (risorius)
buccinator, triangularis).
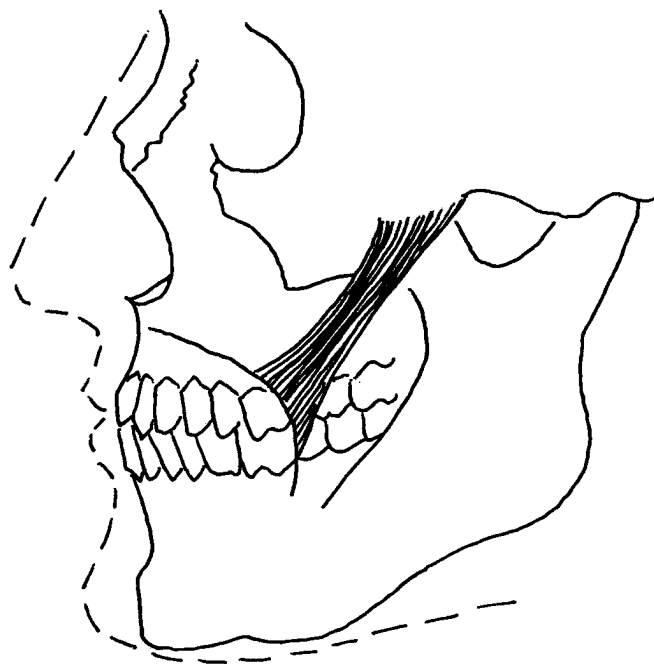
(Gray 418; Cunningham 425-7)

Figure 12. The zygomaticus (major)

4. <u>Levator</u> <u>Labii</u> <u>Superioris</u> (Quadratus) (includes the
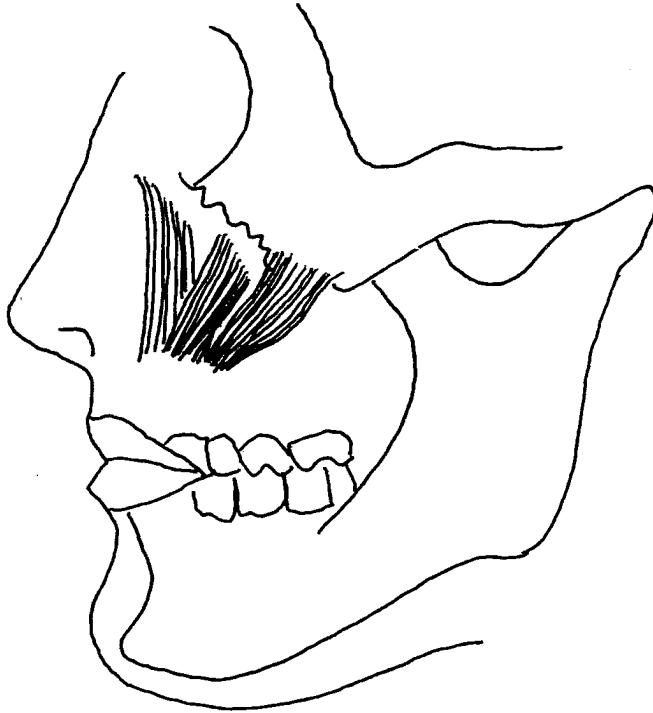<u>Zygomaticus minor</u>)



Figure 13.  Levator labii superioris and
zygomaticus (minor)
(after Quiring 1960)

A three headed muscle usually considered together by
anatomists.

<u>Location</u>: The zygomaticus minor is just beneath the skin.
It corresponds to the most external fibers of the quadrati
labii superioris which forms a separate bundle across the
fibers of the levator anguli oris (caninus) at an acute
angle.  The <u>levator</u> <u>labii</u> <u>superioris</u> is just beneath the
skin of the face between the labium superioris (upper lip)

and the margo infra-orbitalis.

Shape: All three parts of the muscle are thin, flat bands, quadrilateral in shape.

Origin: Angular head arises from the upper part of the maxilla; infra-orbital head arises from the margin of the orbit above the infra orbital foramen; zygomatic head arises from the zygomatic bone in the region medial to and under the bony orbit.

Insertion:  Angular head into greater alar cartilage, skin of nose and lateral part of the upper lip; infra-orbital head into the muscular substance of upper lip between angular head and caninus; zygomatic head into the skin of the naso-labial groove and upper lip.

Nerve: Zygomatic and buccal branches of facial nerve.

Function: Angular head elevates upper lip; infra-orbital head raises angle of mouth; zygomatic head elevates upper lip laterally.  These muscles may help to evert the upper lip.  After the release of bilabial consonants, and alveolar consonants there is a slight eversion of the lips which may involve the muscles.  In the articulation of labio-dentals e.g. [f] and [v], the upper lip is raised directly by the quadratus.

(Gray 418; Cunningham 425, 427)

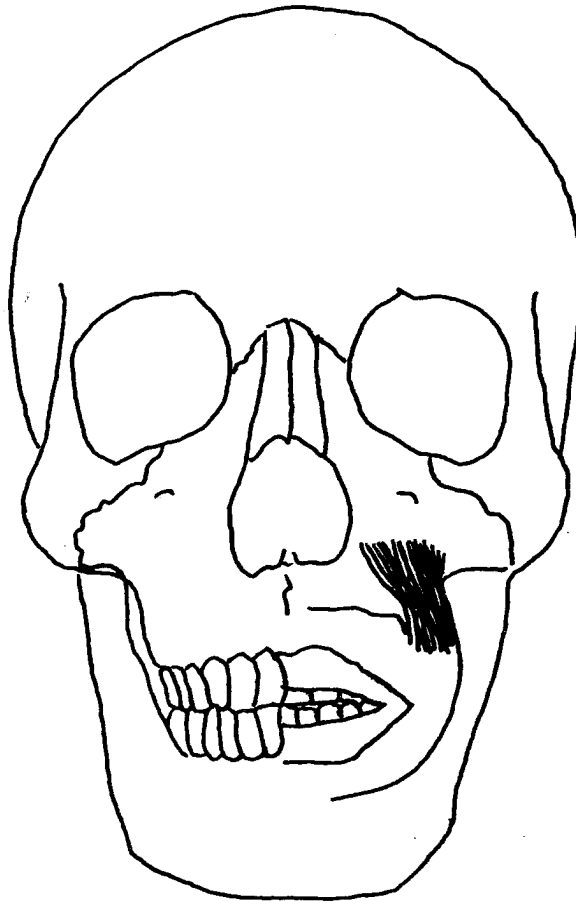5. Levator Anguli Oris (Caninus)



**Figure 14. The levator anguli oris**


Location: This muscle is posterior to the infra-orbital

head and the zygomatic head of the quadratus. (cf. Figure 7)

It is anterior to the buccinator, just above the angulus

oris.

Shape: triangular

Nerve: Zygomatic and buccal branches of the facial nerve.

Function: elevates angle of mouth upward and inward.
In the production of [f] and [v] the upper lip is elevated
and pulled slightly inward by the action of the caninus.
(Gray 418; Cunningham 425)

6. The Risorius
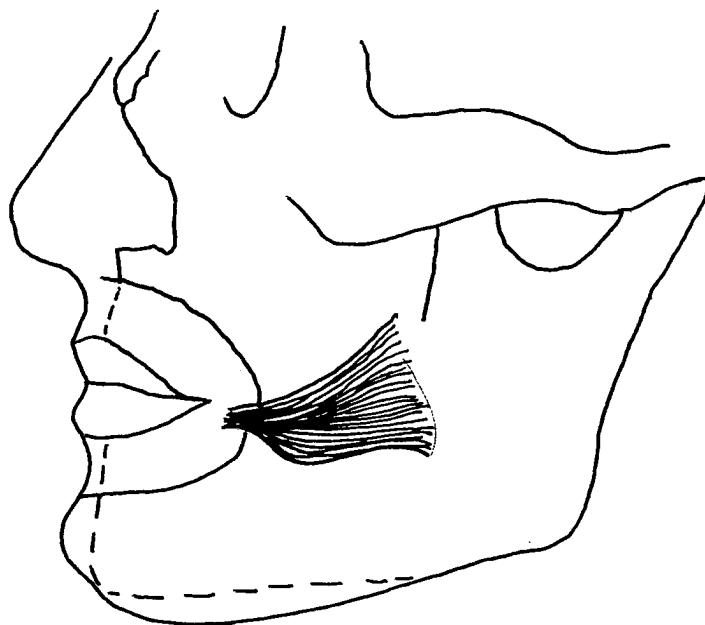


**Figure 15.  The risorius muscle**

Location: external to the masseter and buccinator.
Inferior to the zygomaticus.  From above downward, lies be-
tween the zygomaticus and the depressor anguli oris.  It is
external to the platysma.  (It may be noted that in attempt-
ing to separate the risorius during dissection it is so thin
and so intertwined with the platysma it was impossible to

separate this muscle from the skin or the platysma.)

Shape: Triangular.  Its base is located over the masseter.

Origin: It arises from the parotid fascia near the ear.

Insertion: into the angle of the mouth.

Nerve:  The zygomatic and buccal branches of the facial nerve.

Function: retracts the angle of the mouth.  This is one of the group of muscles which are active in pulling the angle of the mouth away from the midline in the production of the spread vowels.

(Gray 419; Cunningham 426, 427)

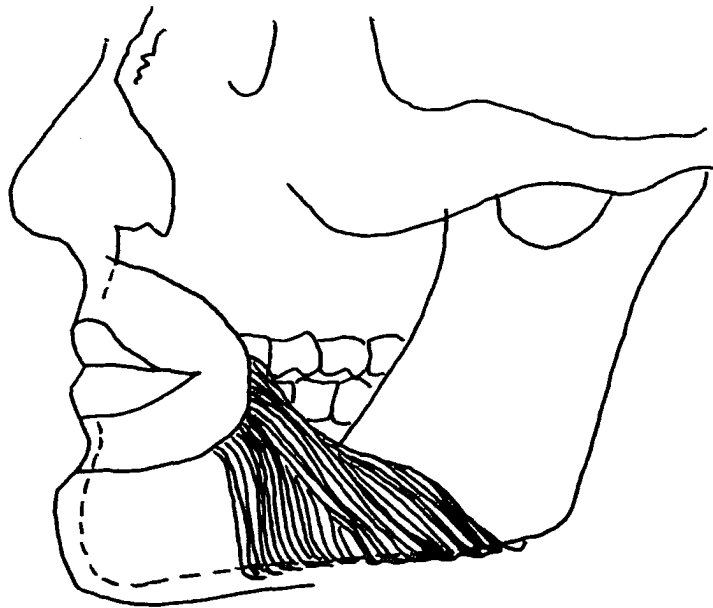7. The Depressor Anguli Oris (Triangularis)

Figure 16.  The depressor anguli oris

Location: external and inferior to the angulus oris. It lies between the angle of the mouth and the anterior part of the lower border of the mandibula. It is directly beneath the skin, external and anterior to the platysma.

Shape: triangular. The apex is at the angle of the mouth and the base at the lower border of the mandible near the mentis.

Origin: arises from the mandible.

Insertion: into the angle of the mouth into the orbicularis and the skin.

Nerve: the mandibular and buccal branches of the facial nerve.

Function: depresses the angle of the mouth.

(Gray 419; Cunningham 426, 427)

8. Depressor Labii Inferioris (Quadratus labii inf.)
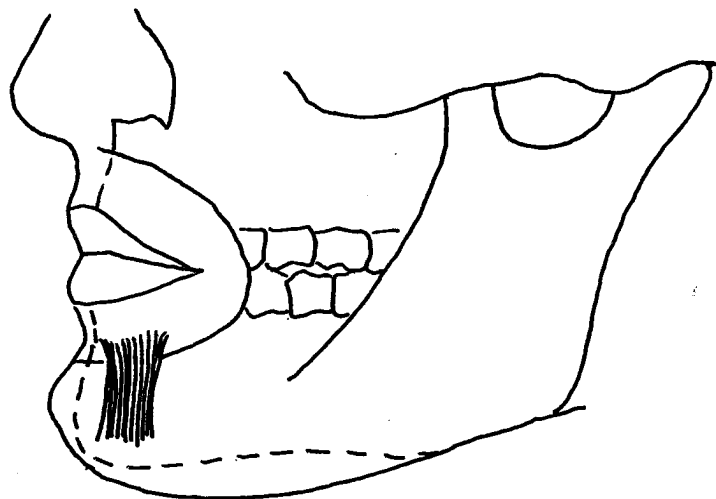


Figure 17. The depressor labii inferioris

Location: below the lower lip and above the mentis;
internal to the triangularis.

Shape: quadrangular.

Nerve: mandibular and buccal branches of facial nerve.

Origin: arises from the lower, central, lateral surface
of the mandible.

Insertion: into the skin of the lower lip, mingling with
the orbicularis oris, its medial fibers joining those of
opposite side.

Function: depresses the lower lip and draws it lateral-
ward. In emphatic speech may assist in pulling lip down
after closure in bilabial consonants.

(Gray 419; Cunningham 426)


9. The Mentalis
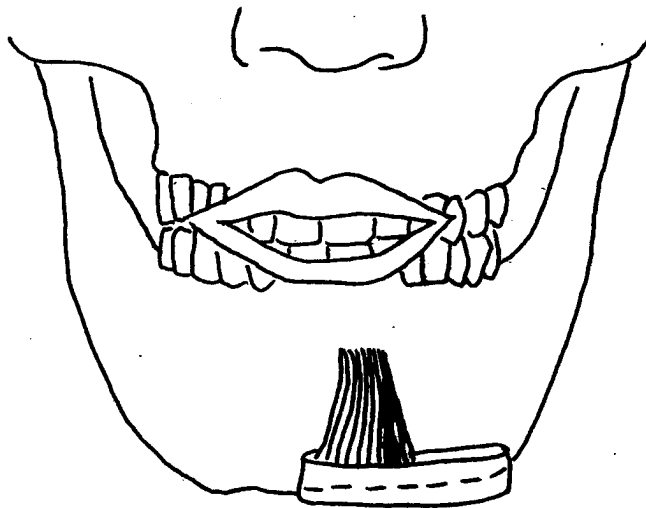


Figure 18. The mentalis muscle

Location: below lower lip at the midline.

Shape: a thin band forming a half circle.

Nerve: mandibular branch of facial nerve.

Origin: fibers arise from front surface of the mandible running downward.

Insertion:  into the skin of chin and lower margin of prolabium of lower lip; into corresponding portion of the orbicularis oris.
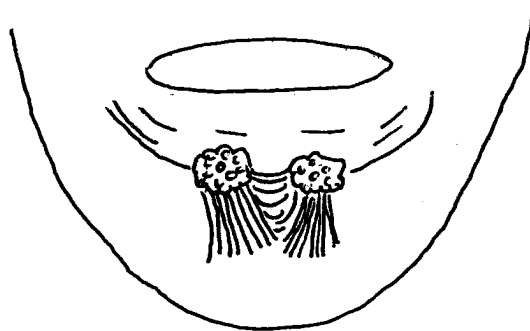


Figure 19.  A view of the mentalis muscle seen
from the inside looking toward the
inner surface of the skin

Function: raises and protrudes lower lip, wrinkles skin. In the production of [f][v][θ][ð][s][z][s] and [z] the mentalis muscle may be involved in the raising and everting of the lower lip.

(Gray 419; Cunningham 426-427)

## 10. The Buccinator
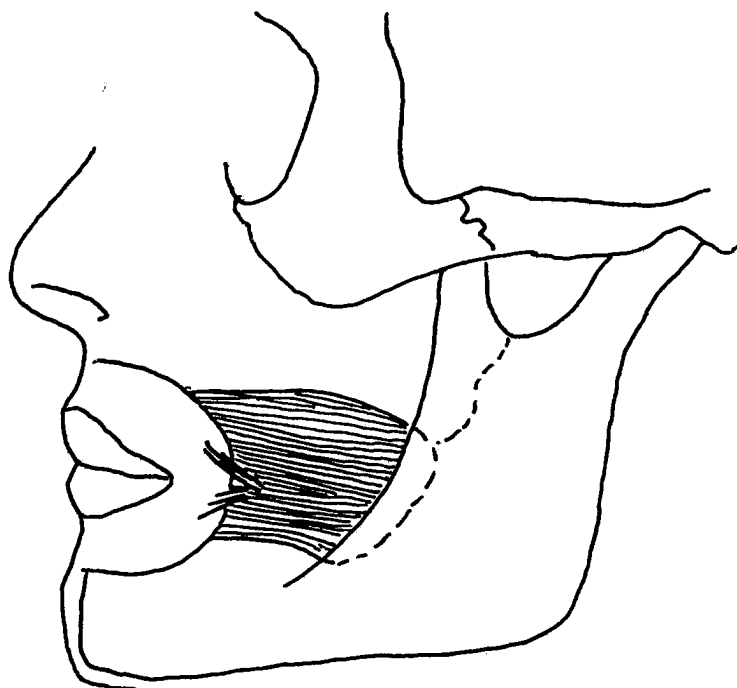


Figure 20.  The buccinator muscle

Location: in the cheek between the tunica mucosa
and the skin. Spans the lateral interval between the maxilla
and the mandibula. The zygomaticus crosses its outer surface
obliquely from above downward and forward.

Shape: quadrilateral.

Nerve: the deep buccal branches of the facial nerve.

Origin: from the lateral surfaces of the maxilla
and mandible, opposite the sockets of the molar teeth; from
the anterior border of the pterygo-mandibular raphe.

Insertion: the fibers converge toward angle of the
mouth, where they blend with the fibers of the orbicularis
oris; the upper fibers pass to the lower segment of the
orbicularis; the lower fibers pass to the upper segment of
that muscle. (cf. Figure 11)

Function: compresses the cheeks, thereby expelling
air between the lips; lengthens the rima oris (mouth open-
ing) by drawing the angulus oris outward and backward. In
the production of the labio-dentals e.g. [f] and [v], the
buccinator pulls the lower lip backward so that it makes
contact with the upper incisors. The buccinator is also
involved in spreading the lips for such vowels as [i] and
[e].

(Gray 420; Cunningham 426, 427)

11. Masseter
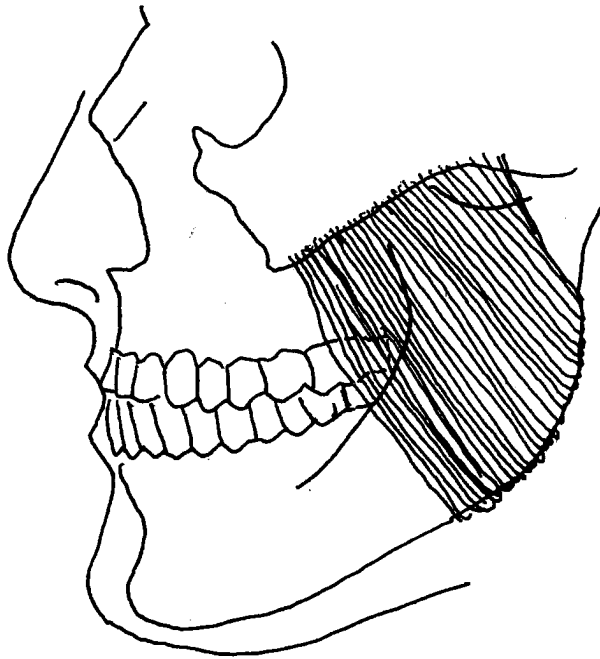


**Figure 21. The masseter muscle**

Location:  It covers the entire outer surface of
the ramus mandibulae, except the neck of the caput mandibulae.

Shape: quadrilateral.

Nerve:  motor root of the fifth cranial or trigeminal
nerve.

Origin: superficial portion arises from the anterior
two thirds of the lower border of the zygomatic arch; the
deep portion from the medial surface of the zygomatic arch.

Insertion: lateral surface, upper half of ramus,
and angle of mandible.

<u>Function</u>: elevates jaw, clenches teeth.  (cf. Figure 3)
(Gray 424; Cunningham 431-433)

It has been suggested that when the mandible performs its closing movement the masseter muscle comes into action only when the mandible has to overcome resistance as, e.g. in mastication, while in speech, the movement is performed by the temporal muscle alone.  (Carlsöö 1952)

12. <u>Temporalis</u>
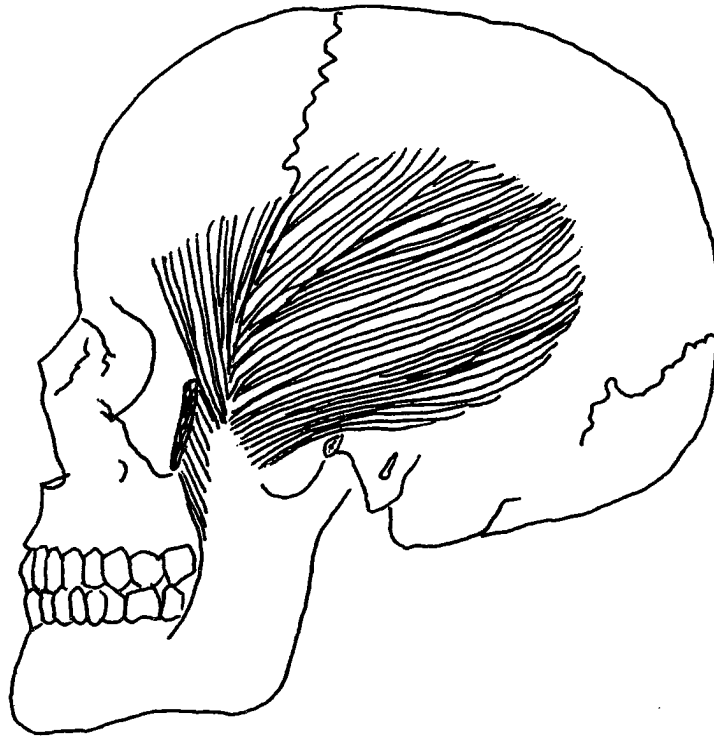


**Figure 22.   The temporalis**

Location: covers the side of the head; fills the entire fossa temporalis, except a small portion at the anterior part; internal to the fascia temporalis and the zygomatic arch.

Shape: fanlike.

Nerve: motor root of the fifth cranial or trigeminal nerve.

Origin: floor of temporal fossa and temporal fascia.

Insertion: Anterior border of coronoid process and anterior border of ramus of mandible.

Function: elevates jaw, retracts mandible, clenches teeth.

(Gray 424; Cunningham 432, 433)

13. The Platysma

Location: In the deep layer of the superficial fascia of the lateral aspect of the neck and of the antero-superior part of the thorax, from the mandible downward.

Shape: a quadrilateral sheet.

Nerve: cervical branch of facial nerve.

Origin: Upper pectoral and deltoid regions by bundles from superficial fascia. These fibers cross the clavicle and pass obliquely upward and medialy along the sides of the neck.

Insertion: anterior fibers of one side interlace below the chin with those of the other and connect with

depressor labii inferioris and depressor anguli oris. Pos-
terior fibers pass across the angle of the jaw and some in-
sert into the mandible; others pass to the skin of lower
part of mouth.

Function: depresses lower jaw and lip; tenses and
ridges the skin of the neck. "It is sometimes called the
muscle of accentuation, on account of its contracting with
nearly every movement of the body which requires an excess-
ive amount of physical strength or mental energy." (emphasis
mine)(Hoeve 1910, 5)

Figure 23. The platysma muscle

D. Glossary of Anatomical Terms

caput: a head or headlike part

decussate: to cross or intersect

fascia: fibrous connective tissue forming sheets or layers

    beneath the skin, for enclosing or connecting

    muscles or internal organs

fossa: a shallow depression or cavity

mucosa: a mucous membrane

process: (Processus): an accessory outgrowth or prominence

    of an organ, bone etc. or any of its parts

ramus: a branchlike division of a forked structure, as

    of a bone, nerve etc.

raphe: a seamlike appearance along the median line join-

    ing two halves of a symmetrical organ or part

septum: a dividing wall between two cavities

tunica: any loose membranous skin or mantle of tissue

    enveloping an organ or part.

E. The Location of Lip Muscles by Electromyography

As is evident from the description of the facial muscles
in Section 2, these muscles are small and close together.
Due to the differences of size and shape of different human
heads, it is difficult to locate the exact places of the
different muscles by superficial examination of the face.
As a preliminary step to an electromyographic investigation
of the role of facial muscles in speech production, it is

necessary to be more exact regarding the location of the muscles involved. Such knowledge would permit the investigator to place the recording electrodes over a known muscle and allow one to make plausible inferences about the electromyographic patterns which are obtained. Therefore, research was conducted to map the location and approximate sizes of the lip muscles for the principle subject.

Using the information given in section 2, a first approximation of the location and sizes of the subject's lip muscles were drawn on a life-size photograph of the subject.

It has been demonstrated (Buchthal 1961) that the amplitude of the single motor unit potential is largely determined by the distance of the recording electrode from the active fiber group. Furthermore, only the potentials from active fibers within a limited area surrounding the electrode will be picked up. By placing the electrodes at one centimeter intervals it would thus be possible to determine the approximate location of the muscles.

In order to allow for exact specification of the electrode placement and to insure exact duplication of the procedure when the experiment was repeated, a stone cast was made of the subject's face. The bottom left quarter of the mask was divided into nine columns and eight rows. A hole was drilled in each cell of this matrix. Prior to the attachment of the surface electrodes used, the cast was

placed on the face, and marks were made through the holes in the cast.  Figure 24 is a photograph of the cast, and Figure 25 of the face marked in preparation for the electrode placement.

In a series of experiments an electrode was placed in each of the 56 points.  The subject repeated the following seven gestures three times: (1) /u/ as in 'who', (2) /a/ as in 'ha', (3) /s/ as in 'hiss', (4) /f/ as in 'fud', (5) smile, (6) upper lip raised, (7) bottom lip lowered.  These gestures were selected since there is general agreement as to which muscles are used to produce them.  (Darwin 1886; Bell 1888; Duchenne 1867, 1876; Spalteholz 1943; Van Riper and Irwin 1958; Gray 1959; Cunningham 1951; et alia)

The action potential spikes were rectified and integrated by an active resistor-condensor circuit which acted as a low-pass filter with a cut off at 42 cycles and a 12 db/octave slope.  The original electromyography signal, the integrated signal, and the audio wave were all recorded on an Oscillomink ink-writer.  Figure 26 shows the Oscillomink traces of the audio signal, the EMG raw signal, and the EMG integrated signal while /u/ was produced by the subject, with the electrode placed on C5, C6, and C7 of the matrix.

A measurement was made from the base line to the highest point of an envelope of the integrated signal. Bigland and Lippold (1954) showed that the integrated potentials vary directly with the strength of a contraction in

Figure 24.    Photograph of stone cast used
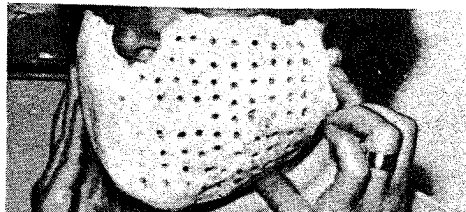to insure proper placement of
electrodes.
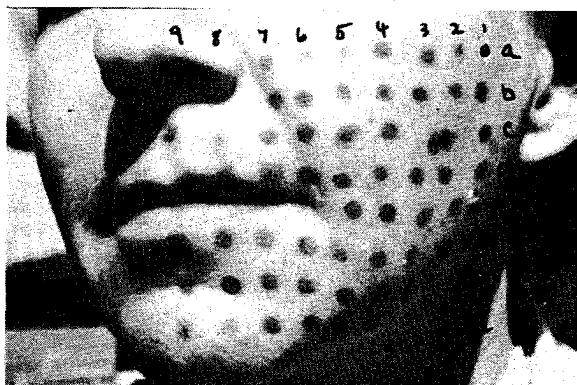


Figure 25.    Photograph of face marked
through holes in stone cast.
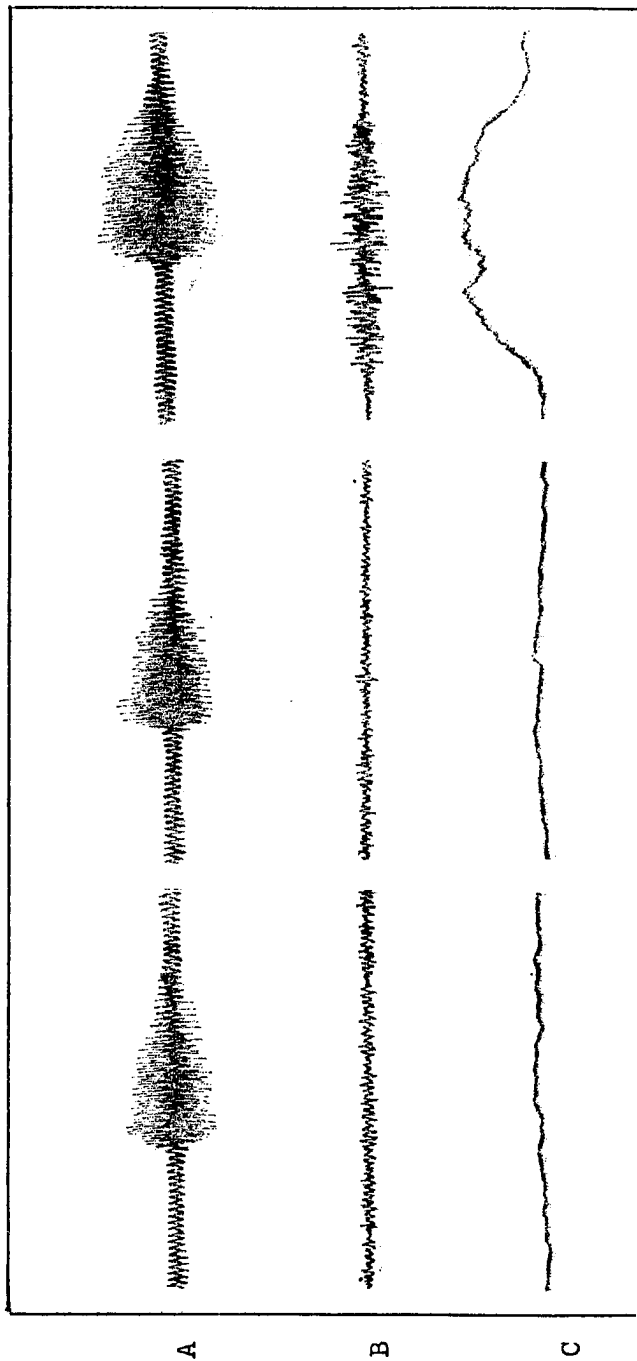
Electrode
Placement

C5        C6        C7

A = audio signal; B = raw EMG signal; C = rectified and integrated EMG signal

Figure 26.  Differences in muscle action potentials resulting from placement of recording electrode on three different facial areas, while subject said /u/.

a muscle. Since the aim of this procedure was primarily to determine whether or not there was muscle action present, the actual measurements were not as important for this experiment as a qualitative judgment of the amount of muscle activity present. The measurements were therefore rounded off to the nearest 5 mm and entered on a life-size photograph of the subject's face with the matrix marked. A number 5 represented a small amount of muscle action, and a number over 20 a considerable amount. Figure 27 illustrates the results, omitting the amount of action and merely showing by the shaded areas those matrix cells where action was recorded. The darkest areas represent the greatest amount of muscle activity.

By combining the above results with the information available about the actions of the individual muscles, a close approximation to the actual location of the muscles was possible. Figure 28 represents a tracing from a photograph of the subject with the muscles drawn in.

Using this information, one can proceed to investigate the relative amounts of lip muscle action for different speech sounds.

/f/

/a/

smile

/s/

upper lip raised

/u/

bottom lip lowered
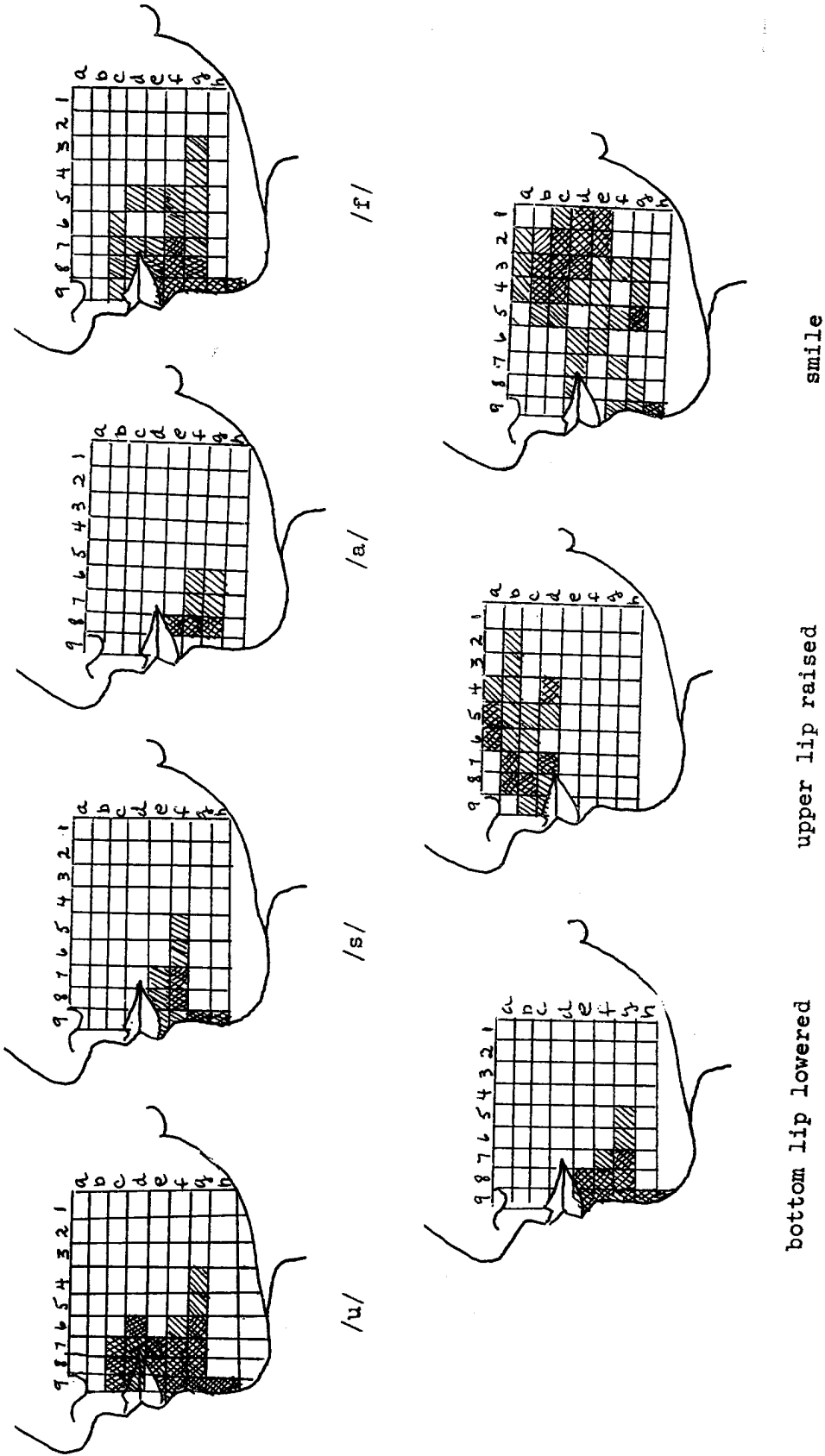
Figure 27. Electromyographic activity of facial muscles for seven gestures.
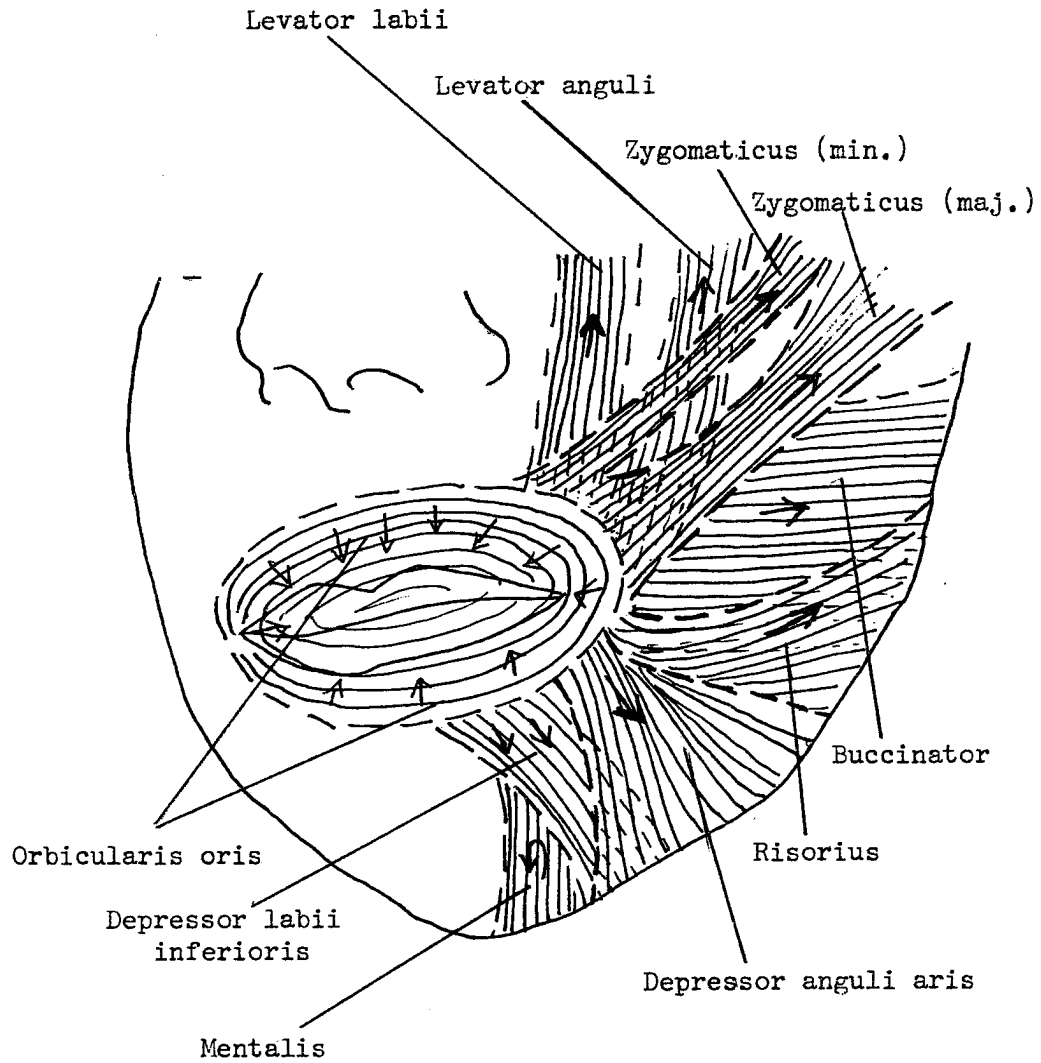
Figure 28.  The positions of the muscles as determined
by electromyography.

CHAPTER IV.


NEURO-MUSCULAR SPECIFICATION OF LINGUISTIC UNITS.


A. <u>Aims of the Experiment and Hypotheses Tested</u>.

The present study attempted to test the possibility of correlating linguistic units such as phonemes or distinctive features with neuro-muscular activity.  Electromyography was selected as the technique by which this objective could be accomplished.  The specific hypotheses tested are as follows: (1) a simple, nearly one-to-one correspondence exists between phonemes and the motor commands that activate the muscles in articulation; specifically, the vowel phoneme; and the bi-labial stops /p/ and /b/ in American English can be characterized by a certain invariance of muscular action without regard to phonetic context; (2) the distinctive feature 'tense-lax' distinguishes /p/ from /b/ in American-English, with /p/ being tense, and /b/ lax; (3) American-English vowels fall into two distinctive sets, a set of rounded or 'flat' vowels produced with action of the orbicularis oris muscle, and a set of unrounded or 'non-flat' vowels produced without action of this muscle.

The first hypothesis was proposed by members of the Haskins Laboratories.  In their attempt to produce a unified model of speech production and perception, they have

suggested (Liberman et al. 1962) that a simple, nearly one-to-one correspondence with phoneme perception may be found "in the motor commands that actuate the articulators". They support this hypothesis with experimental findings: "...with temporally overlapping phonemes that are articulated by different groups of muscles -- such as /f/ and /t/...-- we can find an invariant EMG tracing for each phoneme, regardless of the context in which the phoneme occurs." (Liberman et al. 1965, 2.20) The present study therefore aimed at supplying additional data for evaluating this hypothesis.

Regarding the second hypothesis, certain phonological descriptions of American-English (Gimson 1962; Bloomfield 1933; Gleason 1955) describe the unvoiced stop /p/ as tense or fortis, and the voiced stop /b/ as lax or lenis. The articulatory correlate of the feature tense or fortis has been defined as "greater amount of muscle tension", or "vigor of action in the lips or tongue" (Bloomfield 1933, 99). Gleason (1955) describes fortis sounds as those produced with "relatively stronger articulation" (195) and states that "in English /p t k/ are generally fortis... and /b d g/ generally lenis" (ibid).

The muscle involved in the articulation of the bilabial is the orbicularis oris muscle of the lips, which closes and protrudes the mouth. If /p/ is more tense than /b/, and if this is the principal feature which differentiates these two phonemes, the articulation of /p/ should consist

ently produce more tension than the articulation of /b/. Instead, if gestures for /p/ and /b/ are either identical or if there is no consistent relationship, a feature other than the tense-lax feature must distinguish these two phonemes, e. g. the action of the glottis.

The latter position is the one supported by Haskins Laboratories (Liberman et al. 1962) who found " the electro-myographic activity at the lips (to be)...essentially the same for /p/ and /b/".

These two contradictory positions were subjected to a tentative test in the present study.

B. Methods and Procedures

  1. Selection of the Muscle to be Studied

One variable was singled out for study, i. e. muscular activity of the orbicularis oris muscle. This sphinctor muscle which completely surrounds the rima oris (mouth opening) is located directly under the skin of the vermillion border of the lips and about one centimeter above and below the lips. If different values could be assigned to this selected parameter for a given set of American English phonemes, other parameters could be selected for investigation, with appropriate values assigned, thus permitting an objective physiological specification of these sound segments. The amount and duration of muscle tension produced by this muscle was investigated by means of the electromyography.

It is obvious that many functional sound units of American English cannot be described by reference to the action of this muscle. An attempt to describe /k/ by reference to a feature involved in lip action would be nonsensical. However, American English vowels have been grouped into two 'natural' classes: rounded vs. unrounded. Actually, the term 'rounded' in reference to American English vowels is misleading, since for the most part only protrusion of lower lip is involved. (Fromkin 1964) But in any case, 'rounded' or 'flat' vowels (Jakobson and Halle 1956) must involve action of the orbicularis oris. Furthermore, bilabial consonants involve lip closure. The orbicularis is the principal muscle responsible for this articulatory gesture. All the other facial muscles have as their function opening the lips, retracting the angle of the mouth, etc. While the mentalis, and the incisivus muscles aid in everting the lip, their function does not involve lip closure.

The orbicularis oris is a muscle easy to locate. By selecting this muscle, a reasonable guarantee could be made that action potentials recorded on the lips would reflect activity primarily from the orbicularis oris.

2. <u>Selection of Utterances</u>.

Monosyllabic CVC utterances were chosen for investigation. An attempt was made to select utterances which fulfilled the following conditions: (1) utterances which could be used as references which ostensibly did not involve

action of the orbicularis oris; (2) utterances in which
only the vowels might involve orbicularis action; (3)
utterances in which only the consonants might involve action
of the muscle; (4) utterances in which both consonants and
vowels might involve action of the orbicularis, to permit
an investigation of the possible coarticulation influence.

The reference frame chosen was a /d_d/ syllable, since
at the start of the investigation it was assumed that/d/
would not demonstrate any action of the lip muscles. The
bilabial consonants selected for study were /p/ and /b/.
Twelve vocalic nuclei were selected. Table 1 presents a
list of the utterances selected for study. The phonemic
symbolization of the utterances is followed by a word in
American English to illustrate the quality of the vowel.

| /did/ | 'deed' | /bid/ | /dib/ | /bib/ | |
|-------|--------|-------|-------|-------|---|
| */dɪd/ | 'did' | */bɪd/ | /dɪb/ | */bɪb/ | */pɪd/ |
| /ded/ | 'date' | /bed/ | /deb/ | /beb/ | */pɪp/ |
| /dɛd/ | 'dead' | /bɛd/ | /dɛb/ | /bɛb/ | */dɪp/ |
| /dæd/ | 'dad' | /bæd/ | /dæb/ | /bæb/ | /pud/ |
| /dad/ | 'dot' | /bad/ | /dab/ | /bab/ | /dup/ |
| */dud/ | 'dude' | */bud/ | */dub/ | */bub/ | /pup/ |
| /dʊd/ | 'could' | /bʊd/ | /dɚb/ | /bʊb/ | |
| /dʌd/ | 'dud' | /bʌd/ | /dʌb/ | /bʌb/ | |
| /derd/ | 'dirt' | /berd/ | /derb/ | /berb/ | |
| /dɔd/ | 'dawn' | /bɔd/ | /dɔb/ | /bɔb/ | |
| /dod/ | 'dote' | /bod/ | /dob/ | /bob/ | |

Table 1. A list of the 54 utterances studied, with
examples given of English words in which
the vowels occur. The starred utterances
are those produced by the three non-principal
subjects.

3. Subjects

The subjects were four adult graduate students,
~~three~~ female, one male. Three of the subjects were students

in linguistics, and all were speakers of some dialect of American English. One subject was the principal subject, while the other three were used for comparison, to determine whether the results obtained from the principal subject could be corroborated by the data recorded from the other three. Also, it was felt that a comparison of the four subjects could reveal the variance in muscle action between individuals. A selected set of utterances were produced by the three non-principal subjects. These are starred in Table 1.

With the electrode in place, each of the three non-principal subjects repeated each utterance twenty times. The principle subject repeated each utterance twenty times on two different occasions to permit a comparison of the averaged results obtained at two different times. Thus, electromyographic recordings of 2700 utterances constituted the data of the study.

4. Instrumentation

The subjects were grounded and placed in a shielded cage to help eliminate extraneous electrical signals. A suction electrode such as has been described by Haskins Laboratories (Harris et al. 1964) was placed at the medial line of the lower lip on the vermillion border. (see Figure 29).
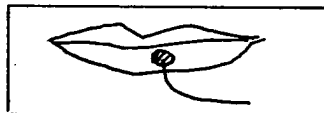


Figure 29. Location of electrode

The EMG signals were fed into one channel of the Tektronix type 502 Oscilloscope with linear dual beam displays. A microphone was placed directly in front of the subject's mouth, and the audio signal was recorded on one channel of a 4-channel Viking model 95 tape recorder. The EMG signal after being amplified through the cathode ray oscilloscope was recorded on another channel of this multi-channel tape recorder.

The cathode ray oscilloscope used had a gain of $10^6$, and the display sensitivity was set at 500 microvolts/cm during all the recordings. The EMG signals were first monitored by watching the oscilloscope screen to make sure that the noise was negligible. The four channels of the Viking tape recorder used had a frequency response of $\pm$ 3 db from 10 to 6,000 cps.

The two heads of the Viking tape recorder were staggered so that when the tapes were played back on a dual channel Ampex tape recorder with in-line heads the audio signal recorded on the Viking would play back from the Ampex .55 seconds prior to the EMG signal.

After the EMG signals and audio signals were recorded on tape, they were played back and recorded on a Siemens direct writing jet Oscillomink with a frequency response specified to be from DC to 1000 cps. This was done as a means of monitoring the data and excluding those samples with excess noise, movement artifacts, and extraneous

signals. It also permitted a comparison of the individual raw EMG signals with the averaged signals.

The value of .55 seconds used above was derived from a study of the Oscillomink records which showed that in all cases the time lapse between onset of muscle activity and the onset of the audio signal was less than the above value. The net effect of this procedure was to make the audio signal available somewhat earlier in time than its corresponding EMG signal.

The EMG and audio signals were then played back on an Ampex dual channel tape recorder. The EMG signal was then rectified using a full wave diode bridge fed from a transformer having a 10 to 1 step up ratio. The rectified EMG signal and the audio signal were fed through two channels of a Cathode Ray Oscilloscope into two channels of a small general purpose computer.

The computer used was the LINC (Laboratory Instrument Computer), a small stored-program digital computer. A program was written specifically for this study by Doctor George Moore, Professor of Physiology at the University of California, Los Angeles. The program was stored on magnetic tape which could then be conveniently retrieved for use at any time. The principle output of the LINC is an oscilloscope display which may be viewed directly or photographed.

The general function of the computer was as follows. On being triggered by the onset of an audio signal the

computer initiated a 1.1 second scan of the subsequent audio
signal and the corresponding EMG signal. The sampled values
of each signal were stored in the computer memory and
successive scans of the repeated audio-EMG signals were
automatically summed for 20 repetitions of the same utter-
ance. These sums (proportional to averages) were displayed
on the LINC oscilloscope as histograms. In addition, as
desired, neighboring points of the histogram could be fur-
ther summed to produce a somewhat smoother trace. These
were scaled down by a factor of 8 to stay within the storage
capabilities of the LINC. The sampling constants were as
follows: duration of sample length for each utterance -
1.1 sec; number of samples of each channel taken during
1.1 sec - 512. Results were permanently recorded as photo-
graphs of the displayed traces.

Figure 30 shows the principal components of the system
used. The computer program flow chart is presented in
Appendix A. Figure 31 shows a raw EMG signal as recorded on
the Oscillomink, 20 EMG signals summed by the computer, and
the summed signal smoothed and scaled down.

A check on the general stability and repeatability of
the computing scheme was made by rerunning large blocks of
the same data at different times and comparing the results.
Figure 32 shows the comparative results. These results
compare closely enough to indicate that effects due to
quantizing noise in the computer, slight shifts in trigger

RECORD DATA

Output for monitoring

Ink writer

4 channel Viking tape recorder (staggered heads)

Two channel oscilloscope

Microphone

Electrode

PLAYBACK & PROCESS DATA

2 channel Ampex tape recorder

Rectifier

2 channel oscilloscope

LINC computer

Display
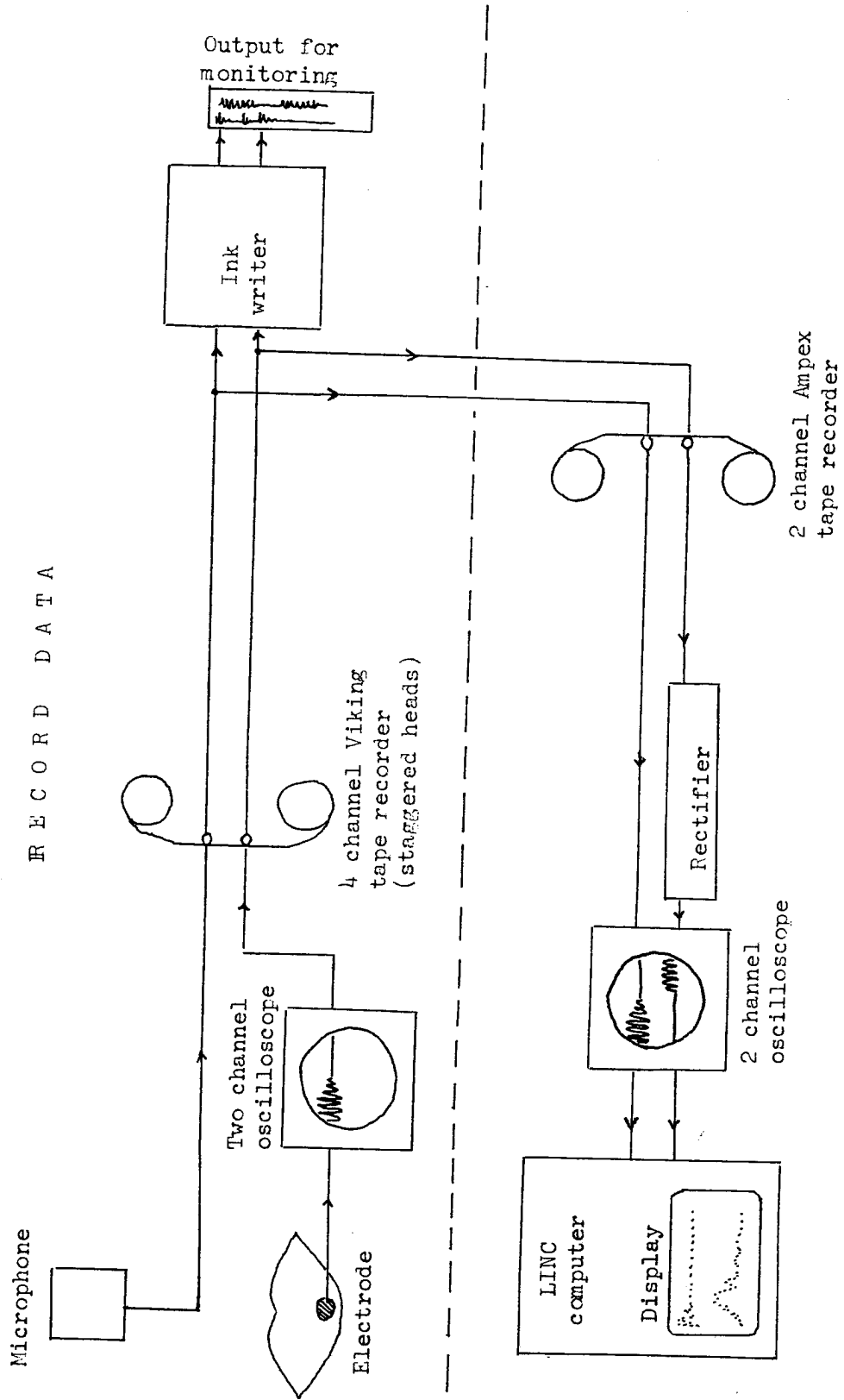
Figure 30. Principal component of the system

B.
Histogram of
average of 20
rectified EMG
signals as
photographed
from LINC

C.
Accumulated
and scaled
down trace of
B.

A. Oscillomink record of
EMG signal of one token
of utterance /bIb/

EMG

audio

1 second

Figure 31. Three stages in data reduction system.
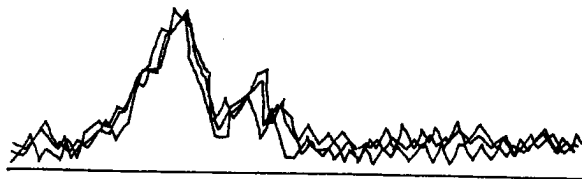
Figure 32.  Superimposition of averaged EMG traces of
same data processed by Link on three occasions.



—— EMG average of 20 tokens

– – – EMG average of 40 tokens

······ EMG average of 60 tokens
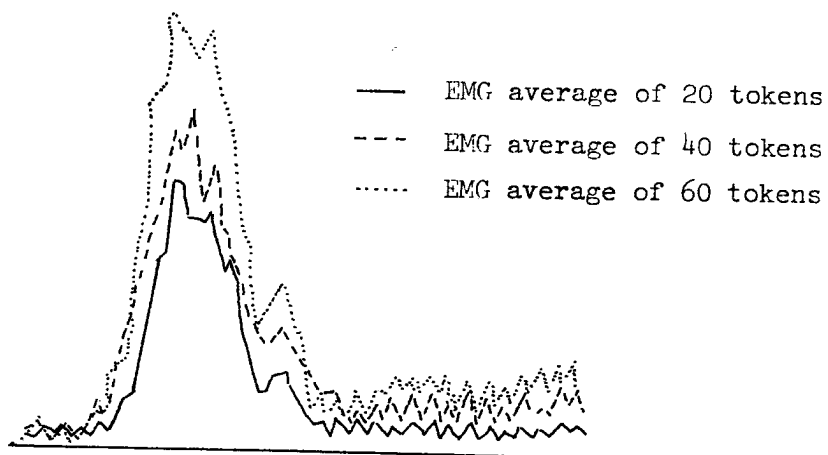
Figure 33.  Superimposition of averaged EMG traces
of different size samples.  (Different
scale factors were used to prevent over-
loading the computer.)



Figure 34.  System noise trace.

levels, and displacements in time amounting to one or two samples have an insignificant effect on the results.

Prior to the actual study, a pilot study was conducted to determine the number of tokens of each utterance which would be required as a suitable sample. In this pilot study 150 tokens of the same utterance were recorded. When the averages of 20 tokens were compared with 60 or more, it was found that a 20 token sample was sufficiently representative. Figure 33 shows the comparison of the averaged 20 tokens, with 40 tokens and 60 tokens of the same utterance.

To determine the noise in the system, 200 audio signals were fed into the computer with the EMG lead detached. The resulting trace was therefore the system noise alone. (Exclusive of that part of the system noise associated with recording and reproducing the EMG signal.) Figure 34 is the noise trace. Given this, only those amplitudes which rose significantly above the noise level for each utterance were considered as displaying significant muscular activity.

Calibration was accomplished by feeding into the EMG channel a sinusoidal signal of 250 microvolts while an audio signal was repeated 20 times. The calibration voltage record was processed by the same computer program.

As was pointed out in Chapter 2, the processing and reduction of EMG data may be accomplished in several ways. The raw EMG signals may be put through a Schmitt trigger which turns all action potentials exceeding a certain

voltage into uniform pulses. These may then be summed and averaged. This has the advantage of discounting such variables as the distance of the action potentials from the recording electrode. On the other hand, since the action potentials recorded from a surface electrode usually represent superimposed spikes the disadvantage of pulse counting is apparent. Because surface electrodes were used it was decided not to use the pulses. However, as a check on the reliability of this method, twenty of the EMG signals of one utterance were first fed through a Schmidt trigger, turned into pulses, and then fed into the computer and summed. Figure 35 presents the histograms and the summed pulses and those of the rectified EMG signals for twenty repetitions of the same utterance. While the summed pulses show less amplitude of the peaks the two traces appear to represent the same configurations of muscle action.

Using the photographs of the summed histograms as the data to be evaluated, the separate dots on the histograms were connected to permit easier measurement and comparison. Figure 36 shows the original trace and the same trace with the dots connected.

The following calculations were made from the photographs: (1) the amplitude of the highest peak of muscle action; (2) the duration of muscle activity from onset of activity to cessation of activity; (3) the time interval between the onset of muscular action and the onset of the

(A) Histogram of rectified
and averaged EMG signals
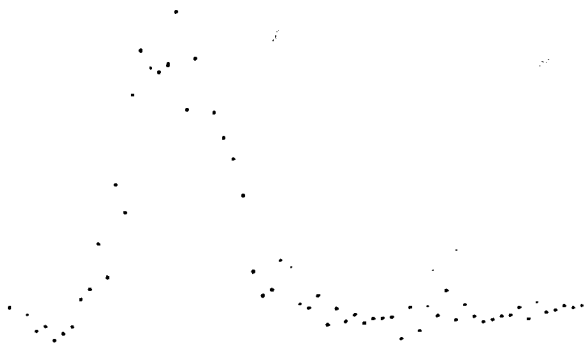
(B) Accumulated and
scaled trace of (A)
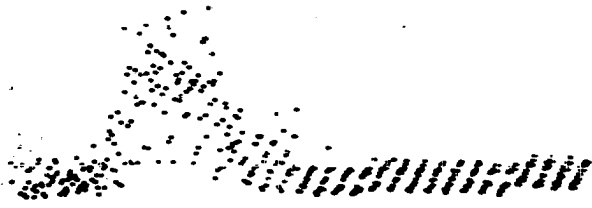
(C) Histogram of rectified
EMG signals turned into
pulses.

(D) Accumulated and
scaled trace of (C)

Figure 35.  Traces of averaged rectified EMG signals and
averaged pulses.

audio signal for initial consonants and for vowels; (4) the
time interval between the onset of muscle action and the
end of the audio signal for final consonants; (5) the time
interval between the peaks of muscular action and the onset
or cessation of the audio signal.  Figure 37 shows the meas-
urements taken.

C. Results

The results refer to the principal subject unless stated
otherwise.

1. Vowels in d_d utterances.

The utterances /dɪd/ /did/ /dɛd/ /ded/ /dad/ and /dʌd/
show little if any muscle activity.  A slight rise immedi-
ately prior to the onset and end of the audio signal is
probably due to a slight closure of the lips as the mandible
is lowered and then raised, and a slight eversion of the
lips with the closure and release of /d/.  This lip muscle
action was not anticipated when the /d_d/ frame was selected.
Motion picture studies of the lips in closure and release of
/d/ should help to determine the involvement of the lips in
the articulation of this phoneme.

The utterances /derd, dɔd, dod, dʊd, dud/ all show
action of the orbicularis oris muscle.  Figure 38a and 38b
present the averaged EMG signals for d_d utterances.

Of the utterances involving orbicularis action, /derd/
shows the shortest duration of activity which occurs just
prior to the onset of the audio signal.  The EMG trace falls
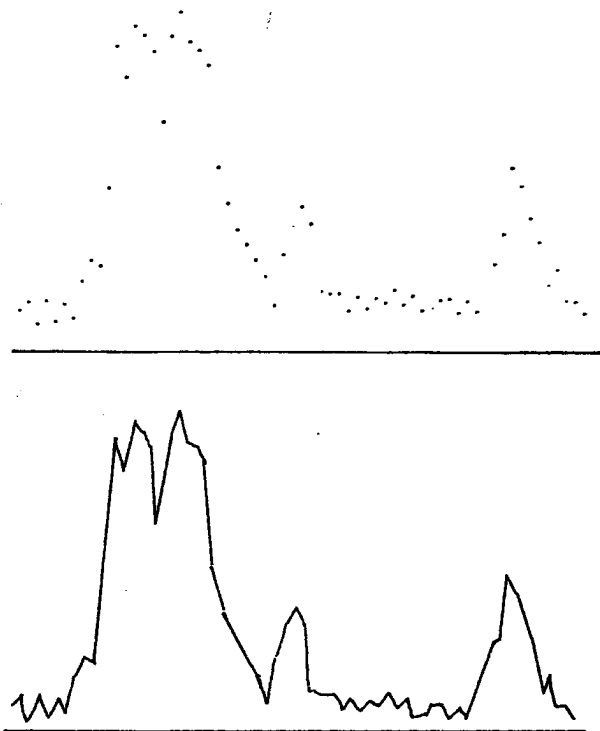
Figure 36. (A) Photograph of original histogram.
(B) Dots connected
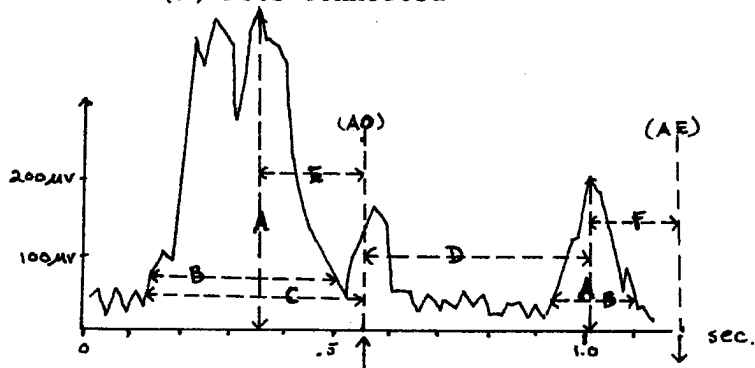


(A) Peak amplitude
(B) Duration of muscle action
(C) Onset of muscle action to audio onset
(D) Audio onset to onset of muscle action
(E) Peak amplitude to audio onset
(F) Peak amplitude to end of audio
(AO) Audio onset (↑)
(AE) End of audio (↓)

Figure 37. Measurements taken

/did/ noise level

/dɪd/

/ded/

/dɛd/

/dæd/

/dad/

/dʌd/

AO         AE

↑ AO – audio onset
↓ AE – end of audio signal

0        .5        1.0    sec.
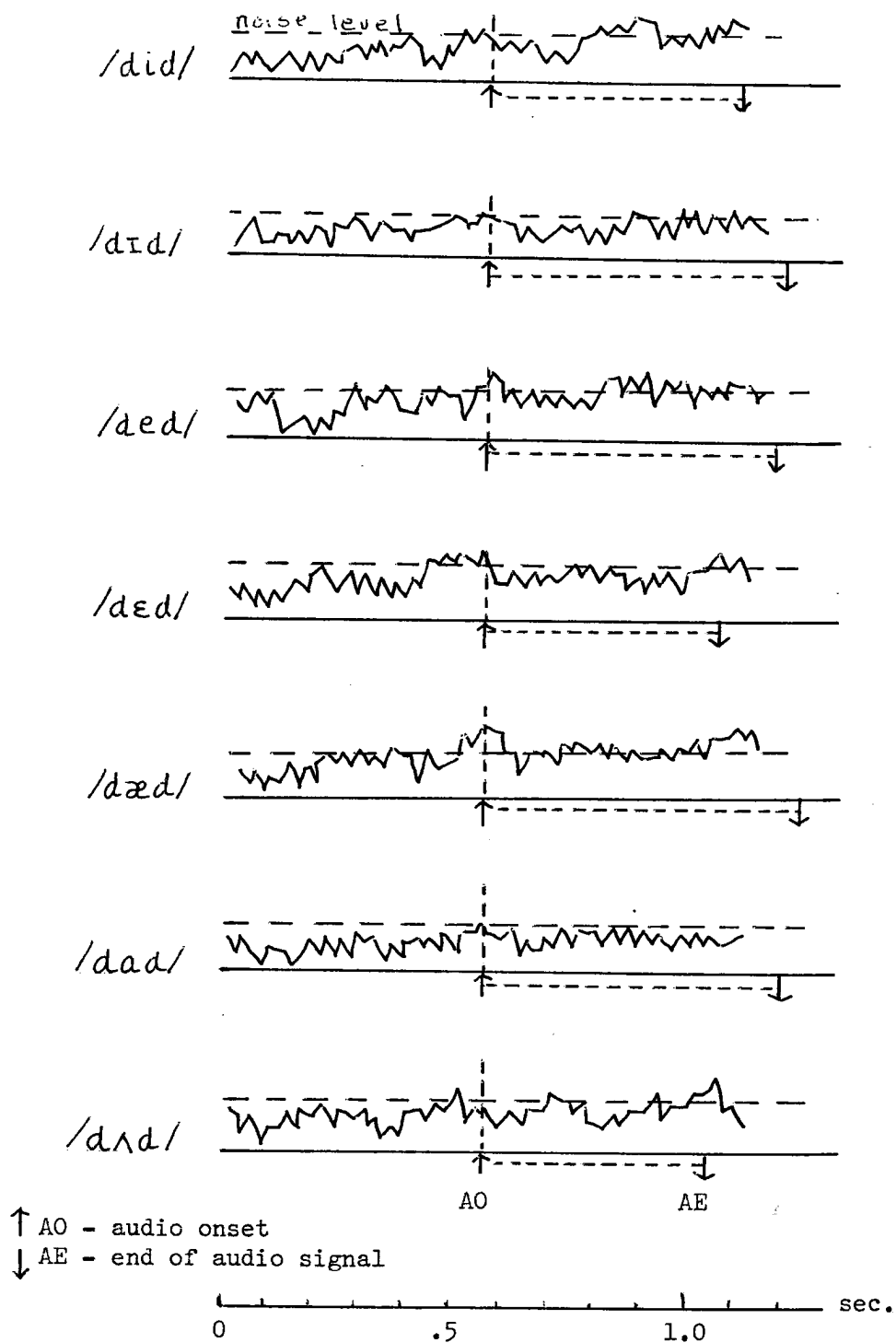
Figure 38a.   Averaged EMG traces of /d_d/
utterances.
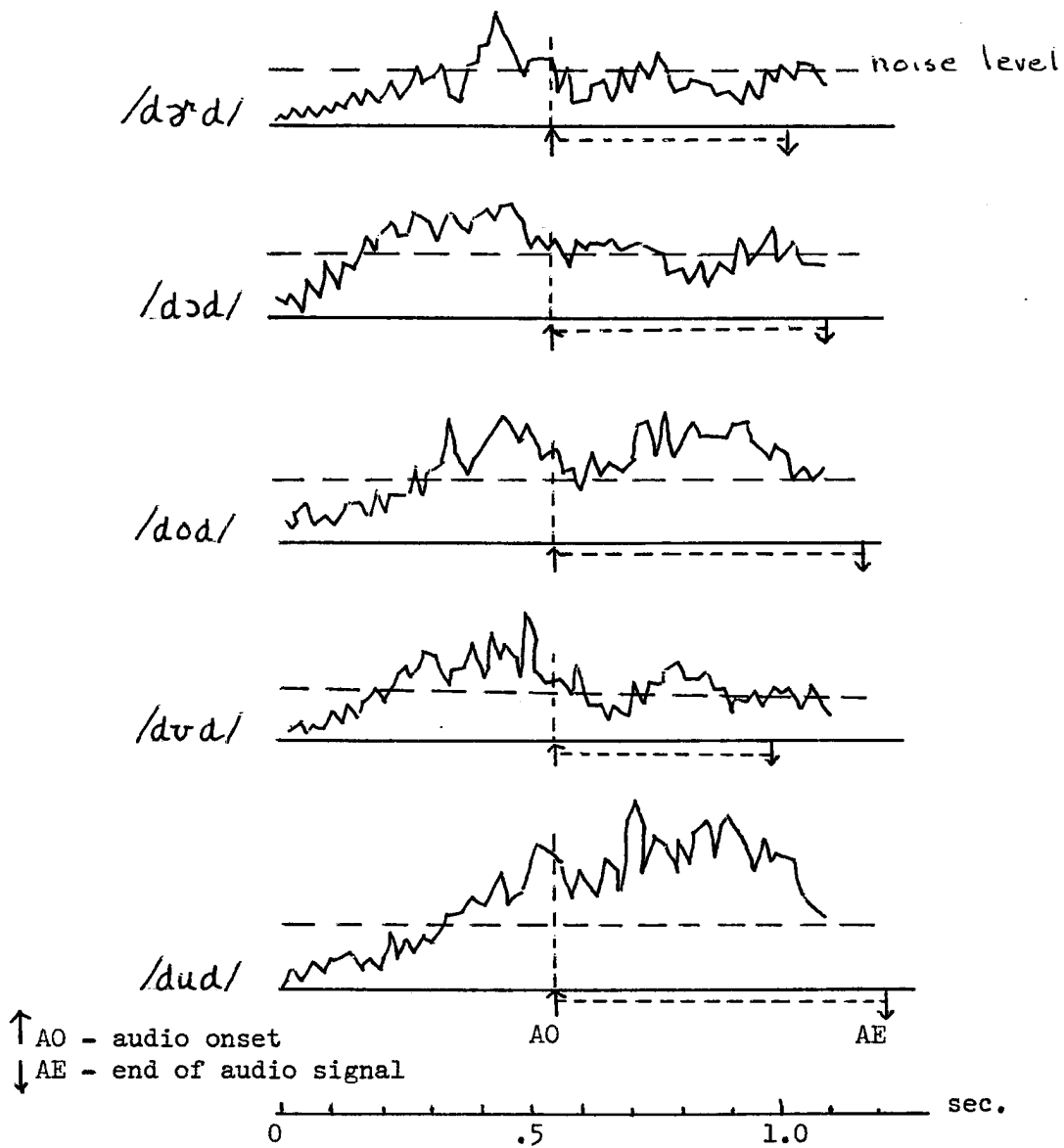
Figure 38b.  Averaged EMG traces of /d_d/ utterances.

to the noise level immediately after the onset of the audio signal. /dɔd/ and /dʊd/ show a relaxation of the action after the audio signal starts. /dod/ amd /dud/, on the other hand, show equal or greater muscular action occuring after the onset of audio. For /dod/ there are two definite peaks of activity, while for /dud/ a slight dip occurs after the onset of audio but the action is for the most part sustained until immediately before the end of the audio signal. The measurements taken from the EMG traces of vowels displaying muscle action are given in Appendix B.

## 2. Initial /b/

The muscle action in the articulation of an initial /b/ was found to be relatively invariant, whether in a /b_d/ or /b_b/ context and appeared to be uninfluenced by the vowels which followed. The mean peak amplitude was 384 microvolts.

The mean duration of muscular action generated in the production of initial /b/ was 332 msec. with the peak of activity occurring 255 msec. prior to the onset of the audio signal, and the onset of muscular activity occuring 411 msec. prior to the onset of the audio signal. The muscular tension associated with the articulation of an initial /b/ ended just prior to the onset of the audio signal.

Figures 39 and 40 present the averaged EMG traces of

/bid/  /bud/

/bɪd/  /bʊd/

microvolts
- -200
- -100
- -0

/bed/  /bod/

/bɛd/  /bɔd/

/bæd/  /bad/

200 msec.

1 sec.

↑ Audio onset    ↓ End of audio signal
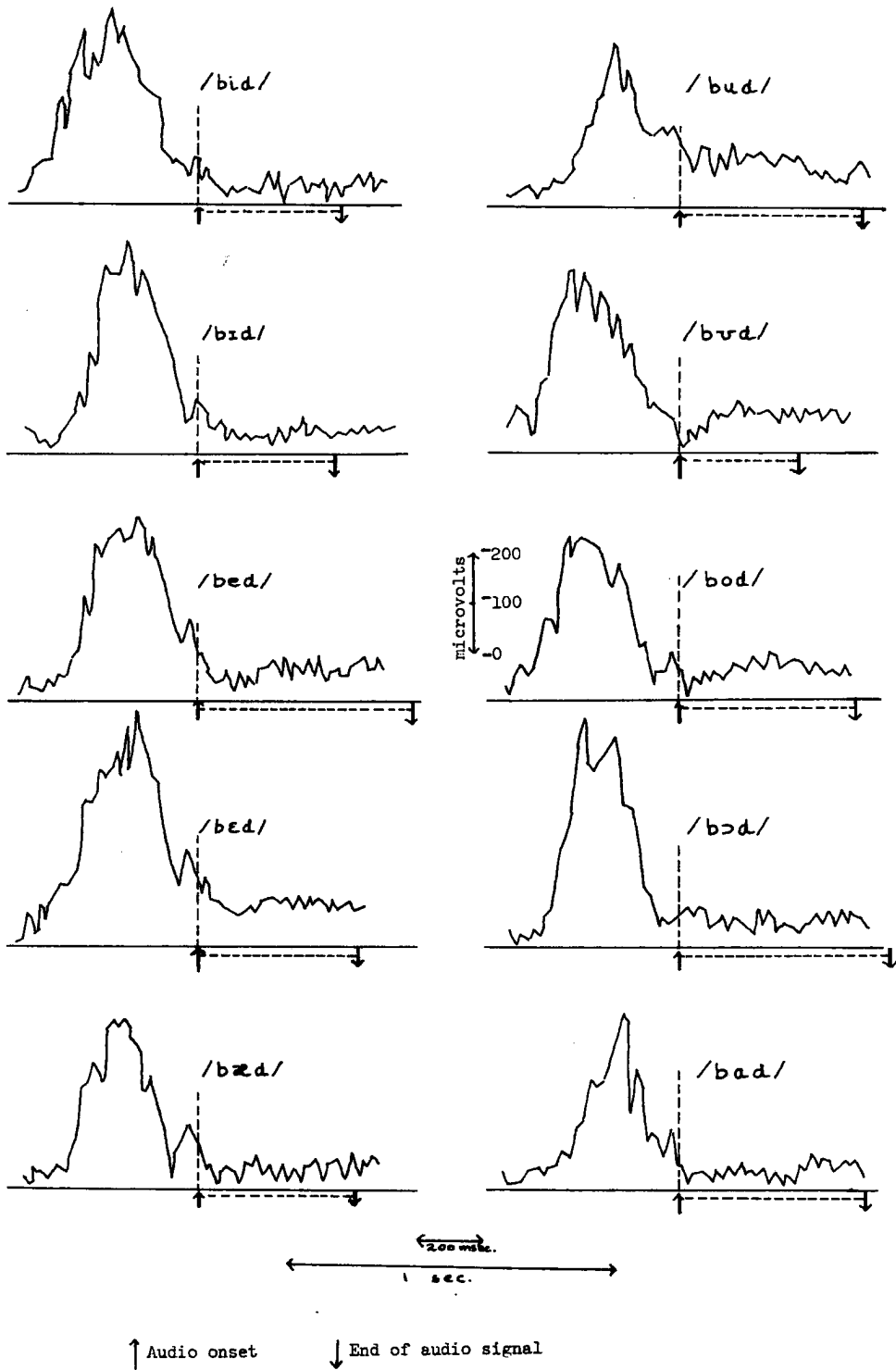
Figure 39.  Averaged EMG traces of initial /b/ utterances

/bib/

/bub/

/bɪb/

/bʊb/

/beb/

/bob/

/bɛb/

/bɔb/

/bæb/

/bab/

voltage

200μv

100μv

0

200 msec

↑Audio onset          ↓End of audio signal
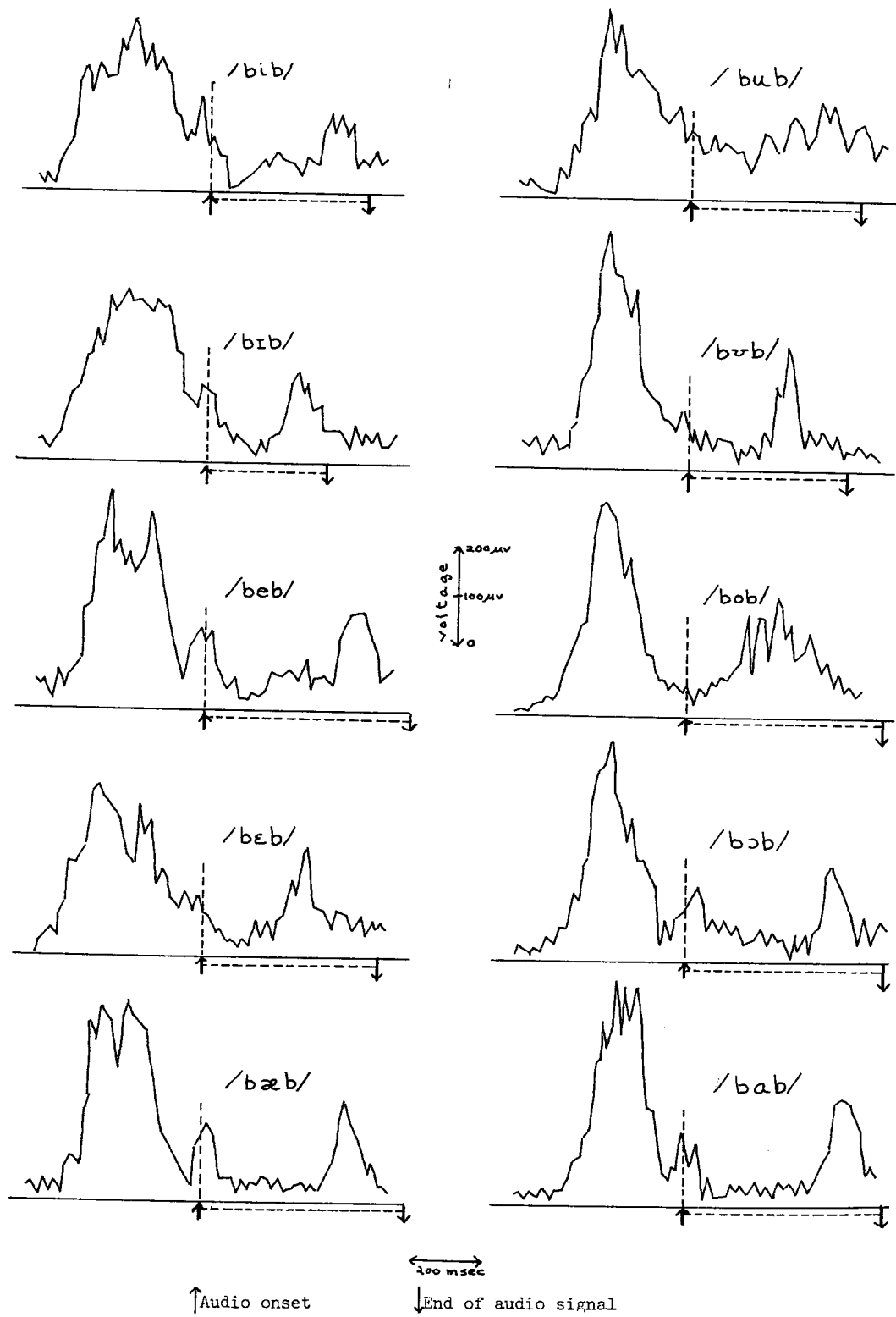
Figure 40. Averaged EMG traces of /b_b/ utterances.

initial /b/ utterances. An examination of the traces reveals that in every case a second, weaker peak occurs immediately after the first peak of muscle activity. This may be due to a ballistic action of the muscles which after closure of the lips overcompensates in opening the lips, therefore requiring muscular action to restore the lips to neutral relaxed position. It is also possible that after closure the lips are pulled apart (lower lip pulled down) by the depressor labii inferioris, and orbicularis action is required to restore the lip to neutral position. The measurements taken from the EMG traces of initial /b/ utterances are presented in Appendix B.

The variability between all the initial /b/ utterances is relatively no greater than the difference between an initial /b/ of the same utterance recorded on two separate occasions. This is evident from Figures 41 and 42. Figure 41 displays the superimposition of averaged EMG traces of initial /b/ utterances recorded at two different times. Figure 42, in a schematic diagram compares the peak ampli- tudes of initial /b/ in /bɪb/ utterances recorded on two occasions, and initial /b/ of the utterances /bɪb/ and /bub/ recorded at the same session. Figure 43 shows the super- imposition of the averaged EMG traces of all initial /b/ utterances.
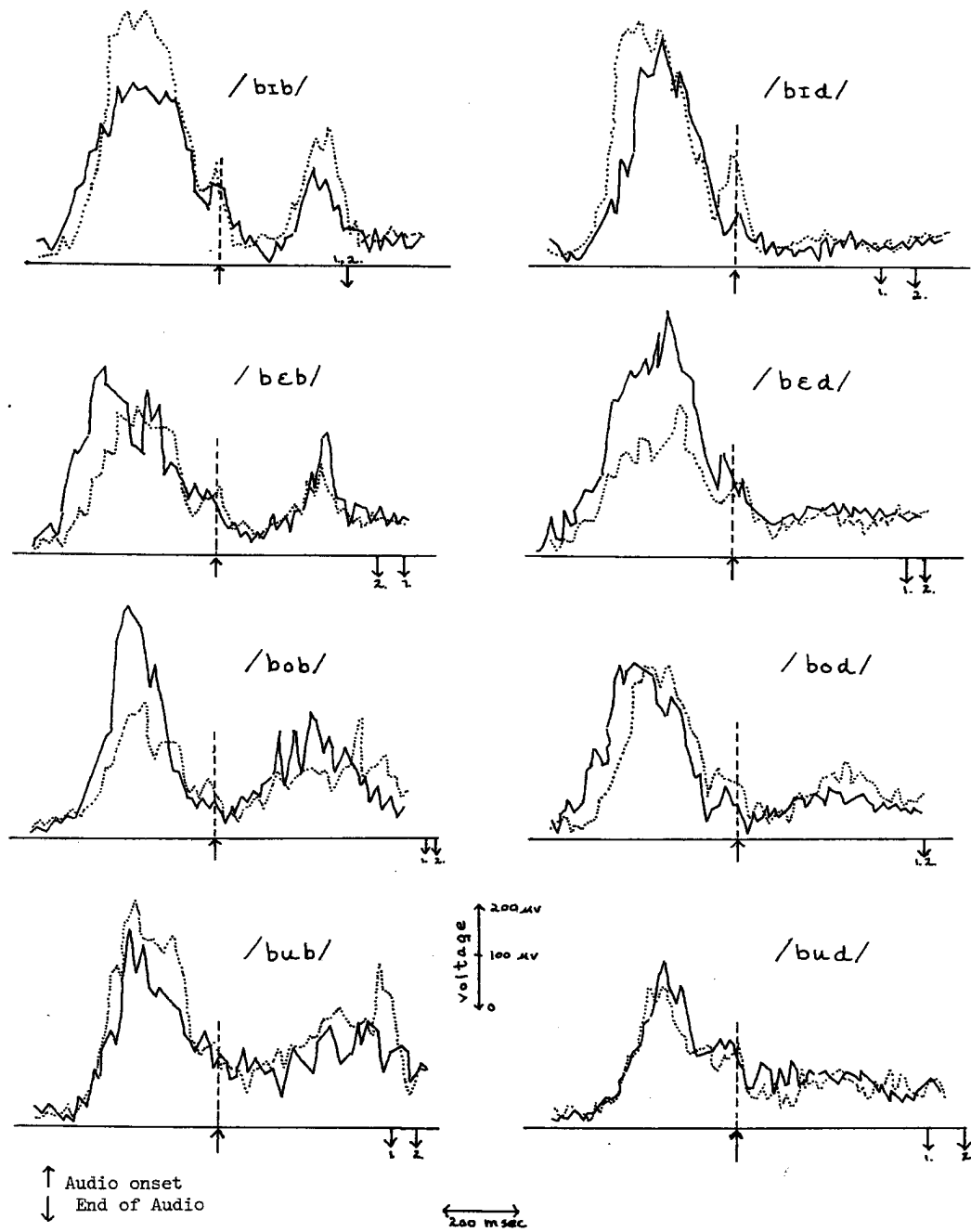
Figure 41. Superimposition of averaged EMG traces of initial /b/
utterances recorded at two different times.
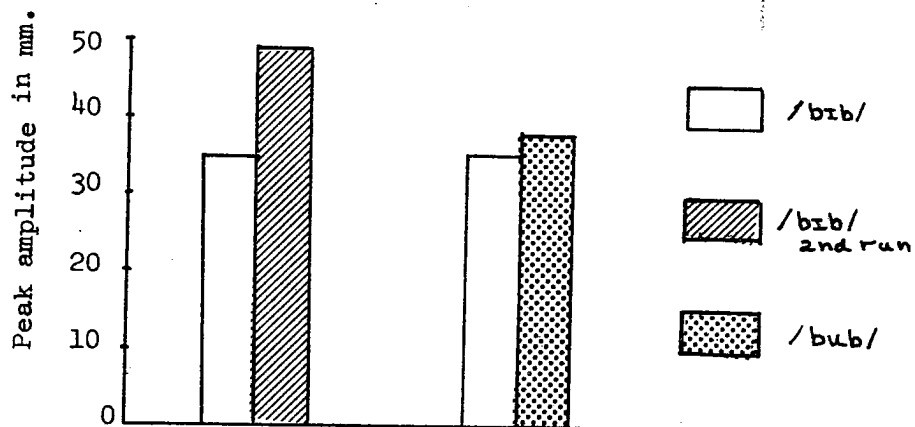
10 mm = approx. 100 microvolts

Figure 42. Diagram comparing peak amplitudes of initial
/b/ in /bIb/ utterances recorded on two
occasions, and initial /b/ of utterances
/bIb/ and /bub/ recorded at same session.
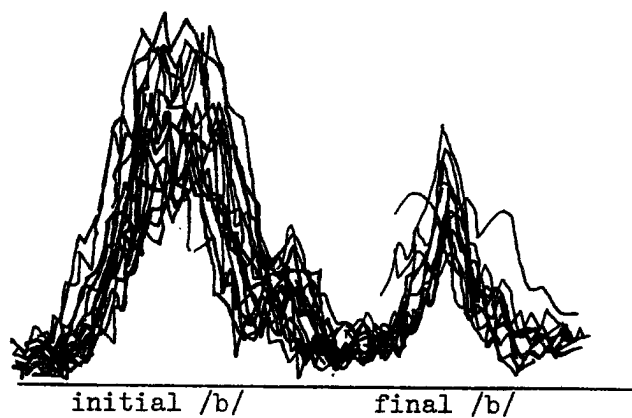


initial /b/          final /b/

Figure 43. Superimposition of averaged EMG traces of
initial /b/ and final /b/ utterances.

/dib/

/dub/

/dɪb/

/dʊb/

/deb/

/dob/

/dɛb/

/dɔb/

/dæb/

/dab/

↑ voltage ↑200 ᴀᴠ
─100 ᴀᴠ
└0

↑ Audio onset
↓ End of audio signal

←——→
200 ᴍꜱᴇᴄ
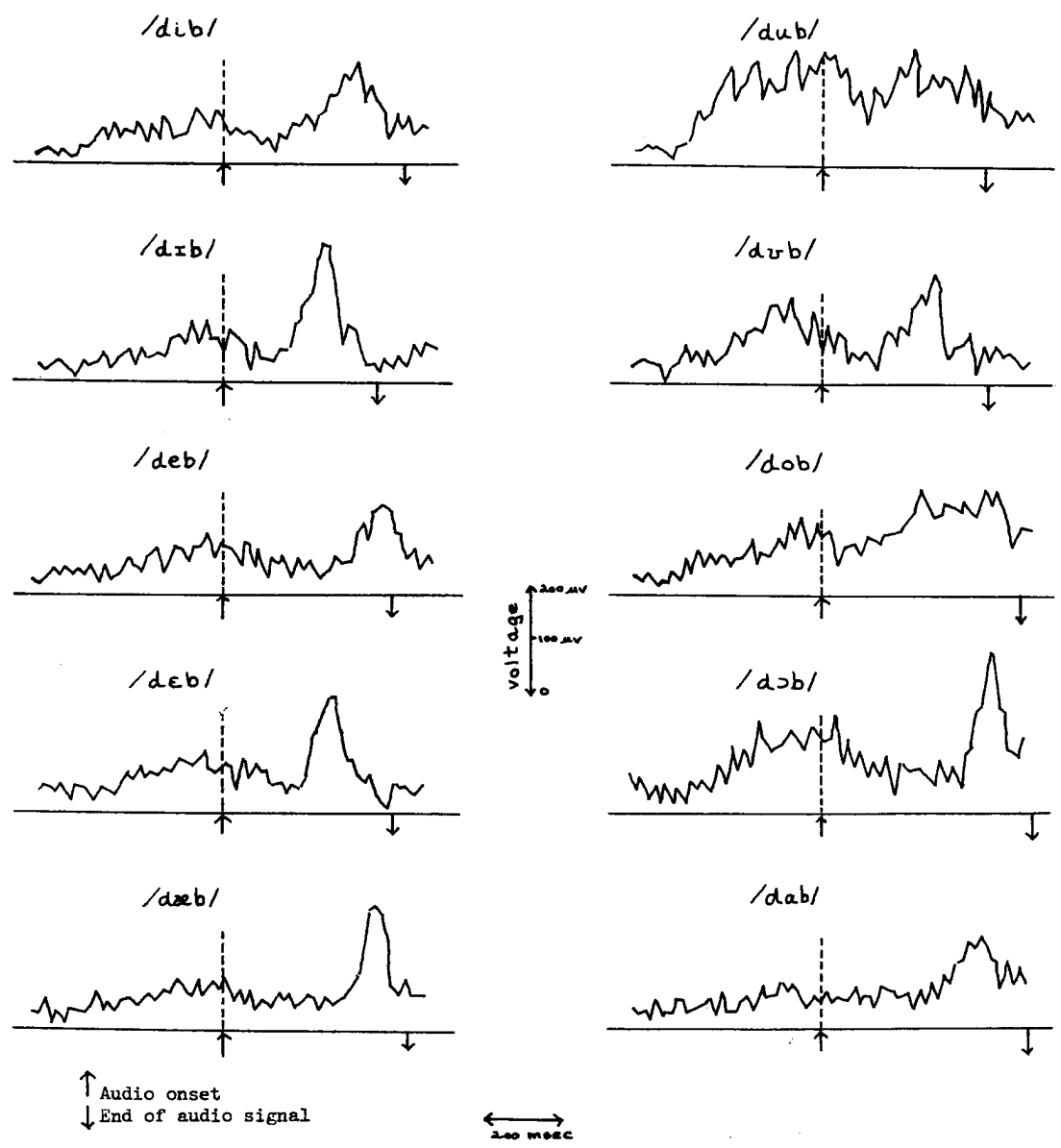
Figure 44 .Averaged EMG traces of final /b/ utterances.

### 3. Final /b/

Like initial /b/ the muscular gesture associated with the articulation of a final /b/ seems relatively unaffected by the vowel which precedes it. Furthermore, it is unaffected by the initial consonant of the utterance, i.e. initial /b/ does not seem to effect the muscular tension of a final /b/. But the muscular gesture for a final /b/ is not the same as that for the production of an initial /b/. Both the mean amplitude of the peak and the duration of muscular action associated with a final /b/ are much lower than those for initial /b/. The mean peak amplitude for final /b/ was found to be 220 $\mu$v. The standard deviation from the mean was 4.61. The mean duration of muscular action was 170 msec. In the case of final /b/ it was impossible to measure the onset or duration of the muscular activity associated with a final /b/ in utterances in which /o/ or /u/ occurred before /b/ since there is no clear delineation point which separates the vowel articulation from the consonant articulation. Figures 44 and 41 present the summed EMG traces of final /b/ utterances.

Figure 45 presents a schematic diagram of the differences in amplitude and duration of initial /b/ and final /b/ utterances.
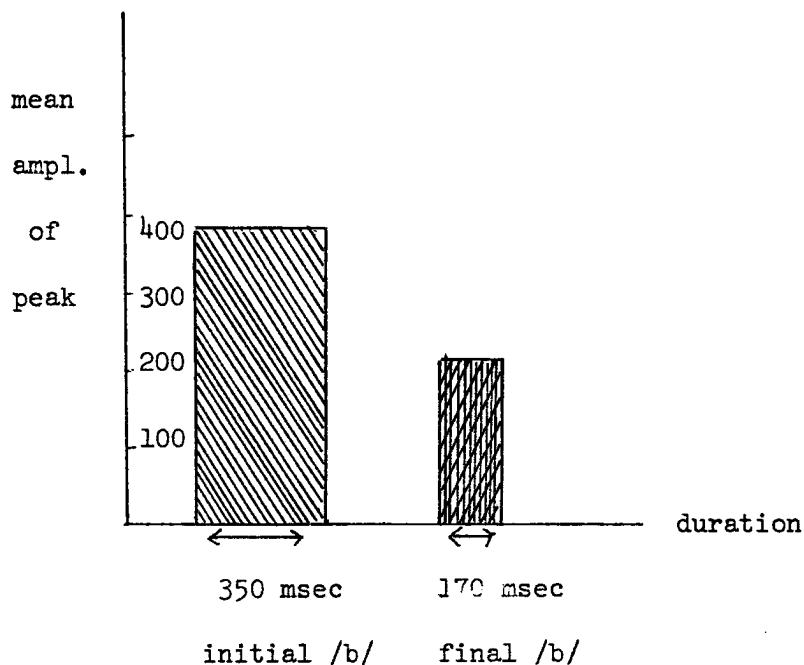
Figure 45. Diagram displaying differences in mean amplitude and duration of muscular tension of initial and final /b/.

    All the measurements taken from final /b/ utterances are presented in Appendix B.  Figures 41 and 46 present the superimposed EMG traces for the same utterances recorded at two different times.  Figure 43 shows the superimposition of EMG traces of all the different final /b/ utterances. It would appear that the variance in muscular gesture is no greater when the final /b/ occurs in different phonetic contexts than when the final /b/ occurs in the same phonetic context produced at different times.

    The peak of activity associated with articulation of a final /b/ occurs approximately 390 msec. after the onset of the audio signal.  The onset of muscular tension (where it can be determined) occurs on the average 260 msec. after the onset of the audio signal.

/dɪb/

/dɛb/

voltage

200 μv

100 μv

0 μv

/dab/

/dob/

/dub/

↑ Audio onset
↓ End of audio

0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 sec.
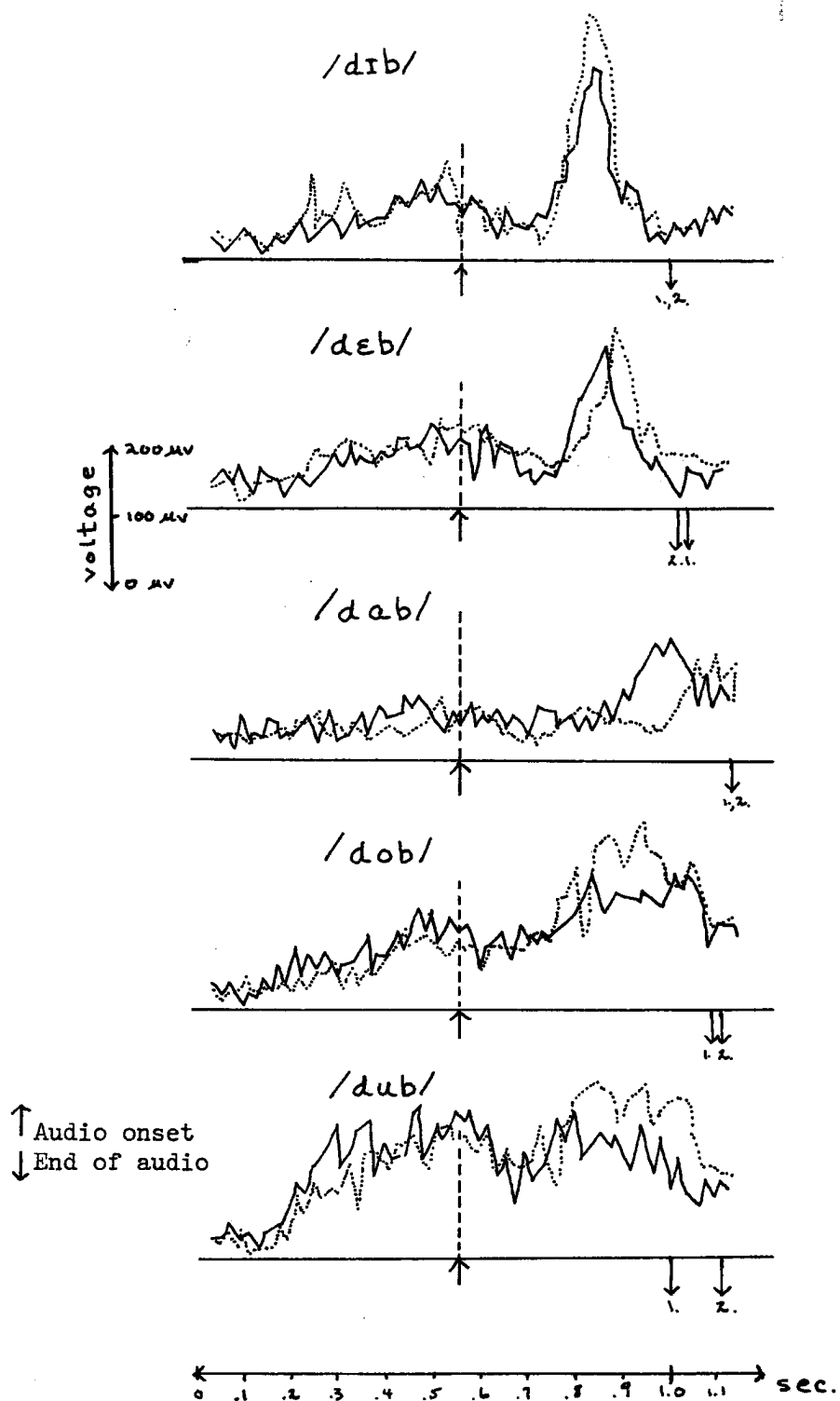
Figure 46. Superimposition of averaged EMG traces of final /b/
utterances recorded at two different times.

### 4. Initial /p/

The muscular gesture which produces an initial /p/ is also independent of phonetic context. It must be noted, however, that a considerably smaller number of utterances were used as the sample for initial /p/, and the findings are therefore not nearly as conclusive as those relating to initial /b/. The mean peak amplitude is 370 $\mu$v. The average duration of muscular action was 225 msec. with the peak of activity occurring 300 msec. prior to the onset of the audio signal, and the onset of muscular tension occurring 375 msec. prior to the audio onset.

Just as in initial /b/, a second shorter, weaker peak occurs immediately prior to the onset of the audio signal. Figures 47 and 48 present the averaged EMG signals for utterances beginning with /p/, the superimposed curves of the same utterances recorded at two different times, and the superimposition of all initial /p/ traces.

### 5. Final /p/

There is less of a difference in peak amplitudes between final and initial /p/ than was found for /b/. The mean peak amplitude was 350 $\mu$v as compared with 370 $\mu$v for initial /p/. It must be remembered that only 8 utterances were averaged in the case of /p/ as opposed to 24 utterances for final /b/.

The mean duration of muscular action was 145 msec. The peak of activity occurred just at the end of the audio
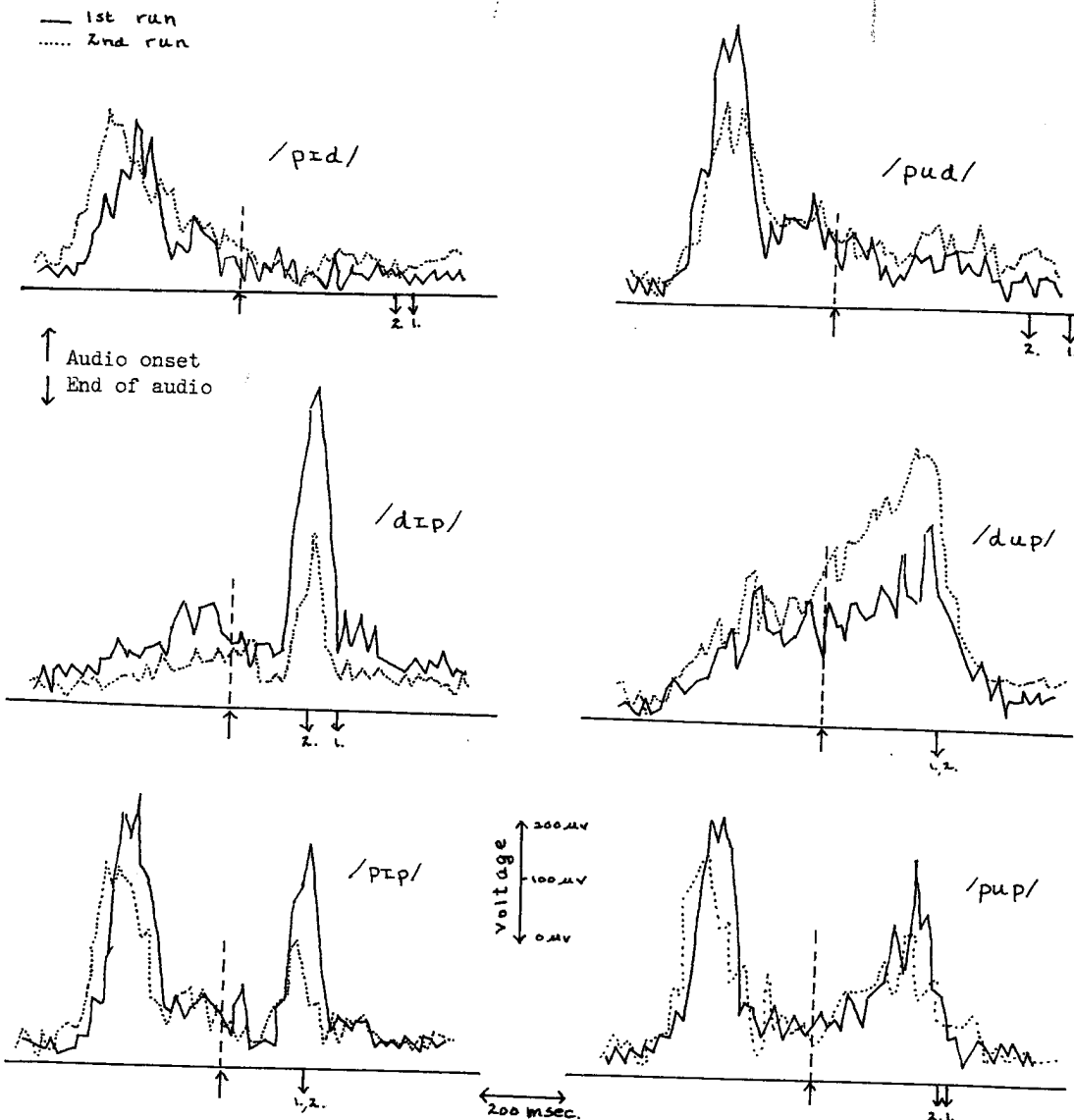
Figure 47. Superimposition of averaged EMG traces of initial and final /p/ utterances recorded at two different times.
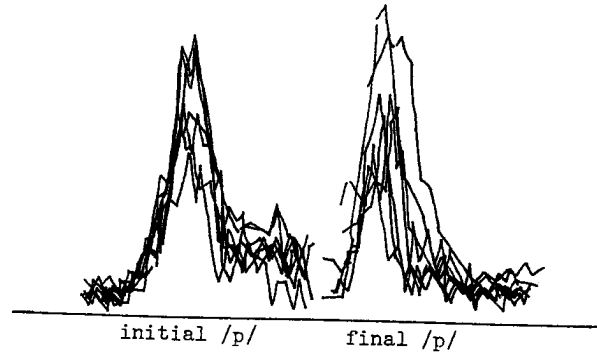


initial /p/          final /p/

Figure 48. Superimposition of averaged EMG traces of initial /p/ and final /p/ utterances.

signal which would be just at the time of closure for the voiceless stop. The onset of muscle tension associated with a final /p/ occurs on the average 130 msec. after the onset of voicing.

The EMG averages for final /p/ utterances and the superimposition of the final /p/ utterances are presented in Figures 47 and 48.

### 6. Vowels in Utterances With Bilabial Consonants

The vowels which showed no appreciable muscular tension in /d_d/ utterances similarly produced no muscle activity when preceded by /p/ or /b/. But there appears to be a decided difference in the muscular gestures associated with the 'flat' vowels when they occur in a context preceded by a bilabial consonant. The amplitude of the first peak of muscular activity measured in the EMG trace of the utterance /dud/ was 180 microvolts immediately after the onset of audio. The measurement of the amplitude immediately after the onset of the audio signal for /bud/ was 110 microvolts. The peak amplitude of the utterance /dud/ measured at 250 microvolts, but that of /bud/ 120 microvolts. The difference was even greater in the utterances /dod/ and /bod/. The peak amplitude after audio onset measured for /dod/ was 170 microvolts while for /bod/ following the onset of the audio signal the amplitude hardly rose above the noise level. Figure 49 shows the

the superimposition of the /dud/ and /bud/ EMG traces, and
the superimposition of the /dod/ and /bod/ traces.



_____ /bud/

--- /dud/

_____ /bod/

--- /dod/
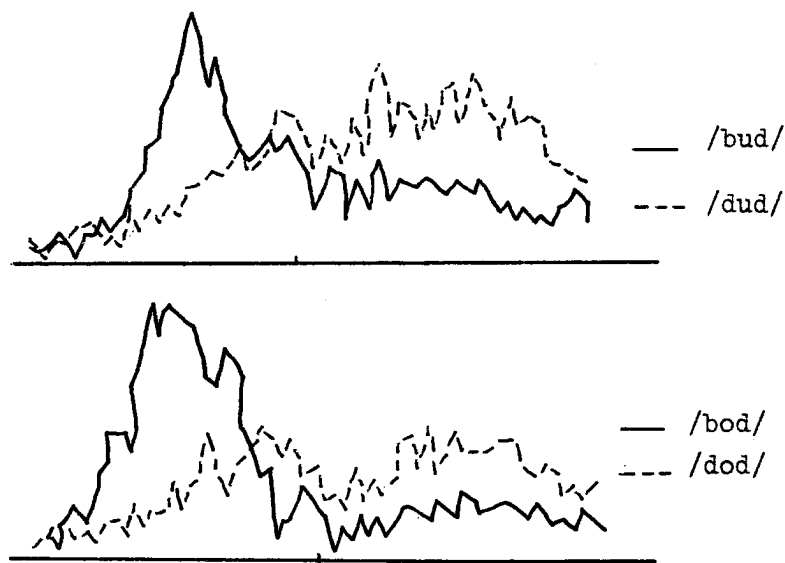
Figure 49. Superimposition of /bud/ and /dud/ EMG
traces, and /bod/ and /dod/ EMG traces.

The other vowels which involved action of the orbicu-
laris in /d_d/ utterances, display relatively no action
after the onset of the audio signal in /b_d/ utterances.
However as has already been noted, the period of muscular
action in the articulation of these vowels occurred prima-
rily prior to the onset of the audio signal. What is cer-
tain, however, is that there is no increase in amplitude for
utterances beginning with a bilabial which is followed by
a 'flat' vowel: which would be the result if two separate
motor commands were simply added together. The possible
physiological reasons for this will be discussed below.

The gestures associated with the production of the
vowels are the same in /d_d/ and /d_b/ utterances. In the
/b_b/ utterances there is some decrease in the muscular
action associated with /u/ and /o/ but not as great a de-
crease as in the /b_d/ text. Figure 50 presents the super-
imposed traces of /d_d/ utterances with those of /d_b/ and
/b_b/.



>       /dud/
- - -    /dub/
===     /bub/
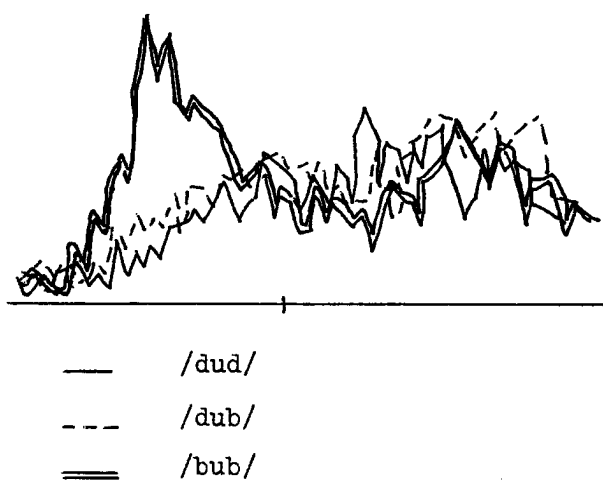
Figure 50.  The superimposition of EMG traces of
            /dud/, /dub/, and /bub/ utterances.

## 7. <u>Variation</u> <u>among</u> <u>subjects</u>

As might be expected there is considerable variation between different individuals.  Subjects differ in the amount of muscular tension exerted in speech.  Other factors also influence the signals recorded.  For example, the amount of muscle activity recorded depends on the suction strength of the electrodes.

The recordings taken from one subject showed so little muscular activity that the averages barely reached a level above the noise.  While the Oscillomink records reveal EMG signals similar in duration to those of the other subjects, the amplitudes were too low to reveal significant averages. The data obtained from this subject were therefore omitted.

A comparison of the results obtained from the two other subjects seem similar to the results obtained from the two runs of the principal subject.  Figure 51 demonstrates this similarity.  The traces obtained from the myographic records of subjects B and C display a smaller amplitude difference between initial and final consonant gestures than is shown for the principal subject.  The differences between initial and final consonants in duration of muscular tension as found in the principal subject, appear to be corroborated.

There is considerably less muscle activity recorded from subjects B and C than from the principal subject A. For the initial /b/ the peak amplitude ratio between
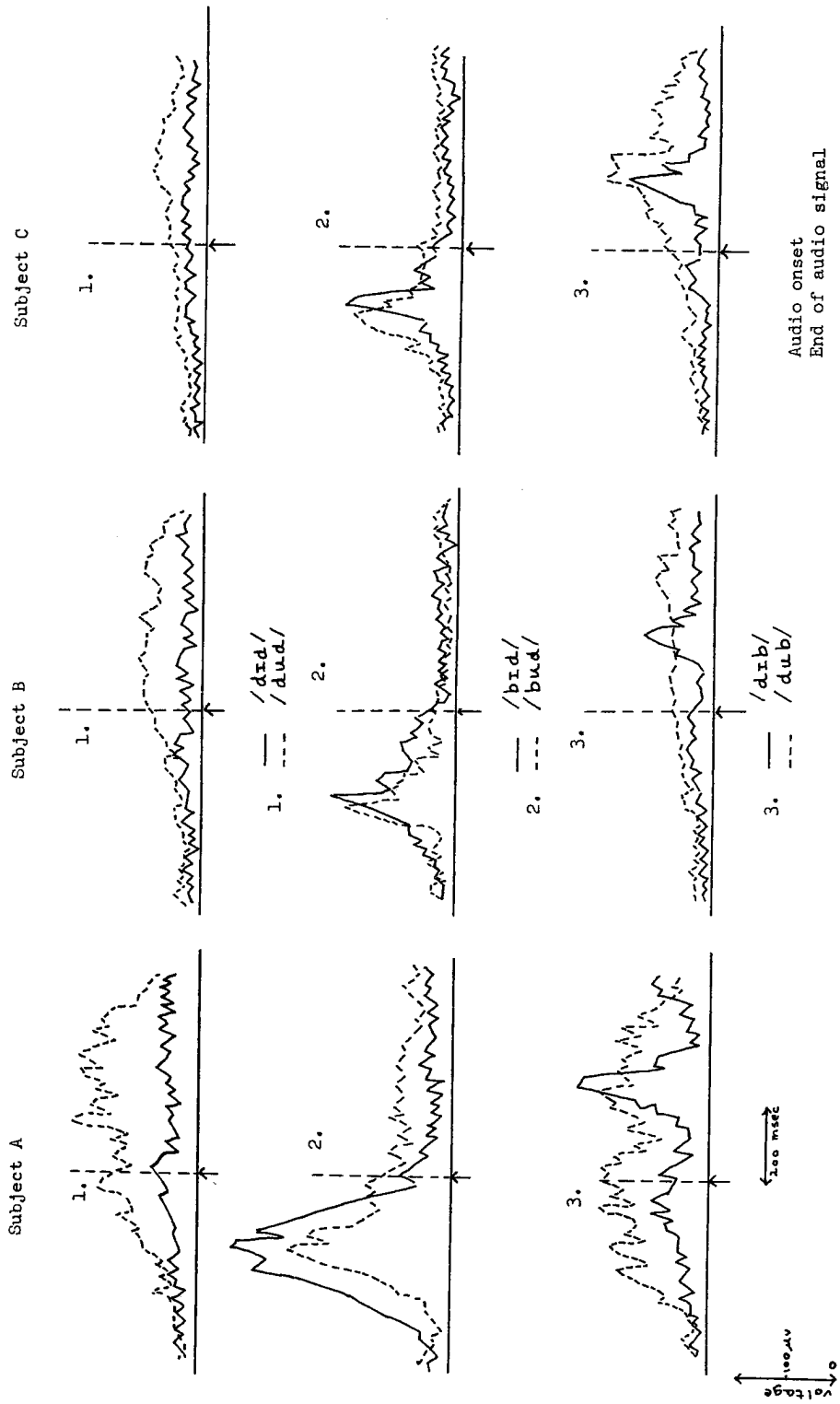
Figure 51. Averaged EMG traces of same utterances recorded from three subjects.

subjects A and B was found to be 2 to 1, and that between A and C a little more than 2 to 1.  Similar ratios are found in the orbicularis action associated with the articulation of /u/ in /dud/.

The absolute variance between subjects was implied in a study conducted by MacNeilage (1963).  Different gain settings were used for different subjects.  The gain settings in the present study were left unchanged from subject to subject, since one aim of the study was to determine the variation in muscle action between individuals.

An investigation of the articulation of the entire set of utterances by many subjects is required before it may be concluded that the results obtained from the principal subject can be generalized to all speakers of American-English.  The variance from utterance to utterance and from individual to individual precludes the assignment of absolute values to the parameter singled out.  It does not, however, exclude the establishment of relative values.

8. Summary of the Results

    a. The vowels

The results of the present study pertinent to American-English vowels may be summarized as follows:

EMG averages of the vocalic nuclei symbolized as /i, ɪ, e, ɛ, a, æ, ʌ/ show relatively no contraction of the orbicularis oris muscle.  Definite muscular tension is

revealed in the electromyographic traces of the vowels /u, ʊ, o, ɔ, er/. Of the latter group, only the recordings obtained during the production of /dod/ and /dud/ show any considerable action of this muscle after the onset of the audio signal. In both /o/ and /u/, a decrease in muscular tension occurs immediately after the onset of the audio signal. This is followed by an increase in muscular tension equal to or greater than the tension occurring before the onset of the audio signal. This second onset of tension is sustained until the end of the audio signal. The EMG average traces for /ɔ/ and /o/ and for /ʊ/ and /u/ are similar prior to the onset of the audio signal. The differences of muscular tension between /ɔ/ and /o/ and between /ʊ/ and /u/ occur only after the onset of the audio signal.

The vowels which showed no action of the orbicularis in /d_d/ utterances similarly showed no muscular tension when preceded or followed by a bilabial consonant.

The vowels which are produced with action of the orbicularis were influenced by the presence or absence of bilabial consonants. In /b_d/ utterances, less muscular tension was recorded for /u/ and /o/ than in /d_d/ utterances. When these vowels occurred in /d_b/ contexts the traces revealed gestures for the vowels similar to the /d_d/ utterances. In /b_b/ utterances less muscular tension occurred in the vowel articulation.

b. The bilabial stops

The results of the present study relevant to the phonemes /b/ and /p/ may be summarized as follows:

The muscular gesture associated with initial and final /b/ and /p/ seems uninfluenced by the vowels which follow or precede. The muscle tension which produces an initial /b/ is of greater amplitude and longer duration than that in the articulation of a final /b/. The difference in peak amplitude for initial and final /p/ does not appear significant. But the duration of muscular tension for an initial /p/ is longer than that for the final /p/.

The mean amplitude of the peak and the duration of muscular tension for initial /b/ is greater than for initial /p/. The duration of muscular tension for a final /p/ is less than the duration for a final /b/.

The onset of muscular action for a final /p/ occurs sooner after the onset of the audio signal than does the onset for a final /b/.

D. Discussion

The findings of the study suggest that linguistic units i.e. phonemes or distinctive features of phonemes, may be specified in terms of neuro-muscular activity. Only a single parameter was singled out for study, i.e. the muscular action of one lip muscle. The fact that certain relative values may be assigned to this parameter for a

limited number of linguistic units suggest that further study of other muscles of the lips, tongue, larynx etc. may be used to fully specify the functional units of speech, differentiating them from each other by means of objective empirical descriptions.

The use of electromyography seems to be adequate for the task set forth. The newness of the technique in speech research leaves certain problems which will have to be resolved by further work: (1) the best method by which to process and reduce the data is still undecided; (2) the lack of any definitive conclusions as to the extent of the area contributing to the recorded muscle potentials makes it difficult to study individual muscles. It is possible that some of the recorded action potentials are produced by muscles some distance away. Other experimental techniques are needed in conjunction with electromyography e.g. cinephotography, X-ray motion picture studies, etc. But with its limitations, this technique does provide a tool for studying the muscles in a dynamic way, and for inferring from the actions of the muscles the motor commands which innervate the contractions.

The variance of muscular tension from one occasion to another, and from individual to individual precludes the possibility of assigning any absolute values to the parameter selected. In other words, one can not assign a specific electrical voltage to the action of the orbicularis oris

muscle which closes the lips in bilabial stops. However, if one of the features listed in a universal phonetic theory is the feature of bilabiality, this may be specified most simply by stating that this feature involves action of the orbicularis oris muscle. Furthermore, a relative scale of values may be suggested, which can be used in a description of a language which differentiates certain bilabials only in terms of degrees of muscular tension. Thus a phonetic matrix may be given as follows:

|          | segments | | |
|----------|----|-----|---|
| features | p  | p'  | t |
| bilabial | +1 | +2  | 0 |

A language in which the degree of muscular action is non-distinctive need only specify the feature by a + or -.

As is evident from the results obtained in this study, the values assigned to the specific features, (in this case orbicularis action), will depend on the phonetic context in which the segments occur. Thus, a fully specified /b/ could possibly be assigned a +2 value for the feature in question when it occurs in utterance initial position, and a +1 value when it occurs in an utterance final position. In the ultimate output of a grammar initial /b/ may be assigned a +4, an initial /p/ a +3, and both final /b/ and final /p/ a +1. This of course would depend on the results of the investigation of many speakers of American-English. If it was found that the relations between the muscular action remained the same from speaker to speaker and from

utterance to utterance, relative values could be assigned.

1.  The Flat/Non-flat Feature of American-English Vowels

The findings of the present study support the hypothesis that American-English vowels can be separated into two distinct sets, i. e. that the distinction flat/non-flat, or rounded-nonrounded is a relevant distinction. What distinguishes the flat vowels from each other in terms of orbicularis action only is not so much the amplitude of the electrical signals (although /u/ showed significantly greater amplitude) but the duration of the action.

No linguistic description of American English to date has differentiated the vowel phonemes on the basis of more or less 'rounding'. Such description of the vowels need only state the presence or absence of orbicularis action.

As was pointed out in section C.1, the averaged EMG trace for the utterance /dod/ showed two definite peaks of activity; the trace for /dud/ might also be considered to have two peaks (though they are far less clear in the case of this vowel). One explanation which might be offered for this phenomenon is that these vocalic nuclei are diphthongs. Figure 52 displays the traces of /dɔd/ and /dod/ superimposed, and similarly those of /dʊd/ and /dud/.
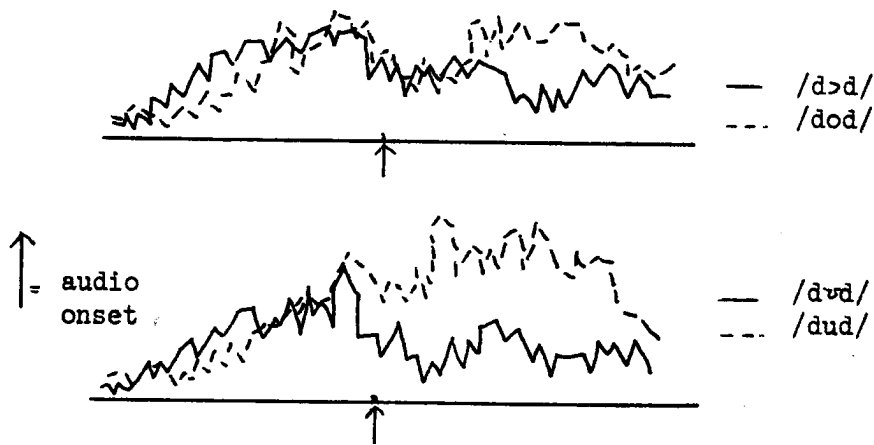
Figure 52. Orbicularis action produced during the
articulations of /dɔd/ and /dod/ and
/dʊd/ and /dud/ superimposed.

Prior to the audio onset the amount of muscle action
is very similar for the two phonemes, while there is a
decided difference following the audio onset. If indeed
these are diphthongs, and if motor commands are related to
phonemes rather than to linguistic units larger than a
single phoneme, one could infer that the gestures are the
result of a simple sequence of two motor commands.

2. The Variance of Motor Commands Associated With
   Individual Phonemes.

The results of the present investigation do not
support the hypothesis that a simple one-to-one correspond-
ence exists between a phoneme and its motor commands.

For the bilabial stops /b/ and /p/ different motor commands produce different muscular gestures for these consonants occurring in initial position and in final position. There is, however, an apparent invariance in the gestures which produce the allophones of these phonemes. In other words the neuro-muscular characteristics of /b/ in initial position in an utterance were found to be relatively identical regardless of the vowel which followed. The same was true of /b/ in final position regardless of the vowel which preceded it. Referring back to Figure 43 showing the superimposition of all initial /b/ utterances and final /b/ utterances, it is clear that as to both amplitude of peak and duration of muscular action, different gestures are responsible for the articulation of /b/ in these two contexts.

While this study did not investigate initial or final consonants in clusters, the lack of influence displayed by the vowels in the immediate environment of the consonant would tend to support the findings of MacNeilage (1963) in his electromyographic study of /f/ where he found the EMG traces to be 'virtually identical regardless of phonetic context'. The phonetic context cannot be generalized, however, to position in the utterance, as shown by Figures 43 and 48 above.

A much more complicated picture is revealed by an evaluation of the myograms of vowel production. Certain

phonetic contexts seem to influence the myographic activity, while others do not. Orbicularis action of an initial /b/ has no effect on vowels which show no muscular tension when preceded by /d/. The muscular action producing the simple, non-diphthongal 'rounded' vowels ( /er, ɔ, ʊ/) occurred in the /d_d/ utterances prior to the onset of the audio signal. The duration of muscular tension for an initial /b/ occurred similarly before the onset of the audio signal. As Haskins Laboratories pointed out (Liberman et al 1965) "for temporally overlapping articulatory gestures involving more-or-less adjacent muscles that control the same structure...it is, for obvious reasons, more difficult to discover what is going on." (2.20) What is evident is that two motor commands directed to the same muscle do not result in a simple addition of the number of motor units contracting. For example, the gesture associated with the closure of an initial /b/ is not modified by a second motor command for vowel rounding. The second gesture seems to be 'locked out' by the first. The result seems to resemble that category of devices which upon being triggered into action remain insensitive to further stimuli during their period of firing and recovery, i.e. the Geiger counter. Another possibility lies in the category of threshold devices which are indifferent to the amount by which their thresholds are exceeded, i.e. a Schmitt trigger.

On the other hand, the myographic traces of utterances beginning with /b/ and followed by /u/ or /o/ reveal a decrease in the muscular tension after the onset of the audio signal as compared to the EMG records of /u/ and /o/ when preceded by /d/. Figure 49 demonstrates this. Physiologically this may be explained by the fact that a strong effort is required to initiate the closure of the lips with many motor units recruited for the task and with the frequency of discharge increasing until the lip closure occurs. Less effort is needed to sustain the partial closure required for the /o/ and /u/ articulation. Where /o/ and /u/ are not preceded by /b/, the initial closure, starting from a neutral, non-activated position, thus requires greater activity. This appears to be a simple inertial effect, i.e. it is harder to start an object moving than it is to keep it moving once it is started. When viewed from the standpoint of motor commands, alternative explanations are suggested. One possible conclusion is that the minimal linguistic unit corresponding to the motor commands which produce speech is larger than the phoneme, perhaps more of the order of a syllable. On the other hand, the findings of the present study do not rule out the possibility that motor commands are related to phonemic segments. If such is indeed the case, these are obviously not invariant commands, but are context restricted, altered either by feedback information concerning the existing state of muscular

motion, or by stored information in the short-term memory.

When /u/ and /o/ are preceded by /d/ and followed by /b/ the same muscular gesture is found as that in the /d_d/ context. Since the onset of muscular action associated with the ending of the vowel occurs immediately after the onset of the audio signal and the onset of activity producing the final /b/ 225 msec. after the onset of the audio signal, this may be the result of simple concatenation. This same kind of concatenation could explain the production of the diphthongs in the /d_d/ context. In utterances beginning and ending with /b/ there is some decrease in muscular activity associated with the vowel production as was discussed above regarding the /b_d/ context, but not as great a decrease. This suggests that the correspondence of motor units is not to the phoneme. For here neither feedback nor stored information would explain the anticipatory effect which the following /b/ seems to have on the vowel which is preceded by /b/.

The findings of this study would therefore agree with the Haskins statement that "some parts of the gesture may be reorganized when the phoneme appears in different contexts". (Liberman et al 1965, 2.20) The nature of this reorganization is not fully revealed by the studies conducted to date. The motor commands associated with different phonemes are certainly context restricted commands as has been indicated.

The results of the present study relevant to the relationship between motor commands and phonetic segments can be summarized as follows: (1) when the motor commands call for gestures to occur simultaneously, the resultant muscular activity is equal to that necessary for the production of the segment requiring the greatest tension; (2) when motor commands call for a sequence of gestures, if the first gesture requires more tension than the following gesture, the tension for the second gesture is decreased; (3) when motor commands call for a sequence of gestures, where both gestures require an equal exertion of the muscle or where the second gesture requires a greater exertion, a more or less simple concatenation of gestures results.

3. <u>Comparison</u> <u>of</u> /p/ - /b/ <u>Muscular</u> <u>Gestures</u>.

Neither of the hypotheses tested relating to the phonemes /p/ and /b/ in American-English were confirmed definitely. The conclusion reached at Haskins Laboratories that "the electromyographic activity at the lips was found to be essentially the same for /p/ (and) /b/" is difficult to test since one is not sure what "essentially the same" means. It must also be pointed out that in the experiment conducted at Haskins the electrodes were placed in different positions than that used in the present study. Electrodes were placed above the vermillion border of the upper lip to investigate the action of the orbicularis oris muscle responsible for lip closure, while in our study the

electrode was placed directly on the vermillion border of
the lower lip.  This might account for the different results.

Results of the present study support the findings of
the Haskins group when only the peak amplitude of the aver-
aged EMG traces are compared.  There is so much overlap
between /b/ and /p/ that one may conclude that the gestures
at the lips were virtually identical.  This is illustrated
in Figure 53 which presents the superimposition of the
averaged EMG traces of /b/ and /p/ utterances.  Figure 54
shows this in a schematic diagram.  However, when the
duration of muscular tension is considered, in every case
the muscular gesture associated with /b/ is of longer dura-
tion than that associated with /p/.  It is also important
that final /p/ and /b/ differ in the timing of the articula-
tory gestures.  Thus, these two sounds cannot be said to
differ only in the action of the larynx.  This fact also
shows that motor commands are highly complex.  It can not
be concluded then, when both variables are considered, that
the gestures are identical.

It is perhaps more significant that the second hypo-
thesis regarding /p/and/b/ was not confirmed.  The results
of this experiment suggest that what differentiates the
phonemes /p/ and /b/, in American-English, is not the tense-
lax distinction.  An examination of Figure 53 reveals that
for subject A, the muscular activity is greater in the
production of /bId/, /dɪb/ and /bib/ than in /pɪd/ and

Audio onset
End of audio

A    —— /bɪd/
     ···· /pɪd/

A    —— /bʊd/
     ···· /pʊd/

A    —— /dɪb/
     ···· /dɪp/

voltage  |¯ 100 μv
         |_ o

A    —— /dʊb/
     ···· /dʊp/

A    —— /bɪb/
     ···· /pɪp/

A    —— /bʊb/
     ···· /pʊp/

Subject A

B    —— /bɪd/
     ···· /pɪd/

B    —— /dɪb/
     ···· /dɪp/

Subject B

C    —— /bɪd/
     ···· /pɪd/

C    —— /dɪb/
     ···· /dɪp/

Subject C

Superimpo

⟵ 200 msec
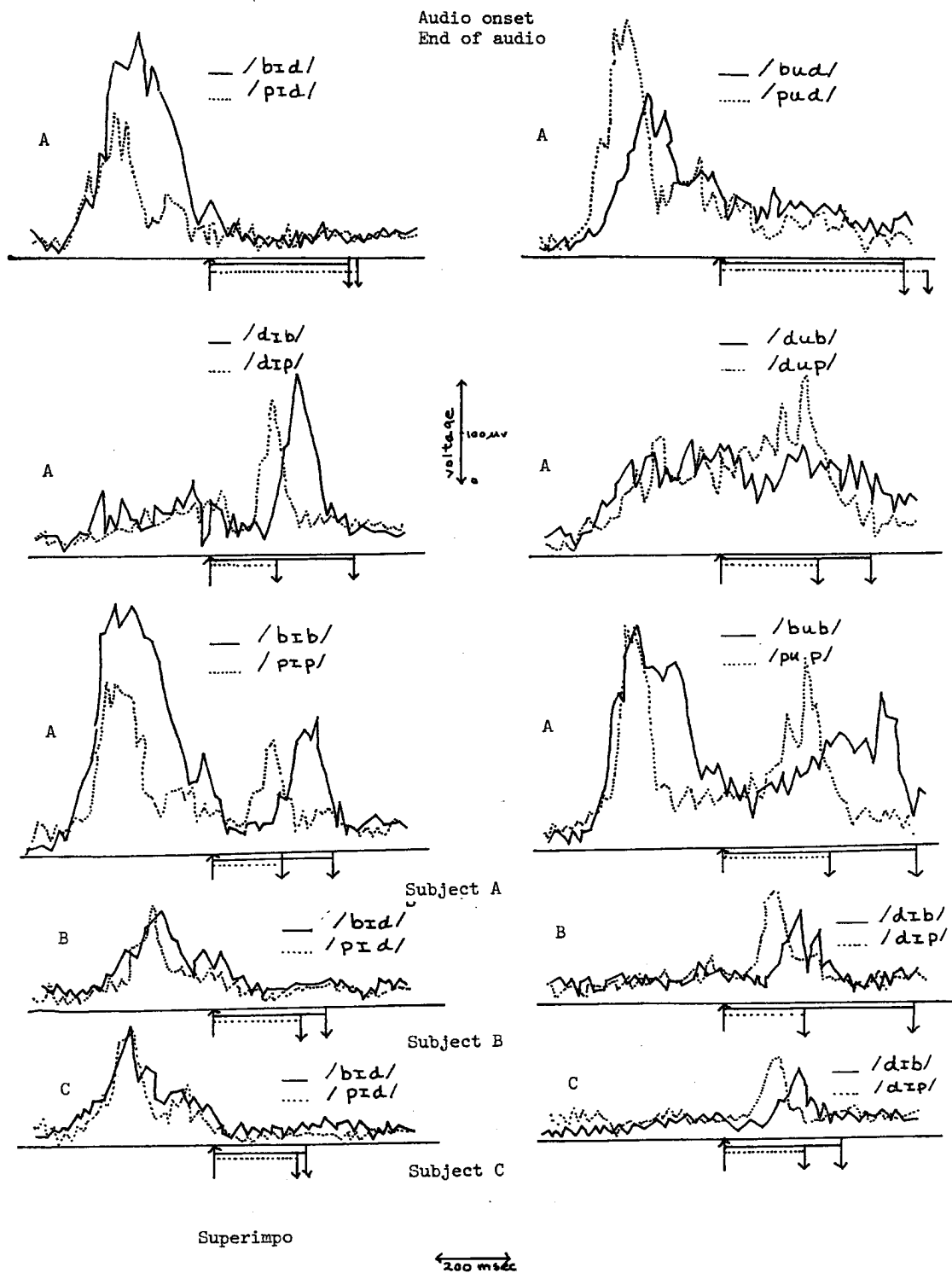
Figure 53. Superimposition of averaged EMG traces of /b/ and /p/ utterances

/pɪp/; it is greater for /pud/ and /dub/ than for /bud/ and /dup/ . For subject C /bɪd/ shows slightly more tension than /pɪd/ and /dɪp/ slightly more than /dɪb/. For subject B there is relatively no statistical difference in the muscular tension of the two consonantal phonemes.

Figure 54 presents a schematic diagram of the average amount of muscular activity for initial and final /b/ and /p/.
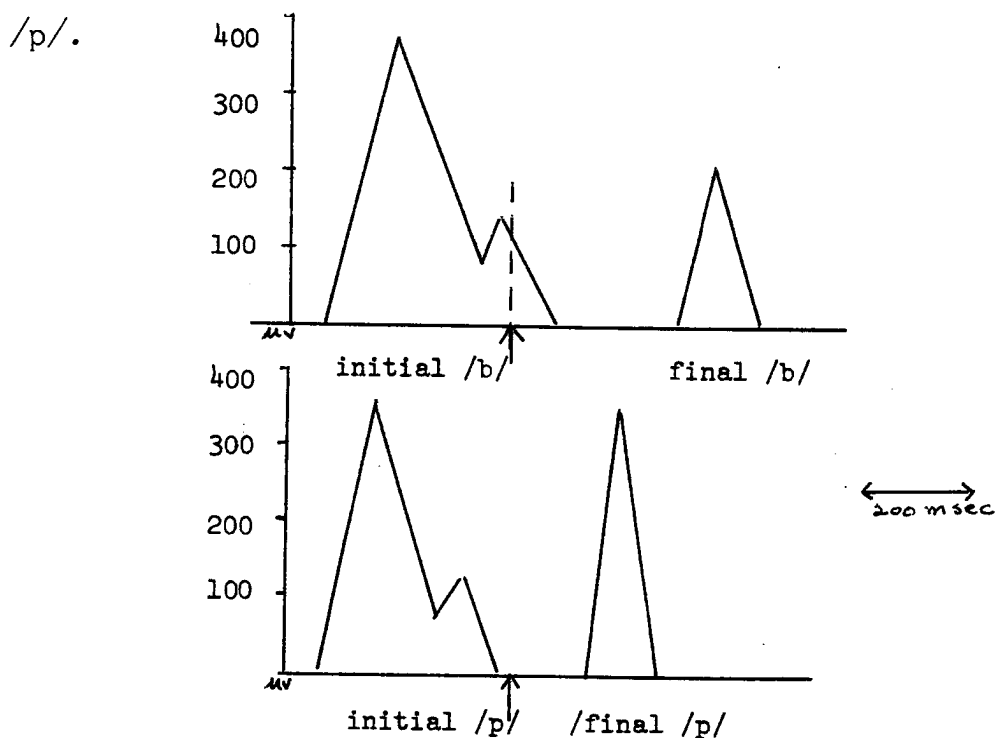


Figure 54. Schematic diagram of the average amount of muscular activity for initial and final /b/ and /p/.

The summed EMG traces of 24 utterances beginning and ending with these consonants, spoken by the principal subject, were averaged to obtain these diagrams. This demonstrates that at least for the utterances produced, initial /b/ shows both greater amplitude and greater duration of muscular activity than initial /p/, while final /p/ shows greater

amplitude but shorter duration than final /b/.

Since the articulation of /p/ does not in any way show consistently greater muscular activity of the orbicularis oris muscle than the articulation of /b/, it can be concluded that a feature other than the tense-lax feature must differentiate these two phonemes in American-English.

E. Conclusions

It is hoped that the experiment discussed above demonstrates the meaning and relevance of physical phonetics to theoretical linguistics. If, as has been suggested, certain definite correspondences must hold between a linguistic model and empirical reality, for the model to be verified, the final test of a phonological description is its ability to predict real events.

By using the technique of electromyography it was found that certain phonetic features associated with phonemic segments may be described with precision. While it would have been encouraging to find a simple one-to-one correspondence between the linguistic unit and neuromuscular activity, this was not the case. But EMG traces did reveal certain invariant characteristics associated with each phoneme. Furthermore, this study of just one muscle, leads one to imagine the possibility that further investigation of all the muscles involved in the production of any one speech sound may provide a means of segmentation of an utterance into phonemes. When muscular gestures overlap

as in the case of an initial bilabial consonant followed by a flat vowel such segmentation can not be accomplished by reference to this particular physiological parameter. But when the tongue muscles are studied, such segmentation may be possible.

The use of experimental data to confirm a linguistic hypothesis was shown in the case of the flat and non-flat vowels. The use of the experimental data of physical phonetics to reject a linguistic hypothesis was also shown in the case of the tense-lax distinction proposed for the American-English phonemes /p/ and /b/.

In conclusion, it is felt that further experimental work utilizing electromyography can provide testable, precise specifications of physiological parameters. And finally, it is felt that, by such techniques, we have the means to test specific linguistic descriptions.

# BIBLIOGRAPHY

Abercrombie. D. (1949) "Forgotten Phoneticians" Trans. of
    the Philol. Soc. 1948, Hartford: Stephen Austin & Sons.

Adrian, E. D. and D. W. Bronk (1929) "The Discharge of
    Impulses in Motor Nerve Fibres. Part II. The Frequency
    of Discharge in Reflex and Voluntary Contractions"
    J. Physiol. 67, 119-151.

Allen, W. S. (1962) "Aspiration in the Harauti Nominal"
    Studies in Linguistic Analysis (hereafter SLA) Oxford:
    Basil Blackwell, 68-86.

Basmajian, J. V. (1962) Muscles Alive: Their Functions
    Revealed by Electromyography Baltimore: Williams and
    Wilkins.

Bauwens, P. (1950) "Electromyography" Brit. J. Phys. Med.
    11, 130-136.

Bauwens, P. (1950) "The Analysis of Action Potentials in
    Electromyography" Proc. Inst. Electr. Engin. 97.107,
    217-222.

Bell, C. The Anatomy and Philosophy of Expression (7th ed.)
    George Bells and Sons (1888) London.

Bergstrom, R. M. (1959) "The Relation Between the Number of
    Impulses and the Integrated Electrical Activity in Elec-
    tromyography" Acta Physio. Scand. 45, 97-101.

Bigland, Brenda and Lippold, O. C. J. (1954) "The Relation
    Between Force, Velocity and Integrated Electrical
    Activity in Human Muscle" J. Physiol. 123, 214-224.

Bloomfield, L. (1933) Language, New York: Henry Holt & Co

de Broglie, L. (1962) New Perspectives in Physics, trans-
    lated by A. J. Pomerans, New York: Basic Books.

Buchthal, F. and Lindhard, J. (1939) The Physiology of
    Striated Muscle Fibre. Denmark: Ejnar Munksgaard.

Buchthal, F., Guld, C., and Rosenfalck, P. (1957A) "Volume
    Conduction of the Spike of the Motor Unit Potential
    Investigated with a New Type of Multi-Electrode"
    Acta Physiol. Scand. 38, 331-354.

Buchthal, Guld, C., and Rosenfalck, P. (1957b) "Multi-Electrode Study of the Territory of a Motor Unit" Acta Physiol. Scand. 39, 83-104.

Buchthal, F., Erminio, F., and Rosenfalck, P. (1959) "Motor Unit Territory in Different Human Muscles" Acta Physiol. Scand. 45, 72-87.

Campbell, E. J. M. (1958) The Respiratory Muscles and the Mechancis of Breathing, London: Lloyd-Luke.

Carlsöö, S. (1952) "Nervous Coordination and Mechanical Function of the Mandibular Elevators: an Electromyo-Graphic Study of the Activity and an Anatomic Analysis of the Mechanics of the Muscles" Acta Odontol. Scand. 10. Supplement 11.

Chomsky, N. (1964) "Current Issues in Linguistic Theory" The Structure of Language, edited by J. Fodor and J. Katz (hereafter, Fodor & Katz) Englewood Cliffs, N. J. Prentice-Hall, Inc., 50-118.

Close, J. R., Nickel, E. D. and Todd, F. N. (1960) "Motor Unit Action Potentials Counts: Their Significance in Isometric and Isotonic Contractions" J. Bone and Joint Surgery 42A. 7, 1207-1222.

Close, J. R., (1964) "Motor Function in the Lower Extremity" Springfield: Charles C. Thomas.

Cooper, F. S. (1965) "Research Techniques and Instrumenta-tion: EMG" Amer. Speech and Hearing Assoc. Reports 1, 153-168.

Conant, J. B. "The Citadel of Learning" Yale Review, 45

Cunningham, D. J. (1951) Text-book of Anatomy (9th ed.,) Revised by J. C. Brash, New York: Oxford Univ. Press.

Darwin, C. (1886) The Expression of the Emotions in Man Animals, New York: Appleton

Delattre, P. (1958) "Les Indices Acoustiques de la Parole. Premier Rapport" Phonetica, 2, 108-118, 210-251.

Denny-Brown, D. and Pennybacker, J. B. (1938) "Fibrillation and Fasciculation in Voluntary Muscle" Brain 61, 311-334

Denslow, J. S. and Hassett, C. C. (1943) "The Polyphasic Action Current of the Motor Unit Comples" Am. J. Physiol. 139, 652-660.

De Palma, A. T., Leavitt, L. A., and Hardy, S. B. (1958) "Electromyography in Full Thickness Flaps Rotated Between Upper and Lower Lips" Plast. & Reconstruct. Surg. 21, 448-452.

Draper, M. H., Ladefoged. P., and Whitteridge, D. (1959) "Respiratory Muscles Involved in Speech" J. Speech and Hearing Res. 2, 16-27.

Draper, M. H., Ladefoged, P., Whitteridge, D. (1960) "Expiratory Pressures and Airflow During Speech" Britt. Med. J. 1837-1843.

Duchenne, G. B. (1867) Physiology of Motion, translated and edited by E. B. Kaplan, Philadelphia: J. B. Lippincott Co., 1949.

Duchenne, G. B. (1876) Mecanisme de la Physionomie Humaine ou Analyse Electrophysiologique de l'Expression des Passions, Librairie J. B. Bailliere et Fils.

Dunstan, Elizabeth (1965) "Electromyographic Recordings in the Mouth" Working Papers in Phonetics, No. 2 UCLA 55-58.

Dutta, C. R. and Basmajian, J. V. (1960) "Gross and Histological Structure of the Pharyngeal Constrictors" Anat. Rec. 137, 127-234.

Einstein, A., and L. Infeld (1954) The Evolution of Physics, New York: Simon and Schuster

Einstein, A. (1934) Essays in Science, New York: Philosophical Library

Faaborg-Andersen, K. (1957) "Electromyographic Investigation of Intrinsic Laryngeal Muscles in Humans" Acta Physiol. Scand. 41, 3-30.

Faaborg-Andersen, K. (1964) "Electromyography of the Laryngeal Muscles in Man" Research Potentials in Voice Physiology (Ed. D. Brewer) 105-123, New York: State Univ. of New York.

Faaborg-Andersen K. (1965) Electromyography of Laryngeal Muscles in Humans Technics and Results, New York: S. Karger.

Fant, G. (1939) "Acoustic Analysis and Synthesis of Speech With Applications to Swedish" Ericsson Tech. Sweden 1, 3-108.

Firth, J. R. (1957) Papers in Linguistics 1934-1951, London
    Oxford Univ. Press.

Firth, J. R. (1962) "A Synopsis of Linguistic Theory, 1930-
    1955" SLA 1-133.

Firth, J. R. (1962) "Introduction" SLA 68-86.

Fischer-Jørgensen, E. (1952) circulated in 1964 by
    Phonetics Dept., Edinburgh Univ., Scotland

Fischer-Jøorgensen, E. (1958) "What Can the New Techniques
    of Acoustic Phonetics Contribute to Linguistics?" Proc.
    of the 8th Intern. Cong. of Linguistics, Oslo Univ. Press
    433-477 (hereafter, 8th Congress)

Fischer-Jørgensen, E. (1964) "The Phonetic Basis for
    Identification of Phonemic Elements" Journ. of the Acous.
    Soc. of Amer., 24.6, 611-617.

Foley, M. G. (1953) Galvani's Effects of Electricity On
    Muscular Motion, Norwalk, Connecticut: Burndy Library

Fritzell, B. (1963) "An Electromyographic Study of the
    Movements of the Soft Palate in Speech" Folio Phonia-
    trica 15, 307-311.

Fromkin, V. A., (1964) "Lip Positions in American-
    English Vowels" Lang. &Speech 7.4, 215-225

Gimson, A. C. (1962) An Introduction to the Pronunciation
    of English, London: Edward Arnold Ltd.

Gleason, H. A. (1955) An Introduction to Descriptive Lin-
    guistics, New York, Henry Holt and Co.

Gray, H. (1959) Gray's Anatomy (C. M. Goss ed.) Phila-
    delphia: Lea and Febinger

Haines, R. W. (1932) "The Laws of Muscle and Tendon
    Growth" J. Anat. 66, 578-585.

Haines, R. W. (1934) " Muscles of Full and Short Action"
    J. Anat. 69, 20-24.

Haldeman, S. (1856) "Report on the Present State of Knowl-
    edge of Linguistic Ethnology" Amer. Assoc. for the
    Advancement of Sciences, published for the Assoc. by
    Joseph Lovering

Halle, M. (1956) "Review of 'Manual of Phonology' by C. Hockett" JASA 28.3, 509-511

Halle, M. (1961) "On the Rule of Simplicity in Linguistic Descriptions" Structure of Language and its Mathematical Aspects, Proceedings of Symposia in Applied Math., Amer. Math. Soc. XII 89-94.

Halle, M. (1964) "On the Bases of Phonology " Fodor & Katz 324-333.

Halle, M. (1964a) "Phonology in Generative Grammar" Fodor & Katz 334-352.

Hamp, E. P. (1962) "The Interconnection of Sound Production, Perception and Phonemic Typology" 4th Congress 639-643.

Harris, Z. (1942) "Simultaneous Components in Phonology" Lang, 20, 181-205

Harris, Z. (1951) Structural Linguistics Univ. of Chicago Press, Chicago, Fourth edition, 1960.

Harris, K. S., Rosov, R., Cooper, F. S., and Lysaught, G. "A Multiple (1964) Suction Electrode System," Electroenceph. Clin. Neurophysiol. 17, 698-700.

Hayes, K. J. (1960) "Wave Analyses of Tissue Noise and Muscle Action Potentials" J. Applied Physiol. 15, 749-752.

Hjelmslev, L. (1935) "On the Principles of Phonematics" Proc. of the 2nd Intern. Congress of Phonetic Sciences, 49-54.

Hjelmslev, L. (1943) Prolegomena to a Theory of Language, page references refer to English translation by F. J. Whitfield, 2nd printing, 1943, Wisconsin: Univ. of Wisconsin Press.

Hjelmslev, L. (1947) "Structural Analysis of Language" Studia Linguistica I, 69-78.

Hoefer, P. F. A. and Putna, T. J. (1939) "Action Potentials of Muscles in Normal Subjects" Arch. Neurol. Psychiat. 42, 201-218.

Hoeve, H. J. H. (1910) A Manual of Dissection and Practical Anatomy of Head and Neck, Desmoines: Geo. A. Miller Co.

Hollingshead, W. H. (1954) _Anatomy for Surgeons,_ New York: Hoeber.

Hoshiko, M. (1960) "Sequence of Action of Breathing Muscles During Speech" _J.Speech and Hearing Res._ 3, 291-297.

Howell, W. H. (1946) _Textbook of Physiology_ (15th Edition) Philadelphia: W. B. Saunders.

Husson, R. "Physiologie de la Phonation et Phoniatrie" (1954) _Rev. Quest. Sci._ 75-89

Huxley, J. (1940) "Towards the New Systematics" _The New Systematics_, Oxford 1-46.

Jackson, C. M. (1933) _Textbook of Physiology_ (9th edition) Philadelphia: P. Blaeston's Son & Co.

Jakobson, R., Fant, G. and Halle, M. (1952) _Preliminaries to Speech Analysis_, Cambridge, Mass., The M.I.T. Press. Page numbers refer to 4th printing, 1961.

Jakobson, R., and Halle, M. (1956) _Fundamentals of Language_ The Hague: Mouton

Katsuki, Y. (1950) "The Function of the Phonatory Muscles" _Jap. J. Physiol._ 1, 29-35.

Kim, C. (1965) "On the Autonomy of the Tensity Feature in Stop Classification" (Forthcoming)

Krnjevic, K., and Miledi, R. (1958) "Motor units in the Rat Diaphragm" _J. Physiol._ 140, 427-439.

Kugelberg, E., and Skoglund, C. R. (1946) "Natural amd Artificial Activation of Motor Units -- a Comparison" _J. Neurophysiol._ 9, 399-412.

Kugelberg, E. (1952) "Facial Reflexes" _Brain_ 75, 385-96.

Ladefoged, P. (1958) "Syllables and Stress" _Miscellanea Phonetica_ 3, 1-14.

Ladefoged. P. (1958) Remarks published in _8th Congress,_ 482-483.

Ladefoged. P. (1960) "The Value of Phonetic Statemets" _Lang._ 36.3. 387-396.

Ladefoged, P. (1962) "Subglottal Activity During Speech" _IV^th Internat. Congr. Phon. Sci.,_ The Hague: Mouton.

Ladefoged, P. (1962) The Nature of the Vowel Quality, Revista De Laboratorio de Fonetica Experimental Da Faculdade de Letras Da Universidade de Coimbra.

Liberman, A. M., Cooper, F. S., Harris, K. S., MacNeilage, P. F. (1962) "A Motor Theory of Speech Perception" Proc. of Speech Communication Seminar, Speech Lab., Royal Inst. of Technol., Stockholm.

Liberman, A. M., Cooper, F. S., Harris, K. S., and MacNeilage, P. F. (1962) "A Motor Theory of Speech Perception" Proc. Speech Communication Seminar, Stockholm.

Liberman, A. M., Cooper, F. S., Harris, K. S., MacNeilage, P. F. and Studdert-Kennedy, M., (1965) Speech Research, Haskins Laboratories, New York.

Liberman, A. M., Cooper, F. S., Harris, K. S., MacNeilage, P. F. and Studdert-Kennedy, M., (1965) "Some Observations on a Model for Speech Perception" Status Report on Speech Perception, SR-1. Haskins Laboratories, 2.1-2.21.

Liddell, E.G.T., and Sherrington, C. S., (1925) "Recruitment and Some Other Features of Reflex Inhibition" Proc. Roy. Soc. 97B, 488-503.

Lindblom, B. (1963) "Spectrographic Study of Vowel Reduction" J. Acoust. Soc. Amer. 35, 1773-1781.

Lindblom, B. (1963) "On Vowel Reduction" Speech Transmission Lab., R.I.T. Stockholm.

Lindblom, B. "Some Temporal Correlates of Stress Contours" J. Acoust. Soc. Amer. (Forthcoming)

Lindsley, D. B. (1935) "Electrical Activity of Human Motor Units During Voluntary Contraction" Am. J. Physiol. 114, 90-97.

Lippold, O. C. J. (1952) "The Relation Between Integrated Action Potentials in a Human Muscle and its Isometric Tension" J. Physiol. 117, 492-499.

Lotz, J. (1950) "Speech and Language" JASA 22.6, 712-730.

MacNeilage, P. G. (1963) "Electromyographic and Acoustic Study of the Production of Certain Final Clusters" J. Acoust. Soc. Amer. 35, 461-463.

MacNeilage, P. F., and Sholes, G. N. (1964) "An Electromyographic Study of the Tongue During Vowel Production" J. Speech and Hearing Res. 7.3, 209-232.

Malmberg, G. (1963) Structural Linguistics and Human Communication, New York: Academic Press Inc.

Martinet, A. (1955) "Phonology as Functional Phonetics" (Three lectures delivered in 1946) Publications of the Philol. Soc. XV. Oxford: Basil Blackwell.

Martinet, A. (1960) Elements of General Linguistics, Page numbers refer to English translation by Elisabeth Palmer, Chicago: Univ. of Chicago Press, 1964.

Moyers, R. E. (1956) "Some Recent Electromyographic Findings in the Orofacial Muscles" Eur. Orthodon. Soc. Trans. Report of the 32nd Congress, Stockholm.

Music, R., Elbert, L., Reilly, N., and Cooper, F. S. (1965) "Automating the Collecting and Reduction of Electromyographic Data on Speech Production" Status Report on Speech Research, SR-1, New York, Haskins Laboratories, 5.1-5.12.

Norris, F. H. Jr., and Gasteiger, E. L. (1955) "Action Potentials of Single Motor Units in Normal Muscle" Electroenceph. and Clin. Neurophysiol. 7, 115-126.

Ohman, S. (1964) "Numerical Model for Coarticulation, Using a Computer-simulated Vocal Tract" J. Acoust. Soc. Amer. 36.5, 1038

Ohman, S., "Coarticulation in VCV Utterances: Spectographic Measurements" J. Acoust. Soc. Amer. (forthcoming)

Paget, R. A. S. (1923) "The Production of Artificial Vowel Sounds," Royal Society Proceedings A102, 752-765.

Penfield, W. (1954) "Mechanisms of Voluntary Movement" Brain, LXXVII, 1, 1-17.

Pernkopf, E. (1963) Atlas of Topographical and Applied Human Anatomy Vol. i "Head & Neck" Philadelphia: Saunders.

Peterson, G. E. and McKinney, N. P. (1961-62) "The Measurement of Speech Power" Phonetica 7, 2-3.

Petersen, I., and Kugelberg, E. (1949) "Duration and Form of Action Potential in the Normal Human Muscle" J. Neurol. Neurosurg. and Psych. 12, 124-128.

Smith, O. C. (1934) "Action Potentials from Single Motor Units in Voluntary Contraction" Am. J. Physiol. 108, 629-638.

Spaltenholz, W. (1943) Hand Atlas of Human Anatomy (translated by L. F. Barker) 13th edition, Philadelphis: J. B. Lippincott Co.

Stetson, R. H. (1927) Motor Phonetics, Archives Neerlandaises de Phonetique Experimentale Tome III.

Stetson, R. H. (1951) Motor Phonetics, (2nd edition) Amsterdam: No. Holland Publishing.

Trnka, B. (1964) "On the Linguistic Sign and Multilevel Organization of Language" Travaux Linguistiques de Prague, 1.

Tulley, W. J. (1953) "Methods of Recording Patterns of Behavior of the Oro-facial Muscles Using the Electromyography" Dental Record 73, 741-748.

Van den Berg, (1958) "Myoelastic-aerodynamic Theory of Voice Production" J. Speech and Hearing Res. 1.3, 227-244.

Van Riper, C. and Irwin, J. V. (1958) Voice and Articulation, Englewood Cliffs, N. J.: Prentice-Hall, 4th printing 1962.

Weddell, G., Feinstein, F., and Pattle, R. E. (1944) "The Electrical Activity of Voluntary Muscle in Man Under Normal and Pathological Conditions" Brain 67, 178-257.

Wells, R. S. (1951) "Review of 'Recherches Structurales 1949'" Language 27.4.

SNS0: { 0 – continue to sum  
{ 1 – display EMG average with scaling

SNS1: { 0 – EMG only  
{ 1 – add audio with scaling

SNS2: { 0 –  
{ 1 – return to sampling and averaging

Set registers to zero.

Read in time base.

Sample audio

no

Is audio positive?  yes

Sample EMG

Index & store EMG

Reset audio & EMG initial address

Time delay base

Add sample. Update EMG address

Sample audio

no

Have 1000 pts. of each been sampled?

Add audio sample. Update audio address

Index & store audio

yes

Display audio

Display EMG

SNS 0   1

0

SNS 2   1

Display scaled audio av.

1   SNS 1

0

Display scaled EMG aver.

Read LSW

0

Appendix A.

Figure 55.  Block diagram of computer program.

180

APPENDIX B

## Table 2 - Vowels

| Utterance | Peak Amplitude | Duration of Action | Onset of Action to Onset of Audio |
|---|---|---|---|
| /derd/ | 160 | 200 | 180 |
| /dod/ | 170 | 350 + 420 | 400 |
| /dɔd/ | 150 | 400 | 380 |
| /dud/ | 200 1st peak 750<br>260 2nd " | | 240 |
| /dʊd/ | 180 | 400 | 370 |

For all following tables the columns are as follows:

    A - Peak amplitude in microvolts

    B - Duration of muscle action in msec.

    C - Interval between onset of muscle action and audio onset in msec.

    D - Interval from audio onset to onset of action in msec.

    E - Interval between amplitude peak and audio onset in msec.

    F - Interval from audio onset to amplitude peak in msec.

# APPENDIX B

## Table 3 - Initial /b/

| Utterance | A | B | C | E |
|-----------|-----|-----|-----|-----|
| bɪd | 430 | 350 | 420 | 220 |
| bɪd(2) | 470 | 360 | 425 | 280 |
| bɪb | 350 | 420 | 450 | 280 |
| bɪb(2) | 490 | 350 | 420 | 280 |
| bid | 400 | 480 | 500 | 280 |
| bib | 340 | 360 | 450 | 240 |
| bɛd | 470 | 400 | 480 | 240 |
| bɛd(2) | 290 | 380 | 420 | 180 |
| bɛb | 350 | 360 | 450 | 310 |
| bɛb(2) | 280 | 320 | 420 | 240 |
| bed | 370 | 350 | 410 | 210 |
| bed | 370 | 350 | 410 | 210 |
| beb | 440 | 320 | 420 | 300 |
| bæd | 340 | 300 | 400 | 240 |
| bæb | 41 | 380 | 420 | 280 |
| bud | 32 | 225 | 320 | 220 |
| bud(2) | 27 | 300 | 350 | 220 |
| bub | 38 | 300 | 400 | 260 |
| bub(2) | 43 | 300 | 400 | 260 |
| bʊd | 37 | 350 | 450 | 320 |
| bʊb | 48 | 300 | 360 | 260 |
| bod | 34 | 360 | 450 | 300 |
| bod(2) | 33 | 300 | 400 | 240 |
| bob | 43 | 300 | 400 | 260 |
| bob(2) | 27 | 300 | 350 | 260 |
| bɔd | 46 | 320 | 420 | 300 |
| bɔb | 44 | 280 | 360 | 260 |
| bad | 36 | 280 | 350 | 180 |
| bab | 46 | 280 | 320 | 220 |
| Mean | 38.4 | 332 | 411 | 255 |

APPENDIX B

Table 4 — Final /b/

| Utterance | A | B | D | F |
|---|---|---|---|---|
| dɪb | 260 | 200 | 180 | 150 |
| dɪb(2) | 340 | 200 | 190 | 150 |
| bɪb | 180 | 220 | 200 | 100 |
| bɪb(2) | 260 | 220 | 190 | 80 |
| dib | 190 | 280 | 190 | 150 |
| bib | 160 | 150 | 220 | 80 |
| dɛb | 22 | 150 | 230 | 150 |
| dɛb(2) | 25 | 180 | 220 | 100 |
| bɛb | 22 | 150 | 220 | 210 |
| bɛb(2) | 18 | 200 | 180 | 150 |
| deb | 17 | 150 | 320 | 60 |
| beb | 20 | 140 | 380 | 150 |
| dæb | 23 | 150 | 320 | 80 |
| bæb | 20 | 130 | 370 | 150 |
| dub | 19 | | | |
| dub(2) | 30 | | | |
| bub | 20 | | | |
| bub(2) | 25 | | | |
| dʊb | 20 | 180 | 160 | 150 |
| bʊb | 25 | 130 | 220 | 150 |
| dob | 19 | | | |
| dob(2) | 26 | | | |
| bob | 25 | | | |
| bob(2) | 22 | | | |
| dɔb | 30 | 150 | 380 | 100 |
| bɔb | 19 | 130 | 390 | 120 |
| dab | 16 | 180 | 310 | 150 |
| dab(2) | 15 | 150 | 420 | 70 |
| bab | 22 | 150 | 390 | 100 |
| bab(2) | 15 | 180 | 380 | 110 |
| Mean | 220 | 170 | 275 | 125 |

APPENDIX B.

### Table 5 - Initial /p/

| Utterance | A | B | C | E |
|---|---|---|---|---|
| pɪd | 27 | 210 | 400 | 300 |
| pɪd(2) | 30 | 280 | 420 | 330 |
| pɪp | 46 | 230 | 350 | 250 |
| pɪp(2) | 33 | 220 | 350 | 300 |
| pud | 47 | 200 | 380 | 300 |
| pud(2) | 34 | 220 | 380 | 300 |
| pup | 42 | 220 | 350 | 280 |
| pup(2) | 37 | 220 | 370 | 300 |
| | | | | |
| Mean | 37 | 225 | 375 | 295 |

### Table 6 - Final /p/

| Utterance | A | B | D | F |
|---|---|---|---|---|
| dɪp | 52 | 150 | 220 | 0 |
| dɪp(2) | 29 | 140 | 200 | 0 |
| pɪp | 37 | 140 | 220 | 0 |
| pɪp(2) | 22 | 150 | 200 | 0 |
| dup | 35 | | 270 | 0 |
| dup(2) | 45 | | 270 | 0 |
| pup | 38 | | 280 | 0 |
| pup(2) | 25 | | 270 | 0 |
| | | | | |
| Mean | 35 | 145 | 240 | |

Addenda to Bibliography

Bauwens, P. (1948) "Electromyography" Brit. J. Phys. Med. 11,
        130-136

Bloomfield, L. (1926) "A set of postulates for the science of
        language" Lang. 2, 153-64

Buchthal, F. (1960) "The General Concept of the Motor Unit"
        Res. Publ. Assoc. Res. Nervous and Mental Diseases
        38:1, Baltimore:  The William A. Wilkins Co.

Carnochan, J. (1962) "Gemination in Hausa" Studies in Linguistic
        Analysis 149-181, Oxford:  Basil Blackwell  (hereafter
        SLA

Cooper, F. S. (1962) "Speech Synthesizers" Proc. of 4th Intern.
        Cong. of Phonetic Sciences, 3-14, The Hague:  Mouton
        & Co.

Jakobson, R. (1962) Selected Writings I:  Phonology The Hague:
        Mouton & Co.

Planck, Max (1959) The New Science, Meridian Books, Inc.

The Principles of the International Phonetic Association (1961),
        London:  IPA

Quiring, D. P. (1960) The Head, Neck and Trunk, Muscles and Motor
        Points (2nd ed. rev.) edited by John H. Warfel, Philadelphia:
        Lea and Febinger

Robins, R. H. (1957) "Aspects of prosodic analysis" Proc. of Univ.
        of Durham Philos. Soc. I. B. 1

Robins, R. H. (1962) "Vowel Nasality in Sudanese" SLA

Rosenfalck, Annelise (1960) "Evaluation of the electromyogram by
        mean voltage recording" Medical Electronics, Proc. Sec.
        Int. Conf. Electron. 9-12, London:  Ileffe

Rubin, H. J. (1960) "The neurochronaxic theory of voice production --
        a refutation" A. M. A. Archives of Otolaryngology 71,
        913-920

Sapir, E. (1925) "Sound Patterns in Language" Lang. 1, 37-51.  Page
        numbers refer to Selected Writings of Edward Sapir ed.
        D. G. Mandelbaum, Univ. of Calif. 1949

Saumjan, S. K. (1964) Remarks printed in <u>Proc. of 9th Intern. Cong. of Linguists 1962</u> The Hague: Mouton & Co.

de Saussure, F. (1916) <u>Cours de linguistique generale</u> edited by C. Bally and A. Sechehave. Page references to the English translation by Wade Bisic, London: Peter Owen, Ltd.

Sawashima, M., Sato, M., Funasaka, S., and Totsuka, G. (1958) "Electromyographic study of the human larynx and its clinical application" <u>Jap. J. Otol</u>. 61, 1357-1364

Sholes, G. N. (1965) "Measuring and averaging the data" <u>Status Report on Speech Research, SR-1</u>, New York: Haskins Laboratories

Siertsema, B. (1955) <u>A Study of Glossematics</u> The Hague: Martinus Nijhoff

Trubetzkoy, N. S. (1939) <u>Gründzuge der Phonologie</u> English translation by Christine Baltaxe, forthcoming

## Corrigenda

p. iii, line 14, for 'criticisma' read 'criticism'

p. 8, 11th line from bottom, for 'contanct' read 'contact'

p. 22, line 4, for 'phychological' read 'psychological'

p. 23, line 13, delete 'the'

p. 29, line 1, for 'apparatusses' read 'apparatuses'

p. 34, line 17, for 'casuality' read 'causality'

p. 34, line 20, for (1965) read (1963)

p. 35, line 8, for (1961) read (1960)

p. 53, line 6, for (1961) read (1962)

p. 54, second line from bottom, for (1955) read (1954)

p. 85, line 2, for 'Meyers' read 'Moyers'

p. 92, line 2, for 'he' read 'the'

p. 92, line 13, for 'zygematicus' read 'zygomaticus'

p. 93, line 4, for 'zyg natic' read 'zygomatic'

p. 127, legend should read 'Principal components of the system'

p. 175, 5th line from bottom, for 'Putna' read 'Putnam'

p. 173, 3rd line from bottom, for 1939 read 1959