1939

The Significance of Various Portions of the Wave Length in the Minimum Duration Necessary for the Recognition of Vowel Sounds.

Gordon E. Peterson

Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses

Part of the Speech and Rhetorical Studies Commons

Recommended Citation

https://digitalcommons.lsu.edu/gradschool_disstheses/7809

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Historical Dissertations and Theses by an authorized administrator of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.
MANUSCRIPT THESES

Unpublished theses submitted for the master's and doctor's degrees and deposited in the Louisiana State University Library are available for inspection. Use of any thesis is limited by the rights of the author. Bibliographical references may be noted, but passages may not be copied unless the author has given permission. Credit must be given in subsequent written or published work.

A library which borrows this thesis for use by its clientele is expected to make sure that the borrower is aware of the above restrictions.

LOUISIANA STATE UNIVERSITY LIBRARY
THE SIGNIFICANCE OF VARIOUS PORTIONS OF THE WAVE LENGTH IN THE MINIMUM DURATION NECESSARY FOR THE RECOGNITION OF VOWEL SOUNDS

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in

The Department of Speech

By

Gordon E. Peterson
B. A., DePauw University, 1936
M. A., Louisiana State University, 1937
1 9 3 9
To

Mr. Giles W. Gray
for his valuable and willing assistance.
CONTENTS

INTRODUCTION ........................................ 1
I. PREVIOUS INVESTIGATIONS ....................... 6
II. RELATED STUDIES ON THE HEARING MECHANISM .................................. 13
III. THE PRESENT PROBLEM .......................... 22
IV. APPARATUS ........................................ 27
V. PROCEDURE ........................................ 47
VI. DATA ................................................ 55
VII. CONCLUSIONS ..................................... 91
BIBLIOGRAPHY ......................................... 94

111
<table>
<thead>
<tr>
<th>TABLE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Vowels Presented at the Short Interval in the First Session</td>
<td>57</td>
</tr>
<tr>
<td>II</td>
<td>Vowels Presented at the Short Interval in the Second Session</td>
<td>76</td>
</tr>
<tr>
<td>III</td>
<td>Separate Tabulations for Each Vowel in the First Set of Data. (1) Distance between Each Two Segments. (2) The Respective Differences in the Number of Recognitions of Each Two Short Sounds Presented</td>
<td>85</td>
</tr>
<tr>
<td>IV</td>
<td>Separate Tabulations for Each Vowel in the Second Set of Data. (1) Distance between Each Two Segments. (2) The Respective Differences in the Number of Recognitions of Each Two Short Sounds Presented</td>
<td>87</td>
</tr>
</tbody>
</table>
FIGURES

Fig. 1.—Diagram of the switch circuit. ... ... 35

Fig. 2.—Pendulum bob and positions of the first speaker switch ... ... ... 37

Fig. 3.—Independent curves of a 435 cycle tuning fork, showing constancy in rotation of the drum ... ... ... 40

Fig. 4.—Curves of a tuning fork, and of the vowels (ɔ), (ɑ), (ʊ), and (ʌ), showing initial and final transients ... 45

Fig. 5.—Schematic diagram of the complete circuit used in the first session ... ... 46

Fig. 6.—Master and short segments of the vowel (ɔ) with the numbers of recognitions, ... 58

Fig. 7.—Master and short segments of the vowel (ɪ) with the numbers of recognitions ... 61

Fig. 8.—Master and short segments of the vowel (ɛ) with the numbers of recognitions ... 63

Fig. 9.—Master and short segments of the vowel (ɛː) with the numbers of recognitions ... 65

Fig. 10.—Master and short segments of the vowel (a) with the numbers of recognitions ... 67

Fig. 11.—Master and short segments of the vowel (ɔ) with the numbers of recognitions ... 69

Fig. 12.—Master and short segments of the vowel (ʊ) with the numbers of recognitions ... 71

Fig. 13.—Master and short segments of the vowel (ʌ) with the numbers of recognitions ... 73

Fig. 14.—Master and short segments of the vowel (ɛ) with the numbers of recognitions ... 77

Fig. 15.—Master and short segments of the vowel (ɔ) with the numbers of recognitions ... 80
ABSTRACT

Previous experimental investigations concerning the shortest identifiable speech sounds have been made by Gemelli and Pastori, and more recently by Gray. The problem has considerable scientific significance, both in vocal theory and in the theory of hearing. Certain general limits, in some instances as low as .003 of a second, were established by Gray for the recognition of short vowel sounds.

The present study is concerned with determining whether the particular portion of the wave length utilized is significant in the recognition of short vowels sounds. Subjects were presented with several series of extremely short sounds by means of a microphone, amplifier, and speaker system. Continuous vowel sounds were intoned before the microphone, the duration of the sounds heard by the subjects being controlled by switches in the speaker circuit. A cathode-ray oscillograph was used in photographing the short segments of the various vowels presented, and these photographs were then used to determine the particular section of the wave length in which each sound occurred. The continuous vowel sounds
from which the short segments were taken were intoned at a pitch of 96 vibrations per second. Two major difficulties in the design of the apparatus were to eliminate effectively disturbing initial transients, and to damp the speaker adequately immediately following the sound. When these difficulties had been removed, two sets of data were taken; the interval used for the first set was .0036 of a second, or approximately .346 of a wave length; the interval used for the second set was .0031 of a second, approximately .298 of a wave length.

Data were taken for eight different vowel sounds, two of which were studied in detail. The position of the segments within the cycle was then studied in relation to the number of times these segments were recognized. It was necessary to choose the boundaries for each cycle arbitrarily. In accordance with the theory of harmonic analysis, a method of determining the extremities of each cycle would have been to discover the point of zero phase for the fundamental, that is, the point in the wave form at which the curve of the fundamental starts to rise above the axis. Since, for the present investigation, this was impossible, some convenient characteristic in each master wave form was arbitrarily chosen as the beginning of the cycle, and the point at which this characteristic was next repeated thus became the end of the cycle. There was no particular relationship, therefore, between the point
chosen as the beginning of the wave length for one vowel and the point chosen as the beginning of the wave length for any other vowel.

From the data obtained, four specific conclusions may be drawn.

1. This study verifies Gray's findings that significant recognitions may occur on only a small fraction of one complete vowel cycle. Gray found considerable recognition at .003 of a second, giving .24 of a cycle; in the present investigation, over 50% recognition was obtained at an interval of .0031 of a second, giving approximately .298 of a cycle.

2. A great number of instances occurred in which the wave form of the short segment closely paralleled a portion of the master wave. In the presentation of these particular segments, the specific section presented from the complete cycle was the only variable. For each vowel, marked differences appeared in the number of recognitions of these various segments. This gives conclusive evidence that for vowel sounds definite differences occur in the facility with which various sections of a given wave length are recognized. These differences were treated statistically. Nineteen subjects were used in taking the first set of data, and the average variation in recognition for the eight vowels studied was 5.9 or 31%; 15 subjects were used in the
second session, and there was an average variation in recognition of 4.9, or 30.6%. The fact that such variations exist will obviously now have to be taken into consideration in any attempt to standardize tests of the minimum duration of vowel sounds necessary for recognition. It should further be pointed out that vowel sounds, as normally intoned by different individuals, vary in pitch and quality, and thus in wave form, so as to preclude any comprehensive statements concerning segments generally most easily recognized.

3. The identification of a short segment as belonging to a given vowel obviously will depend upon how much the segment sounds like the given vowel. This very probably depends chiefly upon the degree to which the acoustic spectrum of the given short segment resembles that of the complete cycle of the vowel. Considerable variation may occur, of course, in the harmonic content of two segments taken from approximately the same section of a given cycle, even though they have a large portion of their wave form in common. It is thus significant to consider the relationship between the distances separating various segments and the differences in the recognition of those segments. For this analysis of the data, the distance was measured between the initial points of each two segments occurring for any given vowel. Magnitudes of the distances separating the segments were then correlated with the differences in the number of
recognitions corresponding to these segments. The correlation coefficient for the first and second sets of data were .176 and .023, respectively. The respective probable errors were .0945 and .0675. This correlation shows that the difference in the number of recognitions of any two segments will have little relation to the distance separating those segments. Thus two segments may be very close together and one recognised with ease, the other with difficulty.

4. As a result of the wide variations in the recognitions of the different segments presented, it follows that variation not only occurs in the facility with which various short sounds are recognized, but that it also occurs in the ability of different individuals to recognize short speech sounds.
INTRODUCTION

Experimental investigations concerning the shortest identifiable speech sounds have only recently been undertaken. The study is believed to have considerable scientific significance, but is not one which would suggest itself from purely practical considerations of speech and speech training. It is true that we occasionally accuse a person of talking too rapidly, but our protest is probably aimed at his inability to articulate clearly at such a rate, rather than at our own inability to perceive distinct sounds uttered so rapidly. The problems of the ability to utter distinct speech at such rapid rates and of the ability to perceive such speech would make significant subjects for investigation.

Hilton Cowan found that for ten prominent actors and actresses "The mean average rate of speech during the uninterrupted flow of speech within phrases was 213 words per minute."1 "The average median pitch level for all

male voices was $141^2$ vibrations per second.

Gray\(^3\) counted the sounds in several passages selected at random and found an average of approximately four sounds per word. With this number as a basis, the average duration of each sound in the example above would be .0704 of a second. Considering these averages of pitch and rate, and including both vowels and consonants, the average number of cycles for each periodic sound would be approximately 9.93. Gray\(^4\) cites a report in the American Magazine for August, 1938, concerning Allen Armbr of Los Angeles, California, who was reputed to have delivered 615 words in 57 seconds. As Gray points out, this would give each sound an average duration of .023 of a second; and, assuming an average pitch of 150 cycles per second, the average number of cycles per sound would be about 3.45.

The scientific implications of the problem of identifying short speech sounds are more numerous than the purely practical ones. There are a great many questions which such an investigation suggests, and a technique for

4. Ibid.
the study of the recognition of short speech sounds should
give valuable information toward their solution. At present
the following problems appear to be the more significant.

1. The Nature of the Function

One of the first questions which presents itself is that of the nature of the ability to recognize short speech sounds. Any test of this ability would first assume that the individual had been well trained in the recognition of speech sounds of normal duration and also in their indication, preferably in phonetic script. There remains, however, the question of the other factors important in this ability to recognize short sounds: whether it is chiefly physiological, or psychological; whether it is a native ability, incapable of improvement, or whether training would promote better performance.

Studies in the correlation between the ability to recognize short speech sounds and other abilities of hearing, such as those involved in the Seashore musical talent tests should also give some further insight into the factors basic to these various capacities.

2. Relationship to Phonetics and Vowel Theory

Another question which presents itself is whether there is any correlation between ability to recognize short
sounds and ability in general phonetics. The teacher of phonetics is well aware of the differences in ability to transcribe, even among persons with similar phonetic training. Still greater are the differences in ability to discriminate among fine shadings in speech sounds, as is especially evident in classes in which close transcription is studied. If such correlation should be found to exist, testing for aptitude in recognizing short sounds might offer considerable information concerning basic phonetic abilities.

We should also expect important information concerning speech sounds from such a technique. It should be possible, in the case of a recorded diphthong, for example, to study, from the standpoint of recognition, various wave lengths throughout the sound, and thus to determine with considerable accuracy the various elements of that diphthong. A similar procedure should give valuable information concerning the many glides in speech.

The significance of phase relationships in hearing has recently received some experimental consideration.4 There is a possible technique employing short sounds which should give important information concerning this problem. Many people are familiar with the fact that a vowel sound,

when played backward on a phonograph record, is, though somewhat distorted, easily recognized. If we consider the acoustic spectrum of an isolated segment taken from a vowel sound, it is obvious that the harmonic content will be the same, regardless of whether the segment is played forward or backward in the record. Phase relationships, however, will be changed, and a comparison of the facility of recognition in the two instances should give information concerning the significance of phase in the perception of speech sounds. This problem of phase relationships in connection with the present investigation is discussed somewhat further in Chapter II.
CHAPTER I

PREVIOUS INVESTIGATIONS

A question of some standing is that of determining the duration of a tone necessary for the perception of its pitch. A survey of attempts to estimate the minimum interval necessary for this perception has been presented by two Italian psychologists, Gemelli and Pastori.¹ According to these authors, Stefanini and Gradenigo concluded that only two complete vibrations are necessary for the sensation of tonality; and Stefanini suggests that one vibration may be adequate.² There is some question here, however, as to whether "tonalità"³ is intended to mean pitch or simply the reception of an auditory stimulus. According to Abraham and Bruehl, the minimum duration necessary for the perception of pitch varies considerably with the pitch studied.⁴ Bowman and Kucharski confirmed the belief that the number of vibrations necessary for the perception of pitch is small.⁵ Kucharski concluded that one

¹ Agostino Gemelli, and Giuseppina Pastori, L'analisi Elettroacustica del Linguaggio, Pubblicazioni della Università Cattolica del Sacro Cuore, VII, No. 1 (Dicembre, 1934).
² Ibid., 152.
³ Ibid., 151.
⁴ Ibid., 152-153.
⁵ Gemelli and Pastori, L'analisi Elettroacustica del Linguaggio, No. 1 (Dicembre, 1934), 155.
single period, and, under certain conditions, only one half period, is sufficient to give tonal sensation. According to Bode, as quoted by Fletcher, the minimum duration for the perception of the pitch of a sound of medium loudness is about 0.043 second. Stevens and Davis, in their recent and commendable work on Hearing report an investigation of this problem by Burck, Kotowski, and Lichte. It is concluded that "The absolute time necessary for the identification of the pitch of a tone is smallest in the middle range of frequencies, where it is approximately 0.01 sec."8

Gemelli and Pastori have also recorded early attempts to estimate the minimum duration of a vowel sound necessary for identification.9 Gianfracheschi concluded that the minimum duration necessary for the recognition of vowel sounds was a constant, independent of pitch and vowel quality.10 Stefanini, by the use of smoke rings, estimated that twelve vibrations were necessary to recognize the vowel (1).11

Gemelli and Pastori made a further attempt to estimate the minimum duration necessary for vowel recognition.12

6. Ibid., 153
7. Harvey Fletcher, Useful Numerical Constants of Speech and Hearing, Reprint from The Bell System Technical Journal, B-142-1 (August, 1925) 3, Table II.
10. Ibid., 152.
11. Ibid., 156.
12. Ibid., 163.
They made oscillograms of the five Italian vowels, and then, with the same speakers, attempted to make oscillograms of words containing these five vowels under similar conditions. The wave forms of the vowels in these words were compared with the wave forms of the vowels made in isolation. It was assumed that the true vowel phoneme existed in the word only where the wave form corresponded to the wave form of the isolated vowel, and that the waves on either side of these "atipici," or typical waves were "atipici," or atypical, and thus played no part in the recognition of the vowel in speech. With this questionable technique as a basis, the authors concluded that two complete and typical vibrations are sufficient for the recognition of a vowel sound. The important factor was thus considered to be the number of typical cycles, rather than the actual duration of the typical wave form.

The fallacies in the technique of Gemelli and Pastori are obvious. It is common knowledge to all who are familiar with the use of the oscillograph in speech work that there are great differences in wave forms of the same phoneme. Even when vowels are presented in immediate succession, and

13. Ibid., 159.
14. Ibid.
15. Ibid., 162.
with the pitch, quality, and loudness maintained as nearly constant as possible, it is a well known fact that the waveform will differ markedly from one period of phonation to the next. As a matter of fact, the mere shifting of the phase of one major component in the vowel can completely alter the visible waveform of the vowel. Thus to assume that there is only one type of waveform which will give a quality recognizable as a given vowel sound and that all associated waveforms are unidentifiable as that sound seems rather unjustifiable.

The first truly experimental approach to the problem was made by Gray at Louisiana State University. In this study, several series of short vowel sounds of varying periods of duration were actually presented to a group of subjects for identification. The subjects were asked to identify short sounds taken from a group of eleven vowels, and the duration of the sounds was reduced until recognition became exceedingly difficult. It was then assumed that the minimum duration necessary for the recognition of the given vowel had been approximately located. The question may arise as to whether sudden sounds of such short duration will give the same psychological impression as will sounds of normal duration. Obviously the impression will not be exactly the

17. Gray, "Phonemic Microtomy."
same; but so long as the sound is identifiable with the original from which it came, it would appear that true recognition has occurred. Of this technique, Gray says: "The final criterion as to the identity of a sound, it seems reasonable to assume, is whether it sounds like that phoneme, and not whether its wave pattern conforms exactly to the pattern set up for that phoneme, even though that pattern is set by the same individual, under as nearly as possible the same conditions as the sound under consideration for identification."

Gray's apparatus consisted of a high fidelity microphone, a pre-amplifier, a main amplifier, and a speaker system, with a set of mercury contact switches in the speaker circuit to control the interval of the sound. These switches were opened and closed by means of cams, which, in turn, were operated by means of a pendulum. One of the switches was movable, and its distance from the fixed switch determined the duration of the interval. In the switch circuit was connected a magnetic time marker which was used to indicate the various time intervals on a kymograph drum. There were many necessary complications of the circuit to avoid transient effects and to completely avoid current transmission between sounds; but the principal features of the operation were

18. Gray, "Phonemic Microtomy."
as follows: The pendulum and the microphone were located in a room well removed from the speaker and the subjects. The first switch in the speaker circuit was open to prevent any sound from passing through to the subjects, but the second switch remained closed. A continuous sound was directed at the microphone and the pendulum was allowed to swing. At the approximate center of the swing, the pendulum struck the cam on the first switch, thus closing the circuit and allowing the current to activate the speaker. At a predetermined interval thereafter the pendulum struck the cam on the second switch, breaking the circuit and terminating the sound emitted from the speaker.

Fifteen subjects from an intermediate class in phonetics were employed, and data were taken at three different periods. Both a masculine and a feminine voice were used, the masculine voice at pitches of 80, 128, and 192 cycles per second, and the feminine at pitches of 256, 320, and 384 cycles per second. The following eleven vowels were used: (i), (ɪ), (e), (ɛ), (æ), (a), (ʌ), (ʊ), (ʊ), and (u). The vowels in each series were given in a different order, and the subjects were asked to indicate in phonetic script the particular vowel they believed each sound to be. The data were tabulated, first, according to recognitions of the separate vowels, and second, according to the performances of the individual subjects.
Gray points out two important conclusions. At an interval as short as .005 of a second, except for the vowels (ɪ) and (e), the number of correct judgments well exceeded the errors. It is important to note that at the lowest pitch of the masculine voice, 80 vibrations per second, this interval would allow the presentation of only .4 of one cycle. A significant number of recognitions was also obtained for many of the vowels even at an interval as short as .003 of a second, which, for the pitch mentioned above, would be only .24 of a cycle. The second significant observation concerns the incorrect judgments made on the series of tests. Where errors were made, adjacent or neighboring vowels on the traditional vowel diagram were usually substituted for the correct ones. As a result of this study, many valuable observations concerning the relationship of various phonemes are made.
CHAPTER II

RELATED STUDIES ON THE HEARING MECHANISM

The identification of the limiting factor in the recognition of short sounds as structural or psychological is a problem which early arises. A major question in this connection is whether transient effects are so pronounced as to mask or seriously distort the short sound as originally presented to the ear. These transient effects occur in the vibration of any system, and their magnitude depends upon the degree of damping. In general, three types of damping may occur.\(^1\) In an overdamped system, vibration does not take place. Instead, the system, when displaced and released, gradually swings back toward a position of equilibrium. In the underdamped system, vibrations do occur when the system is displaced; and these vibrations will decay in a manner determined by the specific degree of damping. The third type of damping is called critical damping, which occurs when the action of the released system falls just between the limits of the two cases mentioned above. This takes

place when damping has been increased to a point such that the system returns to a state of equilibrium in the shortest possible time, but falls just short of vibration. The principle of critical damping is especially important in the design of high fidelity sound apparatus.

If a periodic driving force is suddenly applied to a system capable of vibration, the resulting motion will consist of two essential components. The first is a steady-state vibration at the frequency of the driving force, and this will continue as long as the driving force is maintained constant. The other is called the transient term and will eventually disappear, leaving only the steady-state vibration. The following expression is for a simple oscillator to which a simple harmonic driving force has been applied. The first term is the transient term which will decrease according to the magnitude of the damping factor, $k$, and the second term is the steady-state component.

$$x = \frac{F \sin \varepsilon e^{-kt}}{2k} \cos(nk + \varepsilon) + \frac{F \sin \varepsilon \cos(pt - \varepsilon)}{2k}$$

Where:

- $x$ is the displacement of the driven system
- $F = \frac{p}{2m}$ where $p$ is the maximum value of the driving force
- $m$ is the mass of the driven system
- $F = 2\pi f_a$ where $f_a$ is the frequency of the driving force

\( t \) is the time

\[ k = \frac{F_0}{R} \]

where \( R \) is the resistance constant

\[ \omega = 2\pi f_0 \]

where \( f_0 \) is the natural frequency of

the driven system

\[ \phi = \frac{3k\omega}{g} \]

and is the phase angle between the

\[ \phi = \frac{3k\omega}{-2\pi g} \]

and displacement of the driven system and

the driving force

\[ \omega' = \sqrt{\omega^2 - k^2} \]

Here the damping coefficient \( k \) determines how quickly

the transient term will disappear. To calculate the effect

of the transient term where a simple harmonic motion is

suddenly applied to the ear would thus require an evaluation

of the various constants given in the above equation.

Vibrations which strike the membrane tympani, or

drum of the ear, are transmitted to the fenestra ovalis,

or oval window, of the cochlea by means of the ossicular

chain of the middle ear. The ossicular chain is a chain

of three tiny bones: the malleus, or hammer; the incus,

or anvil; and the stapes, or stirrup.3

Studies made by Stevens and Davis concerning the

transmission characteristics of the auditory ossicles are

especially related to the present problem. A tiny mirror

3. A good description of the anatomy and general

function of the ear may be found in William H. Howell, A

Text-Book of Physiology, (Philadelphia, Pennsylvania:

was attached to the handle of the malleus, and light reflected from this mirror was used to record, on photographic paper, the response to a sharp click impinged upon the ear. The resulting wave forms show that the mechanism is highly, but not critically damped. The curves presented by Stevens and Davis were measured by the present author, and the frequency of the resulting vibration was found to be about 820 cycles per second.\(^4\) This, of course, is not the true natural frequency of the middle ear mechanism as it would occur if isolated from the remainder of the hearing mechanism. The inner and outer ear were both coupled to this mechanism when these curves were made, and this coupling undoubtedly had considerable influence upon the resulting vibration.

Several significant studies have also been made concerning the activity within the cochlea. The oval window of the cochlea transmits to the cochlear duct of the inner ear the vibrations received from the ossicular chain. The floor of this cochlear duct is formed partly by the lamina spiralis, a spiral ledge of bone, and partly by the basilar membrane. Upon this membrane lies the organ of Corti, and projecting from the organ of Corti are tiny hairs. These hairs arise from small cells within the organ, and it is in these cells that the cochlear branch of the auditory nerve is terminated. The membrane of Reissner

\(^4\) Stevens and Davis, *Hearing*, 262-263.
forms the top wall of the cochlear duct. The duct itself is filled with endolymph, and floating in this endolymph, above the tiny hair fibres, is the tectorial membrane.

It has been known since the time of the German physicist, physician, and physiologist, Helmholtz, that the lower end of this system, or that near the oval window, responds to the higher frequencies of the sound, while the upper end of the system responds to the lower frequencies. Thus the mechanism of the cochlea responds to a varying range of frequencies distributed along its length and translates them into active energy.

A series of investigations by such men as Weaver, Bray, Saul, Adrian, Davis, and Newman has shown that an electrical potential, independent of the auditory nerve action currents, is generated by the action of the cochlea. This potential may be picked up by means of a wick electrode on the round window and recorded through the use of the cathode-ray oscillograph. According to Stevens and Davis,

Adrian was the first to suggest the term "microphonic action" for this electrical activity. This microphonic action of the cochlea has been shown by Wever and Bray to give an effective index to the vibrational energy reaching the auditory end-organs.

Measurement of the damping within the cochlea itself is much more complicated. Stevens and Davis suggest that, considering the auditory mechanism as a whole, it requires about .05 of a second after the interruption of a sound before actual ear vibrations become ineffective, and that for the cochlea alone the damping is probably greater.

These same authors also present photographs of the "cochlear microphonic" showing the initial transients which occur when a sound is suddenly impinged upon the ear. The transient appears as a definite disturbance in the wave form for over .005 of a second. This is longer than the shortest interval before actual ear vibrations become ineffective, and that for the cochlea alone the damping is probably greater.

13. Ibid., 327-331.
14. Ibid.
at which recognitions of short speech sounds were obtained by Gray.

Stevens and Davis also present data showing that the action currents which accompany the auditory nerve currents as they are transmitted away from the cochlea often follow the generation of the cochlear microphonic by as much as .0006 of a second. 16

Békésy attempted to measure the duration of auditory sensation after the stimulus had been removed. His procedure was to measure for a given tone the slowest rate of decay which would give the same sensation as that given by the abrupt termination of the tone. Stevens and Davis show that, according to the data presented by Békésy, all tones, regardless of the original intensity, diminish to the value of the auditory threshold in approximately .14 of a second. Such an observation suggests the existence of an auditory after-image. The authors conclude, however, that, if we accept the argument, "It is necessary to assign this phenomenon of persistence to a central mechanism, because no persistence as great as .14 of a second has been observed in the physiological effects detectable in the cochlea or in the auditory nerve." 17

15. See page 12.
17. Ibid., 223.
As has been previously explained, the particular portion of the cochlear mechanism which will respond to a given vibration depends upon the frequency of that vibration. Thus the inner ear appears to perform the function of a harmonic analyser by giving to the auditory nerve an indication of the frequency and amplitude of the various components of the wave impinged upon it. This is known as Ohm's acoustical law. It is believed by some, however, that the phase relationships of these various components have little or no significance in the actual perception of the sound. In this respect, Stewart says, "It is a peculiar circumstance that the ear recognizes the combined tones as the same irrespective of the phase relations among the components." 18 Stevens and Davis express a similar attitude, but qualify it somewhat in saying that "...with slight exceptions, the ear is not sensitive to differences of phase between the components of a complex tone." 19 A thoroughly scientific investigation of this problem has been made by Trimmer and Firestone at the University of Michigan. 20 Two pure tones whose frequencies were in simple integral relationship to each other were

presented to the ears of several subjects. The subjects were then allowed to adjust the phase angle between these two tones, first, for minimum loudness, and, second, for minimum roughness. Both loudness and quality were found to depend upon the phase angle. The effect upon quality, is, in part at least, explained by the nonlinear transmission characteristics of the ear. This nonlinearity tends to introduce additional harmonics, or frequencies, into the tone as finally perceived. The nature and magnitude of these additional harmonics created in the ear will depend upon the phase relationship among the various frequencies presented from without.
CHAPTER III
THE PRESENT PROBLEM

With recognitions occurring on as little as .24 of one cycle, the question immediately arises as to whether one segment from a given cycle is recognized with greater ease than is another. Gray reports that when the interval of .01 was accidentally repeated in his study, "...somewhat different data were secured for the two identical intervals." A one to one correspondence, of course, could not be expected in the results of such a complicated performance as the recognition of short speech sounds; and variations within certain limits could probably be accounted for on this psychological basis. Should wide variations exist, however, one would expect the cause to lie in some physical difference such as that which would occur in the presentation of various portions of the wave length.

This is obviously a question which would have to be answered before any successful attempt could be made

1. See page 12.
2. Gray, "Phonemic Microtomy."
to standardize tests for the minimum duration necessary for
the recognition of speech sounds. It should further be
pointed out that the investigation of nearly all problems
relating to the recognition of short sounds, as for example,
those problems proposed in the Introduction, would require
the standardization of such a test.

A major factor determining the technique finally
employed by Gray was the elimination of transient effects.
In particular, it was considered necessary to put the
switches in the speaker circuit, rather than in one of the
preceding circuits. With the switches here, however, there
appears to be no method of predetermining a particular cycle,
or portion of a particular cycle, to be transmitted. If
it should occur that the special portion of the cycle used
were not significant in recognition, however, it is conceivable
that such an arrangement could be employed for standardized
tests. On the other hand, if the portion used were significant,
it appears certain that the technique for uniform testing
would be considerably complicated.

The present investigation, then, has the purpose of
discovering whether facility in recognizing short sounds
does depend upon the particular portion of the wave length
presented. The proposed technique is similar to that
developed by Gray: the duration of the sound is to be
controlled by switches placed in the speaker circuit of a
public address system. As has been previously explained,
this does not permit a predetermination of the particular segment of the vowel sound to be used; but it does make it possible to reduce transient effects to the necessary minimum. No attempt is to be made to present segments of similar harmonic content; in fact, it is proposed to take an interval which is not even a simple fractional part of the complete cycle.

According to Fourier's integral theorem, the harmonic analysis of one of these short pulses would show an extremely large number of components. Such a pulse would be mathematically described as a curve of zero amplitude from \(-\infty\) to some value, \(t_1\) the amplitude becomes finite and remains so to \(t_2\); and from \(t_2\) to \(\infty\) it again becomes zero. This complete curve, as treated by the integral theorem, would have an infinite period; and if the duration of the pulse were infinitesimal, it would have an infinite number of harmonics. In contrast, if a sinusoidal wave form were repeated in time from \(-\infty\) to \(\infty\), the harmonic analysis, according to Fourier's general theorem, would show but a single component.

The harmonic analysis usually applied to speech is of this latter form. The curves of the sound under con-

4. Ibid., 148.
5. Ibid., 21.
sideration are assumed to be periodic and continuously repeated, and the period taken for analysis is that of a single cycle.

A single pulse, then, could be assumed to be an isolated cycle of a repeated wave form. The period would be equal to the duration of the pulse, and this conventional form of analysis could be applied.

The identification of short segments as belonging to a given vowel will obviously depend upon how much the segment, as heard, resembles that particular vowel. This very probably depends chiefly upon the degree to which the acoustic spectrum of the short segment resembles the acoustic spectrum of the complete cycle of the vowel from which it came. It is very probably true that considerable variation may occur in the harmonic content of segments taken from different portions of a particular cycle. It is quite conceivable, however, that variations, perhaps as great, may occur in the harmonic content of two segments taken from approximately the same section of a given cycle, even though these segments have a large portion of their wave form in common. It is proposed in the present study to discover whether significant differences in the recognition of various segments do occur; and, if differences should be found to exist, it is further proposed to investigate, so far as possible, the nature of these differences.
There are two major requirements for such an investigation. First, a technique is necessary for obtaining short segments of equal duration from a given cycle, and of presenting these segments to a group for the test of recognition. Second, a technique is necessary for recording each segment, and of thereafter identifying the particular portion of the cycle from which each segment came.
CHAPTER IV

APPARATUS

The apparatus for the present study was designed for the specific purpose of determining whether the particular portion of the wave length employed is, in general, significant in the recognition of short vowel sounds. There were several major requirements. First, a method of repeating given vowels with approximately the same wave form was necessary. Second, a method was desired for taking small random segments from these waves and presenting them to a group of subjects for the test of recognition. The third requirement was as complete an elimination of all extraneous effects as was physically possible; most disturbing among these effects are initial associated transients and additional vibrations following the presentation of the segment. Fourth, a method was necessary for photographing each small segment as it was heard, thus providing a method of identifying the particular portion from which the various segments came.

It was finally decided to use, for controlling the duration of the vowels, an electrical method similar to that developed by Gray.
The first unit in this system was a high fidelity crystal microphone. As recorded vowels were also employed, a piezo-electric crystal pick-up was used for reproduction purposes. The turntable employed for reproduction was that used by the Sound Apparatus company in their Fidelitone recorder; it was driven by a Saja synchronous motor.

There were three major considerations in the selection of an amplifier. The first was gain; the second was power output; and the third was fidelity. The amplifier finally chosen for use was also the one used in the Fidelitone recorder. It has a gain of over 80 db, using a pair of 2A3's for the power tubes, and giving a maximum undistorted output of over ten watts.

Both frequency and amplitude distortion, at normal values of amplification, were negligible. Amplitude distortion may be considered to occur if a sinusoidal voltage is used as the signal for an amplifier and the resulting waveform in the output departs from this purely sinusoidal form. In the amplifier used significant amplitude distortion was not observable, even at the lower frequencies. Frequency distortion may be considered as the unequal amplification of different frequencies. In the present instance, frequency

1. 150 West 46th Street, New York City.
3. Ibid., 147.
distortion was negligible, as the overall gain of the amplifier stayed well within the limits of one db up to ten thousand cycles.

There were two considerations in the selection of a speaker, fidelity and the minimisation of transient effects. Initial transients occur when the output of the amplifier is suddenly switched to the speaker, and they are most pronounced in the response of the speaker mechanism itself. The speaker vibration is mechanical and is maintained by electrical energy. The solution to the general equation for a simple oscillator, with a harmonic driving force applied, was given in Chapter II.

As has been explained, the first of the two terms is the transient term and decreases according to the magnitude of the damping constant, k. The second term is a steady-state term which has the frequency of the driving force. When only this system is considered, it is seen that the damping increases in accordance with the resistance, R.

The actual operation of a speaker, however, is much more complicated. Since the mechanical constants are reflected back into the electrical circuit, we cannot consider neither system alone. In fact, the current resulting from a voltage applied across the speaker will depend upon the apparent electrical impedance, which, in turn, results from both the true electrical impedance and the reflected mechanical
impedance. This mechanical impedance, as it appears to the electrical circuit, is often called the motional impedance of the system.

If the speaker circuit is open, the damping will depend primarily upon the resistance of the mechanical system. This is the equivalent of attaching an infinite electrical impedance across the speaker terminals. If we connect very low electrical impedance across the speaker, however, damping will occur in an entirely different fashion. If, in some manner, the speaker is set into vibration, a voltage will appear across the terminals. If the circuit is closed, a current will flow; and if the external impedance is small, the magnitude of this current will be comparatively large. This current produces a self-induced and opposing voltage in the coil of the speaker, which thus counteracts the speaker vibration. This results in an increase in the effective damping, and free vibration will therefore die away much more rapidly.

The net internal electrical impedance of the speaker likewise figures in the magnitude of the current developed. Thus, to achieve a high degree of damping in the practical case, it is necessary to have both a generator and a speaker of low internal impedance. In sound amplification, we may consider the generator to be the power output. The output tubes are usually coupled to the speaker by means of a matching transformer. Since the internal impedance of the
speaker is usually considerably lower than that of the amplifier tubes, this matching transformer is necessary to obtain adequate power transmission. Expressed figuratively, this matching process means that, from the tube end, the line impedance appears to be similar to that of the tubes; while from the speaker end it appears to be similar to that of the speaker. This has an additional significance for the present problem, for, if a speaker of low impedance is properly matched to the output of an amplifier, the output impedance at the speaker will appear to be small, no matter what the tube impedance. This makes a high degree of damping possible for the speaker.

If a periodic voltage of constant wave form is suddenly applied through a transformer to a speaker, the resulting speaker vibration, as has been previously shown, will consist of both a transient and a steady-state component. If the degree of damping is large, the transient term will quickly disappear.

The speaker finally selected for use in the present investigation was also a part of the Fidelitone equipment. It was a moving coil, Model D 16 Jensen type, with a 15 ohm voice coil. The proper acoustic surroundings for speaker analysis were not available, but tests showed a reasonably good response to frequencies of nearly 6000 cycles. The impedance of this speaker was found low enough to afford excellent damping.
The next problem was to avoid the transient effects which would follow the breaking of the speaker-amplifier circuit. Breaking the connection in the normal fashion would leave the speaker on open circuit, and the damping would then depend only upon the mechanical friction factor in the speaker itself. It was decided, therefore, to damp the speaker electrically immediately following the sound by causing a short circuit across the terminals. This would produce a comparatively large current, which would, in turn, produce a voltage to counteract effectively the motion of the speaker. The method of accomplishing this immediate short is explained in a later discussion of the switches employed.

Next, it was necessary to obtain a dummy impedance approximately equivalent to the speaker impedance in order to properly load the amplifier before and after the sound was allowed to activate the speaker. The purpose of this dummy load was to keep the output voltage at all times as nearly constant as possible. This was desirable for two reasons: first, to protect the amplifier from the high voltage which would develop if it were left on open circuit; and second, to prevent the initial distortion of the sound which would result if the amplifier were switched to the speaker from a load of a different value.
The relation of the load on a tube to the voltage across that load is shown by the following equation:

\[ \frac{E_P}{E} = \frac{\mu E}{R_p + R_1} \]

Where:

- \( E_P \) is the effective value of the varying component of the plate voltage
- \( \mu \) is the tube amplification factor
- \( E_\Lambda \) is the effective value of the varying component of the grid voltage
- \( R_1 \) is the value of the load on the tube
- \( R_p \) is the internal a.c. resistance of the tube

Since, for the presentation of the short sounds, the amplifier was to be switched to a speaker at rest, the ideal method would have been to obtain a speaker identical to the one used. The cone of this second speaker could then have been clamped; and an identical speaker, continuously at rest, would have been available for the dummy load. Thus, no voltage change would have occurred in shifting to the speaker used for final presentation of the vowel sounds. An impedance was available, however, which gave output voltages so nearly parallel to the

voltages developed across the speaker that it was deemed satisfactory for the present purpose.

The design of the switch circuit was now fairly well prescribed. According to the specifications above, it was necessary for the first switch to shift from the substitute load to the speaker. Since it was impossible to shift simultaneously from one line to another, it was decided to let the contact which completed the speaker circuit precede, by as small a fraction of time as possible, the break with the substitute load. The function of the second switch as well was clearly defined. It was necessary for this switch to break the contact with the speaker, and at the same time to cause a direct short across the speaker circuit. Again it was decided to let the short circuit contact precede, by as small a fraction of time as possible, the breaking of the speaker circuit. One operation remained: the action of the second switch left the amplifier on open circuit, making it necessary to shift back to the substitute load. Since the switches were operated by a pendulum, it was deemed satisfactory to reset the first switch on the return sweep and to thus re-establish the load on the amplifier. A wiring diagram of the switch circuit is shown in Fig. 1.
Fig. 1.—Diagram of the switch circuit.
Fig. 2 shows the switch construction in more detail. All contacts were made of silver and were soldered to a small strip of fairly heavy shim stock. This, in turn, was backed by a rather stiff spring. The switch contacts were controlled by cams, which, in turn, were operated by levers projecting into the path of a pendulum. Since the switches were purely mechanical in action, a particularly heavy bob, weighing several pounds, was used on the pendulum to insure a uniformity of performance. This pendulum was 44 inches long and was supported and braced by heavy rods rising above the laboratory table. The supporting rod turned in ball bearing collars, and the pendulum was firmly fixed at the center of this rod to prevent lateral motion. A large arc was used to afford considerable velocity at the center of the swing so that the action time for each switch would be negligible in comparison with the total interval during which the sound was transmitted. A metal catch, used to hold the pendulum aside, was so fashioned that the weight was released in exactly the same manner each time, thus insuring constancy of the interval.

The position of the first switch was varied by means of a long worm gear; and a steel pointer indicated the time interval on a calibrated scale. The final measurement of the time interval, however, was taken from the photographs which are to be discussed in the next chapter.
Fig. 2.—Pendulum bob and positions of the first speaker switch.
For photographing the sounds transmitted by the speaker, a General Radio 687-B electron oscillograph, in conjunction with a General Radio 714-A amplifier, was used. At first the sounds were picked up by placing a microphone in front of the speaker. This was done to get an objective indication of the sound as actually heard by the subjects. This technique proved undesirable, however, for reasons explained later; and the actual data were taken with the input to the oscillograph amplifier connected, with the proper protective resistance, across the speaker circuit.

An F:2 anastigmatic lens with a special adjustable mounting was obtained from Burke and James. The oscillograph screen was then covered with a light-proof box, at the front of which the lens was mounted. A light aluminum drum, ten inches in circumference, was mounted vertically before the lens; and this drum was driven by a 1/10 horse power, type 55A Galvin constant speed motor. The coupling offered some difficulty. The method finally used was to bring the two shafts into close approximation and to carefully align them; a short length of rubber tubing was fitted over the two ends, and the entire union was firmly bound with friction tape. A constant speed motor of another type was first tried and found inadequate; the motor used, however, gave exceedingly reliable performance. Many photographs were made with a 435 cycle tuning fork, and when these were

5. 223 W. Madison St., Chicago, Illinois
compared they showed the drum speed to be thoroughly constant. Independent curves checked accurately with each other, and various portions of the same curve showed exact agreement. Samples from this group of curves are shown in Fig. 3.

To provide an adequate spreading of the curves it was necessary that the drum revolve at high speed. This, in turn, necessitated the use of an extremely fast photographic film. That finally employed was Agfa Ultra-Speed film. Eastman D-ll, for high contrast film and plate negatives, was used in developing. The film was cut into ten-inch strips and sealed into rings by means of Scotch Cellulose Tape placed on the inner surface. These rings of film fitted the drum tightly enough to prevent slippage, and the sensitive, or emulsion, side remained exposed to the oscillograph ray.

The length of the interval during which the oscillograph spot was allowed to strike the drum was controlled by means of a shutter provided with the lens. It was found undesirable to allow the spot to strike the film for more than two revolutions of the drum, for the axis then became particularly heavy in comparison with the curve of the sound photographed and made it difficult to calculate the exact time interval. The shutter was controlled by the usual flexible cable, thus preventing a movement of the lens when the shutter was opened. A method was now necessary for the
Fig. 3: Independent curves of a 435 cycle tuning fork, showing constancy in rotation of the drum.
synchronization of the shutter with the presentation of the short sound. The method finally adopted was that of mechanically opening the shutter by means of a falling weight which depressed the trigger on the end of the flexible cable. The weight was released by a strong electromagnet, which, in turn, was activated from the 110 volt a.c. line through a switch in the pendulum system. This switch was similar in construction to the others, but it made only a momentary contact. It was thrown by a cam lever and was placed in the pendulum arc just far enough ahead of the first speaker switch to open the shutter before the sound came through. The speed of the shutter was adjustable between .01 of a second and 1 second. The setting used allowed the spot projected by the oscillograph to strike the photographic film for about two revolutions of the drum. During the first revolution, the curve of the sound emitted by the speaker was recorded; and during the second revolution, an axis was drawn through this curve by the now motionless oscillograph ray.

Several photographs were made using a microphone to pick up the short sounds from the speaker. The resulting curves showed the sounds at the required short intervals; but extremely small additional vibrations distorted the axis, making accurate calculation of the time interval impossible. The source of this disturbance was never determined. Its wave form was periodic and rather complex,
but in no way did it resemble the wave form of the sound itself. Since the windows of the empty room in which the speaker was located were closed when these pictures were taken, a reverberation effect may have been the cause of the disturbance. On the other hand, as the room was not isolated from the remainder of the building and since a fairly high gain was necessary, the difficulty may have been the result of general building noise. One entire wall of this room was lined with windows; and when the data were actually taken, these windows were opened. In addition, there were then several people in the room; and in consideration of the fact that the sounds were of an extremely short duration, it is obviously impossible that any reverberation effect could have been significant in the test of recognition.

The method finally employed for photographing the sounds gave much more satisfactory results than did the technique employing the microphone. This method, as mentioned above, consisted simply of connecting the input of the oscillograph amplifier across the speaker circuit. Sufficient parallel resistance was employed to avoid overloading the input tube; and sufficient series resistance was employed to prevent this parallel resistance from having any effect on the speaker circuit. With this technique, all external

disturbance was eliminated. Since the vibration of the speaker ceased abruptly when the second switch was thrown, the period of the recorded wave form was now distinctly marked, making possible an accurate determination of the time interval.

The curves in Fig. 4 show this abrupt termination of the wave form and an almost complete elimination of transient effects at both the beginning and end of the sound wave. In these curves, somewhat more than one wave length has been recorded to provide steady state portions with which to compare the initial and final sections. These photographs demonstrate the effective elimination of transient components. Splices in these curves indicate that a wave length has been removed from the center of a longer curve or that the photograph of the sound was originally made across the splice of the film.

The motor was, of necessity, placed below the drum, and its counterclockwise rotation caused the beginning of the curves to appear at the right, and the end to appear at the left. The curves in Fig. 4, therefore, are read from right to left, instead of in the usual manner. In each curve photographed, the axis drawn by the oscillograph spot is slightly below the center of the film, providing a ready means of distinguishing the top from the bottom.

The microphone into which the continuous vowel sounds were produced was placed in a sound-proof room.
and was connected to the main amplifier in the adjoining laboratory. It was here that the switches were located, and the person operating them was able to communicate with the person producing the vowels by means of a system of signal lights. The speaker cable was led through a hall into a room located at a distance great enough to prevent any sound transmission through the air. The photographic equipment was assembled in a room adjoining that in which the switches were located, and, because of the hypersensitive film employed, it was necessary that the two persons actually making the photographs work in total darkness.

One individual placed the film on the drum, controlled the motor and signal switches, and replaced the shutter weight after each photograph; while the other person prepared and labeled the fresh films and laid the exposed strips away. These tasks were particularly important for the following two reasons: first, it was necessary to keep the films in order, and second, to present an adequate series of vowels at one session, considerable speed was required. A public address system to the darkroom was used to announce the proper label for each strip of film, and a neon light was flashed when the person operating the drum was prepared to take the next photograph. The schematic diagram in Fig. 5 indicates the important elements in the complete system.
Fig. 4.—Curves of a tuning fork, and of the vowels (i), (a), (u), and (u). Initial transients are shown at the right, and final transients at the left.
Fig. 5.—Schematic diagram of the complete circuit used in the first session.
CHAPTER V
PROCEDURE

The subjects in the present investigation were, for the most part, students enrolled in a class in general phonetics taught at the university. Two faculty members and a few persons who had previously taken the course, having since done further work in phonetics, also served as subjects during the first session. The experiment was explained to the group and a preliminary training period was given at the regular class hour. A few sounds were photographed at this time as a final check against possible flaws in the procedure.

The first set of data was taken at seven o'clock in the evening. This hour, a time at which building and outside noises were at a minimum, was chosen as most suitable for the experiment. Dr. Giles W. Gray, Professor of speech at the university, was chosen to produce the vowels because of his ability to maintain a sound unusually constant in pitch, quality, and force, and because of his ability to produce a clear quality at the pitch (96 dv.)
desired for the present study.

Before the time for taking the data, all film was cut and sealed into rings to fit the drum; the contacts on the switches were thoroughly cleaned; the apparatus was carefully checked; and the subjects were provided with cross-ruled paper on which to indicate the vowel symbols.

The procedure in taking the first set of data was as follows: When the person operating the drum had put the film in place and had turned on the motor, he flashed the neon light as a signal to the operator of the pendulum. This operator turned on the first signal light to the sound-proof room in which the microphone was located, and at the same time closed the first switch in the speaker circuit. The column and number for the next vowel were announced to the subjects over the microphone; the first speaker switch was reset; and after a moment's pause, the second signal light was flashed in the microphone room. This was the signal for the production of the vowel, and a moment later the pendulum was released and allowed to swing. The first switch thrown was that opening the shutter on the lens; the second started the vowel sound through the speaker, and, at the same time, into the oscillograph amplifier for the photograph; the third switch broke the speaker circuit, cutting off the sound current from the speaker and oscillograph. On its return sweep, the pendulum reset both the first speaker switch and the shutter
switch. The second speaker switch was reset by hand; and, while the drum was being loaded for the next photograph, the operator of the pendulum announced to the darkroom the label for the film which was to follow the one then being placed on the drum. In this manner, a fresh film was always ready to be placed on the drum immediately following the photographing of the preceding vowel. When the shutter weight had been replaced, the drum reloaded, and the motor turned on, this procedure was repeated.

A brief preliminary practice period, during which longer sounds were presented, was given. At this time, a master photograph of well over one wave length was made of each vowel; the short curves taken thereafter were compared with these longer wave forms. The period was then progressively shortened until the interval desired for the present study was reached. At this short interval, several series of vowels were presented for recognition and were simultaneously photographed.

Eight vowels were used, those tending toward diphthongization being avoided. The vowels were presented in series of nine, with one vowel repeated. One of the duplicate vowels used in each series was arbitrarily chosen as a "joker" and was not photographed. This was to reduce the possibility of guessing the correct symbols. The only explanation made to the subjects concerning the vowels was
that they all occurred on the conventional diagram, and that (a) was not used. This left a minimum of 15 sounds from which to choose. On this basis it is possible to compute the probability of correctly guessing one or more symbols in each series.

This problem will be made somewhat clearer if we imagine the 15 symbols to be written on cards. If the cards are then shuffled, the probability of drawing a given number of specified symbols in a predetermined order may be computed. The probability of drawing an (a) the first time is obviously 1/15. If it is assumed that the same symbol may be repeated any number of times in this predetermined series, then the probability of next drawing an (i) is also 1/15; for, if (e) may be repeated, there are still 15 symbols from which to draw. The probability, therefore, of drawing both of these symbols correctly is 1/225.1 Thus the probability of drawing all eight significant symbols according to a predetermined order is 1/158. If it is assumed that the subjects in the present experiment were entirely ignorant of the arrangement of the vowels in the series, then 1/15 is the probability of their having guessed any one symbol right, and 1/225 is the probability

---

1. The two probabilities are simply multiplied together. A clear discussion of this type of probability may be had in Palmer H. Graham, and F. Wallace John, Advanced Algebra, (New York: Prentice-Hall, Inc., 1930), 133-157.
of their having guessed any two symbols correctly.

The subjects might conceivably have concluded, however, that no vowel in any series was given more than twice. Since any one of the 15 vowels could have been repeated the second time, there would have been 15 symbols from which to choose each time until one of the symbols was duplicated. Thus, until some symbol had been duplicated, the probability of guessing the correct symbol each time was $1/15$. Thereafter, the succeeding probabilities became $1/14, 1/13, 1/12, \text{ etc.}$ The probability of getting all nine symbols correct was then:

$$\frac{1}{15^a} \cdot \frac{1}{14} \cdot \frac{1}{13} \cdot \ldots \frac{1}{15-(9-n)}$$

where $a$ was the series number of the duplicated vowel.

The probability may be still further limited by assuming that the subjects in some manner discovered which vowels were being used, and further, that all eight occurred in each series, or, in other words, that only one vowel was duplicated. The probability of guessing the first symbol correctly would then be $1/8$; but, since this symbol could be repeated, the probability of guessing correctly the next succeeding symbol would also be $1/8$. This would hold true until the duplicated
vowel appeared. From there on the probabilities would become:

\[ \frac{1}{9-n} \cdot \frac{1}{9-(n+1)} \cdot \frac{1}{9-(n+2)} \cdots \cdot \frac{1}{9-(n-x)} = 1 \]

and the total probability of guessing all symbols correctly would be:

\[ \frac{1}{9^a} \cdot \frac{1}{9-n} \cdot \frac{1}{9-n-1} \cdot \cdots \cdot \frac{1}{9-(n-x)} = 1 \]

Gray obtained, except for the shorter intervals, rather consistent results in the substitutions made for the correct vowel symbols. He found that, when errors did occur, the correct symbol was usually replaced by one of its two closest neighbors on the traditional vowel diagram. In an occasional instance, this was also strikingly true in the present study, even at the shortest intervals. Frequently, however, erroneous judgments, even for the same individual, were not thus limited to neighboring vowels.

Let it nevertheless be assumed that certain audible characteristics did distinguish each vowel as one of a group of three. It still follows that, even under the most favorable and specialized arrangement in the series, the probability of guessing more than one correctly would not be significant. This is especially true in the present experiment as the vowels occurred only in pairs on the

2. Gray, "Phonemic Microtomy."
Further, it is obviously true that, by the very assumption of such distinguishing characteristics, a considerable degree of recognition of the vowel is already admitted.

A second set of data was taken in an attempt to get more complete information on one or two particular vowels. The procedure varied somewhat from that for the previous experiment. This time, instead of producing the vowels over the microphone, phonograph recordings were employed. The voice used in making the record was the same one used to produce the sounds for the first set of data. The vowels were viewed on the screen of the cathode-ray oscillograph, and the recording was made at a period during which the vowel showed a particularly steady wave form. A switch in the recording head circuit made it possible to record only this steady wave form. The recording head was first placed on the disc with no current activating it; at the desired moment the switch was thrown, and several seconds of the vowel were recorded. The head was then picked up from the record, thus leaving a space between each two vowels.

When the segments were presented, the individual operating the switches placed the phonograph pick-up on the recording. There was sufficient vibration from the pick-up itself for the operator to tell when each vowel
began, and an attempt was made on all vowels to allow the same interval to elapse each time before the pendulum was released. With this technique, the segments presented could be taken from the record at approximately the same point from which the master wave forms were taken. In this way it was hoped to obtain segments which would be much more easily identifiable with the master waves.

In this second experiment, the members of the phonetics class again served as subjects; and the data were taken at two o'clock in the afternoon, the regular class hour. The technique for photographing was the same as before, and the column and series number for each vowel was announced to the subjects over the microphone by an additional person.

The vowels were given in series of five, and with no duplications. (æ) and (o) were photographed for later analysis, and the other three vowels were presented merely as "jokers." A total of 17 vowels was used, and 15 subjects served in the experiment.
CHAPTER VI

DATA

The photographs taken of the vowels are given in the following pages. Each page presents the data for a given vowel. It was necessary to choose the boundaries for each cycle arbitrarily. In accordance with the theory of harmonic analysis, a method of determining the extremities of each cycle would have been to discover the point of zero phase for the fundamental, that is, the point in the wave form at which the curve of the fundamental starts to rise above the axis. Since, for the present investigation, this is impossible, some convenient characteristic in each master wave form is arbitrarily chosen as the beginning of the cycle, and the point at which this characteristic is next repeated thus becomes the end of the cycle. There is no particular relationship, therefore, between the point chosen as the beginning of the wave length for one vowel and the point chosen as the beginning of the wave length for any other vowel. The parallel lines in the figures are drawn through these points, thus indicating the
The first set of data, the photograph on which a numeral 1 follows the vowel symbol shows the master wave form. The number following the vowel symbol on each shorter curve indicates the series in which that vowel occurred. The number at the right of each photograph indicates the number of persons who recognized the vowel correctly. The total number of subjects was 19 for the first experiment. There were 328 recognitions of the vowels photographed. The total possible number of recognitions was 703; thus there was 46.6% recognition. This was the approximate percentage considered necessary to give accurate information concerning the problem in the present study.

Table I gives the series of vowels used at the first session. The vowel used as the "joker" in each series is underlined. The interval for the short segments is a constant throughout, and is .00359 of a second, or approximately .345 of one wave length at 96 vibrations per second. As previously explained, the curves are read from right to left instead of in the usual manner. The short segments are set irregularly on the page so as to fall beneath the corresponding wave forms in the master photograph.
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>o</td>
<td>i</td>
<td>e</td>
<td>i</td>
</tr>
<tr>
<td>2</td>
<td>i</td>
<td>a</td>
<td>u</td>
<td>a</td>
</tr>
<tr>
<td>3</td>
<td>u</td>
<td>o</td>
<td>i</td>
<td>a</td>
</tr>
<tr>
<td>4</td>
<td>a</td>
<td>i</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>5</td>
<td>e</td>
<td>u</td>
<td>u</td>
<td>u</td>
</tr>
<tr>
<td>6</td>
<td>a</td>
<td>e</td>
<td>i</td>
<td>o</td>
</tr>
<tr>
<td>7</td>
<td>u</td>
<td>a</td>
<td>a</td>
<td>i</td>
</tr>
<tr>
<td>8</td>
<td>i</td>
<td>u</td>
<td>o</td>
<td>u</td>
</tr>
<tr>
<td>9</td>
<td>u</td>
<td>e</td>
<td>i</td>
<td>e</td>
</tr>
</tbody>
</table>
Fig. 6.—Master and short segments of the vowel (i) with the numbers of recognitions.
Fig. 6 shows the master (i) vowel, and photographs of the four short segments presented to the subjects; beside each file is given the number of persons, out of the total of 19, who recognized the segment. All of these wave forms correspond reasonably well with that of the master, (i)3 being the most difficult to locate.

The two vertical lines on the page represent the arbitrarily chosen boundaries of the master wave form, the beginning of this wave length occurring at the right and the beginning of the next succeeding wave form occurring at the left. Fortunately, all portions of the cycle are represented by this particular set of curves. With the exception of (i)4, the sounds appear fairly difficult to recognize; this vowel, however, shows 100% recognition. It is interesting to note that the distinguishing feature of this segment appears to be the right hand section, as the left half appears in (i)3, which was recognized only 5 times.

Whether there is a special facility in the recognition of segments containing this particular portion, however, could only be determined with an exhaustive set of data concerning this particular cycle. It may be, of course, that the acoustic spectrum of this specific segment renders it much more easily recognized than segments which even occur in an almost identical position, and which thus
have considerable of its wave form in common. The
significant fact to the present study, however, is that
this great difference in recognition did occur.
Fig. 7.—Master and short segments of the vowel (r) with the numbers of recognitions.
Five short segments of the (r) vowel were presented for recognition tests and are shown in Fig. 7. Unfortunately, a much poorer sampling of the complete cycle was obtained. (I)5 and (r)6 show especially significant recognitions. (I)6, however, appears to come from an almost identical portion of the cycle as (I)3. Since this latter segment was recognized only 6 times, the question arises as to the source of the difference in the number of recognitions between the two segments. It seems hardly possible that this difference can be attributed entirely to the slight variations in quality which appear, but it may have resulted from psychological variations beyond the control of the experimenter. It should also be pointed out that, at this extremely short interval, factors which would otherwise appear insignificant may have considerable bearing upon recognition.
Fig. 8.—Master and short segments of the vowel \( \varepsilon \) with the numbers of recognitions.
Fig. 3 presents the data gathered concerning the recognition of the vowel \( \varepsilon \). Somewhat more significant data are given by this set of curves; though most of the first half of the wave length is not represented; and \((\varepsilon)3\) and \((\varepsilon)5\) do not conform particularly well to the master wave. A definitely greater recognition, however, is shown for the pair of curves falling in what is arbitrarily chosen as the latter section of the cycle. Considering the number of subjects used, an increase of 14 over 5 appears very significant.
Fig. 9.—Master and short segments of the vowel (æ) with the numbers of recognitions.
A still more representative group of curves is shown in Fig. 9. Some of the short (£) segments agree rather well with the master; but others do not. It should be remembered, however, that, as far as was humanly possible, the actual quality produced at the microphone was held constant. Wide variations in recognition appear throughout the cycle. Certainly the difference between 0 recognitions and 17 recognitions in 19 indicates that one segment taken from the (£) cycle is more easily recognized than certain others.
Fig. 10.—Master and short segments of the vowel \( a \) with the numbers of recognitions.
The percentage of recognitions of the vowel (a) as shown in Fig. 10, was especially high. Here, again, the wave forms of many of the segments are not easily located in the master cycle. Throughout this study, however, it is assumed that the master wave form resembles fairly well the wave form from which any short segment was taken. To avoid inaccuracy, the position of each segment was determined by two individuals; and careful examination of the figure will show that each of the short segments is located in the only portion of the wave length from which it could have come. Segments occurring at the extremities of the arbitrarily chosen wave length are more easily recognized than the segment which appears near the center of the cycle. The recognition score of 17 for the vowels (a)3 and (a)4 near the beginning of the wave length is especially significant.
Fig. 11.---Master and short segments of the vowel (ɔ) with the numbers of recognitions.
Nearly all portions of the master wave length are represented by the short segments of the vowel (ɔ), as shown in Fig. 11. Those segments near the arbitrarily chosen beginning of the wave length appear especially difficult to recognize; while that portion represented by (ɔ)3 was recognized with considerable facility.
Fig. 12.—Master and short segments of the vowel (υ) with the numbers of recognitions.
For the most part, the segments shown for (υ) do not closely parallel the master wave form. The significant feature in this set is the fact that the segment at the end of the wave length was recognized only 4 times, while the recognitions for the curves at the beginning of the wave form are consistently higher.
Fig. 13.—Master and short segments of the vowel (u) with numbers of recognitions.
A major portion of the master wave length for the vowel (u) is represented in the short segments shown in Fig. 13; and the wave forms of the various segments correspond rather closely to that of the master. The wave occurring in the latter portion of the cycle chosen was most often recognized. The low percentage of recognitions for (u)6 may probably be attributed to its unusually small amplitude; for it appears to come from approximately the same position as (u)5 which was recognized 9 times. It should be pointed out, however, that the various figures presented show practically no correlation between the number of recognitions and the amplitude of the respective segments. The two segments falling in the arbitrary middle of this cycle are those most difficult to recognize.

The phonograph technique, as explained in the discussion of Procedure, was used in taking the second set of data. The numbers on the photographs precede the vowel symbols to distinguish these curves from those of the previous group. Table II shows the series used. (æ) and (ɔ) were photographed. There were no duplications in the series for this set of data. This time an interval of .0031 of a second was used, giving approximately .293 of one cycle. A total of 17 short segments was photographed, and 51.7% recognition of these two vowels was obtained from the 15 subjects serving in the experiment. This slight increase
in the percent of recognition may have been due to a number of things. A check showed that \( \alpha \) and \( \beta \) did not receive this high a recognition in the first experiment. The explanation may lie in the fact that an identical group of subjects was not used; the difference, on the other hand, may have resulted from the chance presentation of more easily recognized segments; or, further, it may be that this particular fraction of a wave length makes for better recognition than does the other, in spite of its shorter interval. If this latter should prove to be true, the basis would probably lie in the acoustic spectra.
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>i</td>
<td>e</td>
<td>o</td>
<td>u</td>
<td>e</td>
<td>a</td>
<td>i</td>
<td>e</td>
</tr>
<tr>
<td>2</td>
<td>e</td>
<td>i</td>
<td>e</td>
<td>o</td>
<td>i</td>
<td>i</td>
<td>o</td>
<td>u</td>
</tr>
<tr>
<td>3</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>u</td>
<td>e</td>
<td>a</td>
<td>o</td>
<td>a</td>
</tr>
<tr>
<td>4</td>
<td>o</td>
<td>a</td>
<td>i</td>
<td>e</td>
<td>i</td>
<td>e</td>
<td>e</td>
<td>o</td>
</tr>
<tr>
<td>5</td>
<td>o</td>
<td>o</td>
<td>a</td>
<td>i</td>
<td>e</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
</tbody>
</table>

Table II. Vowels Presented at the Short Interval In the Second Session
Fig. 14.—Master and short segments of the vowel \( \ae \) with the numbers of recognitions.
Fig. 14.--(Continued) Master and short segments of the vowel (/æ/) with the numbers of recognitions.
Eight segments of the (ɔ) vowel, shown in Fig. 14, were presented for recognition. In this set of data, the numbers are placed before the vowels to distinguish them from the photographs of the first set. The wave forms, with one or two exceptions, show a much closer parallel to the wave form of the master vowel. Every point on the wave was repeated in at least two segments, thus affording an excellent representation of every portion of the master wave form. In general, recognitions decrease as the segments progress from the beginning of the wave form to the end.
Fig. 15.—Master and short segments of the vowel (ɔ) with the numbers of recognitions.
Fig. 15.—(Continued) Master and short segments of the vowel (o) with the numbers of recognitions.
(ɔ), presented in Fig. 15, was the other vowel studied while using the recording technique. Nine segments were photographed, and one of the best representations of the master wave form was obtained. With the exception of 7(ɔ), the vowels follow the exact wave form of the master exceedingly well. The segments near the end of the cycle are much more easily recognized; toward the beginning, recognitions are not so great; though 8(ɔ) appears to offer an exception. It is interesting to note that 8(ɔ), which was recognized by 13 of the 15 subjects, covers almost the same portion of the curve as 11(ɔ), which was recognized only 7 times. Whether this is due to a difference in the acoustic spectra of the two segments, to the slight difference in position within the cycle, or to uncontrollable and disturbing psychological factors cannot be at present determined. If the second of these possibilities should prove true, recognition depends upon even more specialized portions of the wave length than can be ascertained from the data here presented.

In these two sets of data wide variations appear in the recognitions of various segments throughout the cycle. Some understanding of the differences may be had from a study of the average variation in recognitions. Each vowel was first considered separately, and the difference between the numbers of recognitions for each two segments was tabulated. In each set of data, the differences for
the various vowels were then considered together. The average of these differences was next found, thus giving the average variation occurring throughout the cycle.

It is obviously beyond the scope of this study to determine whether segments coming from one general section of the cycle are generally recognized more easily than others. Such a study would demand a large quantity of data for each specific vowel.

The identification of a short segment as belonging to a given vowel obviously will depend upon how much the segment sounds like the given vowel. This very probably depends chiefly upon the degree to which the acoustic spectrum of the given short segment resembles that of the complete cycle of the vowel. Considerable variation may occur, of course, in the harmonic content of two segments taken from approximately the same section of a given cycle, even though they have a large portion of their wave form in common. It is thus significant to consider the relationship between the distances separating various segments and the differences in the recognition of those segments.

This problem may be attacked by determining whether the distance separating each pair of segments is highly correlated with the difference in the recognitions of those segments. For this treatment of the data, the distance was measured between the initial points of each two segments of each vowel.
Since the wave forms are periodic and continuous, these measurements must obviously be of the shortest distance between the respective points on the two segments.\footnote{1}

As explained, the difference in the number of recognitions for each two segments had been previously tabulated. Since, within the range of one or two millimeters, the vowels all have the same wave length, the tabulations for each of the vowels were combined; and, for each set of data, differences in recognition were then correlated with distances between the corresponding segments. Tables III and IV show the respective tabulations for the first and second sets of data.

The order for the data given in these tables is the same throughout. The first row indicates, for the first vowel, the distance between the first and second short segments and the difference in recognition of those segments. The next row is for the first and third segments. When the differences for the first and each segment which followed it were obtained, the differences for the second and each successive segment were then determined; etc.

The order for (1) is thus: (1)2--(1)3; (1)2--(1)4; (1)2--(1)5; (1)3--(1)4; (1)3--(1)5; (1)4--(1)5.

\footnote{1}{This is somewhat easier to understand if we consider two sections on the circumference of a circle. Obviously, the distance between two similar points on these sections will depend upon whether we consider the longer or the shorter distance around the circumference. Thus the distance can never be greater than one-half the circumference of the given circle.}
TABLE III. Separate Tabulations for Each Vowel in the First Set of Data. (1) Distance between Each Two Segments. (2) The Respective Differences in the Number of Recognitions of Each Two Short Sounds Presented.

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Distance in mm</th>
<th>Difference in Recognitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>11.6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>36.6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td>(i)</td>
<td>6.5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>8.5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>13.5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>15.5</td>
<td>0</td>
</tr>
<tr>
<td>(3)</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>21.5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>20.5</td>
<td>9</td>
</tr>
<tr>
<td>(ɔ)</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>22.2</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>21.8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>15</td>
</tr>
</tbody>
</table>
TABLE III. (Continued) Separate Tabulations for Each Vowel in the First Set of Data. (1) Distance between Each Two Segments. (2) The Respective Differences in the Number of Recognitions of Each Two Short Sounds Presented

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Distance in mm.</th>
<th>Difference in Recognitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>16.2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>15.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>16.7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>16.3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25.8</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>26.3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>.5</td>
<td>6</td>
</tr>
<tr>
<td>(c)</td>
<td>27.5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>36.5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>31.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>21.5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>32.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>35.5</td>
<td>2</td>
</tr>
<tr>
<td>(u)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>38.7</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>33.5</td>
<td>6</td>
</tr>
<tr>
<td>(u)</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>27.6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>15.4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2</td>
</tr>
</tbody>
</table>
TABLE IV. Separate Tabulations for Each Vowel in the Second Set of Data. (1) Distance between Each Two Segments. (2) The Respective Differences in the Number of Recognitions of Each Two Short Sounds Presented.

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Distance in mm.</th>
<th>Difference in Recognitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>æe</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>10.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>38.5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>14.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>38.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>37.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>30.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>32.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>9</td>
</tr>
</tbody>
</table>
TABLE IV. (Continued) Separate Tabulations for Each Vowel in the Second Set of Data. (1) Distance between Each Two Segments. (2) The Respective Differences in the Number of Recognitions of Each Two Short Sounds Presented.

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Distance in mm.</th>
<th>Difference in Recognitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ɔ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>54</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>54</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>40.5</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>39.5</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>16.5</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>29.5</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>16.5</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>25.5</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
By the use of these tables, the distances separating the various segments were correlated with the corresponding differences in recognitions. The correlation coefficient for the first and second sets of data were .176 and .032, respectively. The respective probable errors were .0845 and .0676. These correlations show that the difference in the number of recognitions of any two segments will have little relation to the distance separating those segments. Thus two segments may be very close together and one recognized with ease, the other with difficulty. On the other hand, two segments may lie at some distance from each other and yet be recognized with the same degree of facility.

This does not imply, it should be pointed out, that in general segments coming from one portion of the wave length are as easily recognized as those coming from another. For example, if one very specialized portion of the wave length should prove to be much more easily recognized than all others, it is still possible for such a correlation coefficient as that found above to occur. Second, it is conceivable that two or more general sections of the complete wave form may be more easily recognized than others. This situation, likewise, would not preclude such correlation coefficients as obtained in the present study.

The results obtained in the present investigation
show that variation not only exists in the facility with which various short sounds are recognized, but that variation also exists in the ability of various individuals to recognize short sounds. This results from the following. First: If the facility of recognition for the various segments, and the recognition ability of the subjects, had both been constants, there would either have been complete recognition by all subjects on all segments, or there would have been zero recognition on all segments. Second: If facility of recognition were variable, but individual ability constant and equal for all subjects, then some segments would have received recognition by all, and those remaining would have received no recognition whatever. Third: If, on the other hand, ability is assumed to vary from subject to subject, while facility of recognition is assumed to be constant, all segments should have received the same number of recognitions. Since none of these three possibilities actually occurred, and since there was instead a great variety in the number of recognitions for the various segments, it can only follow that variation occurs both in ability to recognize short vowel sounds, and in the facility with which these various short sounds are recognized.
CHAPTER VII
CONCLUSIONS

From the data as here presented, four specific conclusions may be drawn.

1. This study verifies Gray's findings that significant recognitions may occur on only a small fraction of one complete vowel cycle. Gray found considerable recognition at .005 of a second, giving .24 of a cycle; in the present investigation, over 50% recognition was obtained at an interval of .0031 of a second, giving approximately .298 of a cycle.

2. A great number of instances occurred in which the wave form of the short segment closely paralleled a portion of the master wave. In the presentation of these particular segments, the specific section presented from the complete cycle was the only variable. For each vowel, marked differences appeared in the number of recognitions of these various segments. This gives conclusive evidence that for vowel sounds definite differences occur in the facility with which various sections of a given wave length are recognized. These differences were treated statistically. Nineteen
subjects were used in taking the first set of data, and
the average variation in recognition for the eight vowels
studied was 5.9, or 31%; 15 subjects were used in the
second session, and there was an average variation in
recognition of 4.9, or 30.6%. The fact that such variations
exist will obviously now have to be taken into consideration
in any attempt to standardize tests of the minimum duration
of vowel sounds necessary for recognition. It should
further be pointed out that vowel sounds, as normally
intoned by different individuals, vary in pitch and
quality, and thus in wave form, so as to preclude any
comprehensive statements concerning the segments generally
most easily recognized.

3. The distance was measured between the initial
points of each two segments occurring for any given vowel.
Magnitudes of the distances separating the segments were
then correlated with the differences in the number of
recognitions corresponding to these segments. The
correlation coefficient for the first and second sets
of data were .176 and .023, respectively. The respective
probable errors were .0845 and .0675. These correlations
show that the difference in the number of recognitions of
any two segments will have little relation to the distance
separating those segments. Thus two segments may be very
close together and one recognized with ease, the other with
difficulty.
4. As a result of the wide variations in the recognitions of the different segments presented, it follows that variation not only occurs in the facility with which various short sounds are recognized, but that it also occurs in the ability of different individuals to recognize short speech sounds.
BIBLIOGRAPHY

Books


Journals and Monographs


Gordon E. Peterson was born at Danville, Illinois on October 14, 1913. He was graduated from the elementary and secondary schools of Alvin, Illinois. His undergraduate work was done at the University of Illinois, and at DePauw University in Greencastle, Indiana, where he received his A.B. Degree in June, 1935. The following year he received a fellowship in the Department of Speech at Louisiana State University, where he received the Master's Degree in August, 1937. His work was continued at Louisiana State University until June, 1939, at which time he completed the requirements for the Degree of Doctor of Philosophy in Speech.
EXAMINATION AND THESIS REPORT

Candidate: Gordon E. Peterson

Major Field: Speech

Title of Thesis: The Significance of Various Portions of the Wave Length in the Minimum Duration Necessary for the Recognition of Vowel Sounds.

Date: May 10, 1939

Approved:

[Signatures]

Major Professor and Chairman
Charles W. Repp
Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]