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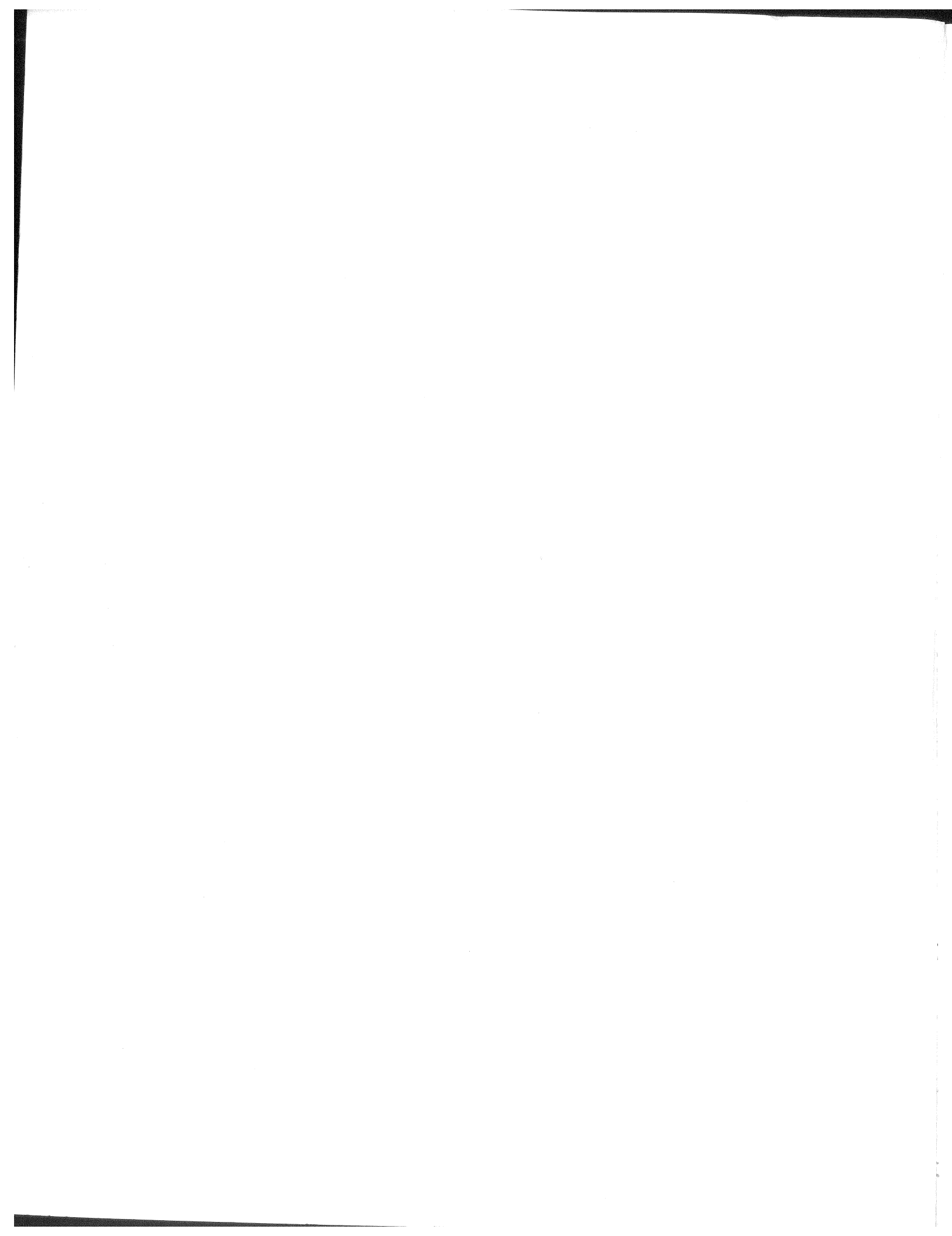
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**A GUIDE TO THE HISTORY OF
THE PHONETIC SCIENCES
IN THE UNITED STATES**

**Issued on the occasion of the
14th International Congress
of Phonetic Sciences,
San Francisco, 1-7 August 1999**

back. cusisquar sun. cutlaquas
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a blanket. aqueewants.
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A GUIDE TO THE HISTORY OF THE PHONETIC SCIENCES IN THE UNITED STATES

*Issued on the occasion of the 14th International Congress of
Phonetic Sciences, San Francisco, 1-7 August 1999*

Edited by
John J. Ohala, Arthur J. Bronstein, M. Grazia Busà, Julie A. Lewis, &
William F. Weigel

University of California, Berkeley
1999

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PREFACE

INTRODUCTION

The history of any science in the United States, part of the New World, is not going to be very long in comparison to comparable history in the Old World. This is the case with the history of the phonetic sciences in the U.S., too. The earliest works are from the colonial era (late 17th century) involving phonetic analyses of Native American languages. Nevertheless among the scientific activity of that period, achievement in phonetics is certainly one of the earliest. Work in phonetics accelerates considerably starting in the late 19th century. There are a number of milestones that have had considerable impact on the field. First among these is the invention of the telephone by ALEXANDER GRAHAM BELL in 1876¹. Further significant developments were made by Bell Telephone Laboratories, including the invention of the vocoder and the synthesis techniques that followed from it, statistics on speech acoustics, and the sound spectrograph. The work at several other laboratories, notably Haskins, MIT, UCLA, and Iowa, have been major influences on the direction of phonetic research in the US and the world.

ABOUT THIS VOLUME

The present volume has been prepared for distribution at the 14th International Congress of Phonetic Sciences (ICPhS) (1-7 August 1999, San Francisco). The title, *A Guide to the History of the Phonetic Sciences in the United States*, is, perhaps, too long and quite unwieldy, but it is perfectly descriptive. A key word in the title is 'guide'. We had neither the resources nor the time to produce a work that could be considered either complete or comprehensive. It is intended merely to document as accurately as possible some of the major events in the practice and development of the phonetic sciences in the US and to guide the interested reader to sources where further details might be obtained. The 'phonetic sciences' constitute any and all scientific studies of speech within linguistics, psychology, clinical studies, and communication engineering. The geographical scope is limited to the US in order to make the task manageable and to mark the first time in ICPhS's 67 year history that it has been held in the US.

The inspiration and motivation for this volume were many. First there was a similar work issued by the Netherlands Association of Phonetic Sciences at the 10th ICPhS (1983) at Utrecht, *Phonetic Sciences in The Netherlands, Past and Present*, edited by Tjeerd de Graaf, Toni Rietveld, Vincent van Heuven, and G. L. Meinsma (the latter of whom also mounted a very edifying exhibition of books and instruments related to the history of the phonetic sciences in The Netherlands). We appreciated that booklet and this volume is our way of returning the favor. Second, one of us (AJB) had edited a similar work 22 years ago (*A Biographical Dictionary of the Phonetic Sciences*, ed. by ARTHUR J. BRONSTEIN, Lawrence J. Raphael, and Cj Stevens) and was eager to continue the documentation begun there. We were also influenced by numerous other historians of phonetics who have approached their subject with a contagious passion, among them

¹ Canada can take some of the credit for the invention of the telephone. ALEXANDER GRAHAM BELL's family was living in Ontario while young Bell was working in Boston. He traveled to Canada frequently to see his family and later claimed that although his telephone was born in the United States, it was conceived in Canada.

David Abercrombie, Konrad Koerner, Michael MacMahon, and Alan Kemp.

WHY STUDY THE HISTORY OF THE PHONETIC SCIENCES?

There is undeniable entertainment value in history. It satisfies our curiosity; it uncovers unexpected links between people, things, and events; it makes us see familiar things from a new perspective. History is a story and we all enjoy stories. Whatever form of satisfaction is derived from reading the Guinness Book of Records or books of "firsts" may also be provided by histories. But many believe there are also moral, philosophical, and sound scientific lessons to be derived from the history of science. History may inspire us to emulate the pioneers in the field — those who had the daring to break from tradition and try something new. Tracing the history of ideas can enlarge a researcher's horizons: What is the basis for common assumptions underlying current practice? Are they well-founded? Were some of the "modern" discoveries in the field anticipated and, if so, what factors account for the earlier ideas or findings being neglected? Are there similar factors present today causing some ideas to be ignored? Are there common elements of methodology to some of the significant advances in the past?

We hope that this modest effort at the history of the phonetic sciences in the United States fulfills at least some of the above functions.

THE SCOPE OF THIS VOLUME

It has often been noted that all histories are selective and in that sense, biased. This volume is no exception. We will attempt to make our selectivity and thus biases explicit. Our overall aim was to attempt to make this work moderately comprehensive but at the same time to make it manageable.

Part I. In the case of the thematic essays, we tried to pick areas of the phonetic sciences which represent some of the broad categories of research and applications of phonetics.

Part II. For the histories of specific institutions — private, industrial, and university — we selected those that, in our opinion, produced a substantial amount of significant research over an extended period. Needless to say the phonetic sciences flourish at many more US institutions than these but we had to make our task manageable.

Part III. This part contains short biographical entries on individuals who have contributed to the phonetic sciences in the U.S. Inevitably it is the selection made for this section that will be the most controversial. Our intent was to include those individuals — living and dead — who had made significant and influential contributions to the field before 1980 and/or were current heads of leading research institutions. Inevitably there are many who met or meet that criterion but who are not included. This could have occurred due to a variety of reasons (a) oversight, (b) e-mail communications gone astray, (c) failure of correspondents to deliver a promised article, (d) inability to find someone to write the requested biography. Our call for contributions on deceased individuals was made through the electronic newsletters *The Linguist List* and *foNETiks* as well as on the web page of the ICPhS 99. We had

about a 75% success rate in these cases. A notable omission, which we regret, is an entry on Harvey Fletcher. In the case of living persons, they were contacted directly with a request to provide a short factual autobiographical sketch. In a few cases, unfortunately, the person in question simply could not be easily located, did not respond, declined to participate, or failed to deliver on time. In a few cases the entries for living subjects were written by the editors based on published material and/or the subjects' home web pages. To living individuals who should have been included but were not: our apologies. If and when a second edition of this work is produced we may be able to correct this defect.

Nevertheless, the 92 persons whose contributions are documented in the following biographical sketches represent the breadth and depth of the phonetic sciences in the United States from its colonial beginnings to the present. They are a varied group: alongside professional scientists and scholars are politicians, inventors, missionaries, and explorers. Many readers will no doubt be surprised to discover that several of the early European settlers and founders of the United States were actively involved in phonetic investigations, often as part of the earliest attempts to systematically understand the languages of the native American peoples that they encountered.

Variation in the length of the sketches of historical (deceased) subjects reflects a combination of the relative significance of the individual and their work in the phonetic sciences, the availability of information about the subject, and the enthusiasm of the author of the entry. The living subjects, however, were given uniform "bare-bones" guidelines. Because of space limitations, none of the sketches provides more than the most cursory outline of the subject's life and work. The references listed after each entry offer a starting point for readers who wish to know more.

We are aware that there are many shortcomings and, indeed, possible inaccuracies in this volume. We beg the readers' indulgence. Please bring any detected errors to our attention and these can be corrected in possible subsequent editions.

THE EDITORS
Berkeley, 1 June 1999

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We thank, first, the authors of the articles in this volume. It is evident from reading their entries that they have a sophisticated command and overview of their subjects and approached their task with enthusiasm. We also thank the following:

- Am. Philosophical Society (for the photograph of the manuscript page by Thomas Jefferson),
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- Lehman College Press for reprinting material from *A Biographical Dictionary of the Phonetic Sciences*, edited by Arthur J. Bronstein, Lawrence J. Raphael, and C. J. Stevens.
- The International Phonetic Association for permission to reprint portions of the entry on Y. R. Chao which first appeared in *J. Int. Phonetic Assoc.*
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- *The (Harvard) Studies and Notes in Philology and Literature* for the kymographic tracings in the entry on Raymond Weeks.

Charles Read, for information on Heffner and Joos.

The photographs of Yuen Ren Chao, Franklin Cooper, Pierre Delattre, Peter Denes, Homer Dudley, Roman Jakobson, Dennis Klatt were taken by John Ohala.

THE EDITORS

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Bronstein is the author of *The Pronunciation of American English* (Appleton-Century, 1960), co-author, with B. F. Jacoby of *Your Speech and Voice* (Random House, 1967). Senior Editor of *Essays in Honor of C. M. Wise*, with C. Shaver and Cj Stevens (Speech Assoc. of America, Hannibal, MO, 1970) and Senior Editor of *A Biographical Dictionary of the Phonetic Sciences*, with L. J. Raphael and Cj Stevens, a volume sponsored by the American Dialect Society, the American Association of the Phonetic Sciences, the Speech Communication Association, and the International Society of the Phonetic Sciences, issued by the Press of Lehman College in 1977.

He has acted as consultant in American English pronunciation for the American College Dictionary, the Random House Dictionary of the English Language, Collier's Encyclopedia, and the Longman's Dictionary of Contemporary English. His published papers and reviews have appeared in such journals as *American Speech*, the *Quarterly Journal of Speech*, *Speech Monographs*, the *Journal of Speech and Hearing Disorders*, the *Journal of Education Research*, and *Dictionaries*.

Bronstein is a member of the Modern Language Association, the Linguistic Society of America, the American Dialect Society, the International Phonetic Association, the American Association of the Phonetic Sciences, and the International Society of the Phonetic Sciences. His honors include the status of Fellow in the American Speech and Hearing Association, the New York Academy of Sciences, and the Dictionary Society of North America, and elected membership to Phi Beta Kappa. A volume of *Essays in Honor of Arthur J. Bronstein: Language and Cognition*, edited by L. J. Raphael, C. B. Raphael and M. R. Valdovinos, appeared in 1984 (The Plenum Press, New York and London.)

Bronstein's interests bridge the areas of phonetics, phonology, American dialectology, lexicography, general linguistics and sociolinguistics.

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this congress. She is a member of LSA and ASA and was on the planning committee for the 1999 meeting of DSNA.

WILLIAM F. WEIGEL is a PhD candidate in Linguistics at the University of California, Berkeley. His research focuses on various aspects of language contact, especially language shift and language obsolescence.

ABBREVIATIONS

- AAAS:** American Association for the Advancement of Science
ACLS: American Council of Learned Societies
ARPA: Advanced Research Projects Agency
ARO: Association for Research in Otolaryngology
ASHA: American Speech and Hearing Association
ATR: Advanced Tongue Root
BDPS: A Biographical Dictionary of the Phonetic Sciences
CASE: Council for Advancement and Support of Education
CASS: Center for Auditory and Speech Sciences
CMU: Carnegie-Mellon University
CSL (University of Florida): Computer Science Laboratory
CSL (University of Michigan): Communication Science Laboratory
CUNY: City University of New York
DAT: Digital Audio Tape
DOC: Department of Commerce
FFT: Fast Fourier Transform
GRI: Gallaudet Research Institute
IASCP (University of Florida): Institute for Advanced Study of the Communication Process
ICA: International Congress on Acoustics
ICPhS: International Congress of Phonetic Sciences
ICSI: International Computer Science Institute
ICSLP: International Conference on Spoken Language Processing
IEEE: Institute of Electrical and Electronic Engineers
IJAL: International Journal of American Linguistics
ILS: Interactive Laboratory System
IPA: International Phonetic Alphabet OR International Phonetic Association
IREX: International Research & Exchanges Board
LPC: Linear Predictive Coding
LSA: Linguistic Society of America
LSU: Louisiana State University
M.I.T.: Massachusetts Institute of Technology
MPI: Max Planck Institute, Nijmegen, The Netherlands
NBC: National Broadcasting Company
NEA: National Endowment for the Arts
NICHD: National Institute of Child Health and Development
NIDCD: National Institute of Deafness and other Communication Disorders
NIDR: National Institute of Dental Research
NIJ: National Institute of Justice
NIH: National Institute of Health
ONR: Office of Naval Research
PMLA: Publications of the Modern Language Association
RLE: Research Laboratory of Electronics (M.I.T.)
SCRL: Sensory Communication Research Laboratory
STL: Speech Technology Laboratory
SUNY: State University of New York
SUR: Speech Understanding Research
UCB: University of California, Berkeley
UCLA: University of California, Los Angeles
UCSD: University of California, San Diego
UCSF: University of California, San Francisco
UPSID: UCLA Phonological Segment Inventory Database
VA: Veteran Administration

Note on cross-referencing: cross references are signaled by the use SMALL CAPS, e.g., in the cases of ALEXANDER GRAHAM BELL and James Madison, the former has his own entry in the volume whereas the latter does not. This typographic device is used only on the first mention of an individual within a paragraph.

PART I. THEMATIC ESSAYS

A SHORT HISTORY OF ACOUSTIC PHONETICS IN THE U.S.

Ignatius G. Mattingly

Haskins Laboratories and University of Connecticut

Acoustic phonetics concerns itself with those topics in experimental phonetics that can reasonably be investigated by the analysis, manipulation, and synthesis of speech signals. These topics include the spectrotemporal structures of the signals and the relation of these structures both to the vocal tract configurations that produced them and to the linguistic units intended by speakers and perceived by hearers. In this essay, some account is given of the history of acoustic phonetic research in the U. S. Speech perception research, however, is considered in a separate paper in this volume and will be referred to here only incidentally.

Acoustic phonetics in the U. S. began in 1879 with a paper read by A. G. BELL before the National Academy of Arts and Sciences. By this time, European scientists such as Willis, Wheatstone, and Helmholtz had already defined two questions that were to preoccupy the field for the next sixty years. First, how many vowel "pitches" (i.e., resonances) are there, and how are they related to the cavities of the vocal tract? Helmholtz's (1877-1954) experiments had led him to the conclusion that these cavities acted as simple resonators. There was one pitch for a back vowel, produced by a single resonator, and two pitches for a front vowel, produced by two connected resonators. Second, are the vowel pitches laryngeal partials amplified by the resonators (the Chord-Tone Theory, proposed by Wheatstone, 1837, and favored by Helmholtz) or are they unrelated to the laryngeal partials, resulting from the momentary excitation of the resonators by successive laryngeal pulses (the Inharmonic Theory, proposed by Willis, 1830). Although Rayleigh (1894-1945) argued correctly that both theories were true and consistent with each other, the issue was to remain alive through the 1930s.

BELL was well aware of these questions. In his paper, he claims to have found, by tapping his throat or cheek, two pitches, systematically related to cavity size, for *all* the vowels, but does not report their values. He supports the Chord-Tone Theory, arguing that laryngeal partials are reinforced to some extent even if they are merely close in frequency to the cavity pitch. But he refutes a variant of this theory proposed by the British investigators Jenkin and Ewing (1878), according to which the pitches of a vowel maintain a constant harmonic relationship, by showing that the quality of a recorded vowel does alter when the speed of rotation of a phonograph cylinder is suddenly altered.

BELL's paper did not immediately inspire further work in acoustic phonetics. At this time, there was in the U.S. no strong tradition of experimental phonetic research such as existed in Britain and Germany, and no further significant acoustic work was done until the next century. Bell's real contribution to

acoustic phonetics is surely the insight expressed to his assistant Thomas Watson during their experiments in telegraphy: "If I could make a current of electricity vary in intensity precisely as the air varies in density during the production of a speech sound, I should be able to transmit speech telegraphically" (Watson, 1915, p. 1506). Not only the telephone, but the electrical technology that was to transform acoustic phonetic research and the theories later developed to explain the relation between the vocal tract and the speech signal, depend ultimately on the analogy between sound and electricity, whose practical importance Bell seems to have been the first to recognize.

1900-1920

But electrical technology did not become available for phonetic research for quite a while. In the meantime, Fourier analysis of speech was a laborious and not very rewarding affair. First, an oscillogram of the sound wave had to be prepared, by optically transducing the vibrations of the membrane of a horn receiver, as with D. C. MILLER's Phonodeik (1916-1922); or the varying depth of the grooves of a wax cylinder recording (as in L. Bevier's work (e.g., 1900). It was of course extremely difficult to do this accurately and reliably and the frequency range now known to be important for speech was very poorly preserved. From the oscillogram, Fourier coefficients were computed from series of ordinate values measured for each pitch pulse, either by hand (Bevier) or with a Henrici analyzer (Miller). Using this device, the experimenter traced the waveform of a pitch pulse with a stylus, the movement of the stylus was mechanically analyzed, and the sine and cosine coefficients of five components appeared on dials. To do twenty components and then compute amplitudes and phases must have taken well over an hour for each pitch pulse.

In general, the number of resonances and their values obtained by these early investigators were consistent with those given by Helmholtz. Indeed, Helmholtz's account was so influential that contradictory data were brushed aside. For example, although a back vowel was supposed to have only one resonance, both Bevier and MILLER report cases where [ɑ] has two resonances at frequencies now known to be appropriate for F1 and F2 of this vowel. Of one such case, Miller observes, "The double peak for this vowel is peculiar to certain voices, and probably there is only one resonance, which is separated into two parts by the absence of a particular partial tone from the sound of a particular voice". (1916-1922, pp. 226-227).

MILLER also synthesized some vowels and CV syllables, using wooden organ pipes with adjustable output levels. Each

pipe produced one harmonic component of the vowel being synthesized, ten pipes being required for a baritone [a]. By opening and closing the air supply, he synthesized the word *papa*.

While MILLER and Bevier accepted the Chord-Tone Theory, the psychologist E. W. SCRIPTURE was a fierce partisan of the Inharmonic Theory, as elaborated by the German investigator L. Hermann (e.g., 1893). Scripture (1906) insisted that a standard Fourier analysis gave a false picture of the vowel spectrum, and proposed a method for analyzing the speech waveform into "frictional" (i.e. damped) sinusoids. He also synthesized waveforms, though not actual signals, from such components. Understanding that the vocal resonators were interdependent, he accomplished this by using two pendulums of different lengths linked so as to vibrate together, anticipating the principle of the serial formant synthesizer. He also gave much attention to "qualitative analysis", that is, close scrutiny of waveforms of connected speech, at a time when others looked only at sustained vowels. His commentaries are remarkably insightful, anticipating many ideas not commonplace until much later. For example:

...the cavity tones in the spoken vowels are never constant. This fact, when thoroughly understood and recognized, must effect changes in the prevailing views of sounds found in the books on phonetics and the dictionaries. These are really written with notions of sounds that are derived from typography and not from actual speech; the conclusions often have little relation to the really spoken sounds. (1906, p. 41).

1920-1945

After World War I, the Research Laboratories of the Bell Telephone System undertook an ambitious program of research on speech and hearing (Fletcher, 1929). The Bell electrical engineers found it natural not only to use electrical methods but also to draw on electrical analogies in thinking about phonetic questions.

An early example was Stewart's "Electrical Analogue of the Vocal Organs" (1922). Stewart's device, the first electrical synthesizer, was actually a *terminal* analog (FLANAGAN, 1957) formant synthesizer, consisting of a buzzer exciting two resonant circuits in parallel. Recognizable versions of all the vowels and some consonants were obtained by varying the tuning of the circuits.

Stewart's synthesizer had two resonators, rather than three or four, because he shared the still generally held Helmholtzian notion that "the air in the mouth cavities possesses, as a rule, only one or two important modes of vibration" (1922, pp. 311). But Crandall (1925), another Bell engineer, found evidence against this view with the help of his electro-optical system for making oscillograms, a great advance over previous systems. He observed for back vowels not only the expected "mean low characteristic frequencies" but also, in the case of several speakers, "scattered low frequencies" that are obviously second-resonance frequencies and, for both back and front vowels, "scattered high frequencies" that may represent higher resonances. As recording and analyzing equipment improved, the number of resonances observed in vowel sounds continued to increase, further embarrassing the Helmholtzian account. In Steinberg's (1934) analysis of *Joe took father's shoebench out*,

three resonances were regularly seen and sometimes four; Lewis (1936) found five resonances in each of the vowels he analyzed, and therefore proposed that there were five simple resonators in the vocal tract, without specifically locating them. Moreover, G. OSCAR RUSSELL (1931) found the Helmholtzian account inconsistent with his x-ray data.

Homer Dudley was another Bell engineer intrigued by electrical analogies. In a 1940 paper, he says, "The fundamental processes in human speech production are ... analogous to those of electrical carrier circuits" (p. 504). He embodied this idea in the Vocoder (Dudley, 1939), a device to reduce the channel capacity required for speech communication. At the sending end, the smoothed outputs of a pitch-detector and a bank of filters covering the speech spectrum were coded as slowly-varying signals; at the receiving end, these coded signals controlled the frequency of a buzzer and the input levels of the buzzer signal to another bank of filters, whose summed outputs formed the synthesized speech. The Voder (Dudley, Riesz and Watkins, 1939) was a terminal analog synthesizer similar to the Vocoder's receiving end. The control signals, however, were provided by a human operator by means of a keyboard, wrist bar, and pedal. It took a long time for an operator to become skilled and the synthetic speech, to judge from recordings that still survive, was not highly intelligible.

1945-1970

The impressive accomplishments of the post-World War II years were due mainly to three developments: The invention of the sound spectrograph, the replacement of the Helmholtzian account of vocal resonance by the Acoustic Theory of Speech Production, and the availability of digital computers for phonetic research.

The spectrograph (Potter, 1945; Koenig, Dunn and Lacy, 1946) had been developed by Ralph Potter and his associates at Bell Laboratories just before the War, but was used for military purposes and not made public until 1945. The spectrograph provided, in a few minutes, a time-frequency-intensity display of a previously recorded 2.4 sec signal, by means of repeated analyses with a band pass filter automatically retuned to increasing center frequencies. For the first time, spectrotemporal phonetic events could be readily observed.

In *Visible Speech*, Potter, Kopp and Green's (1947) textbook for reading spectrographic displays, a great many very clear spectrograms are shown and many of the significant acoustic features of speech are pointed out in colorful terminology. Stops are characterized by a "stop gap" followed by a "spike". Formants are "bars". Every sound has a "hub", the explicit or implicit frequency of "bar 2". The hub, a forerunner of the "locus" (DELATTRE, LIBERMAN and COOPER, 1955), is said to be "relatively fixed" for many sounds, but Potter et al. were quite aware of coarticulatory effects (pp. 49-51). While little of their terminology has survived, most of their observations have proved in subsequent research to have been accurate and important.

Up to this point, linguists and conventional phoneticians had avoided acoustic phonetics. BLOCH and Trager had observed, "Acoustic terms, for all their precision, are meaningless to nearly every linguist" (1942, p. 12). But the advent of the spectrograph awakened linguists' interest. Martin JOOS, who had worked with the spectrograph for three years in the Army Signal Corps, was probably the first linguist to realize its potential value for phonetic research. His *Acoustic Phonetics* (1948) was extremely

influential and is still worth reading today for its discussions of segmentation and coarticulation. Another linguist, ROMAN JAKOBSON, found support in spectrograms for his theory of phonological distinctive features. In Jakobson, Fant and HALLE (1952), the features are defined in acoustic terms, with spectrographic examples. Unfortunately, the interests of phonologists and experimental phoneticians would soon diverge again, owing to differences in training and scientific goals.

The spectrograph also inspired FRANKLIN COOPER's Pattern Playback synthesizer at Haskins Laboratories (Cooper, LIBERMAN and Borst, 1951). The Playback could convert spectrotemporal patterns, either actual spectrograms or hand-painted creations, to sound. These control patterns were stable, unlike the human manipulations that had controlled earlier synthesizers, so that as many identical repetitions of an utterance as desired could be produced, yet the patterns were also readily modifiable. These features made the Playback the first synthesizer that enabled systematic perceptual experimentation, and it was the main tool for research at Haskins during the next fifteen years.

Many investigations aimed at describing the various phonetic categories were carried out during this period with the help of the spectrograph. DELATTRE (1951) elaborated on the correspondence, to which JOOS (1948) had called attention, between F1-F2 plots and the traditional phonetic vowel quadrilateral based on tongue position. This correspondence received further abundant support from an extensive study of the vowels of 76 speakers at Bell Laboratories (PETERSON and Barney, 1952). This study also revealed consistent formant patterns within speaker but systematic differences across speakers, dependent on sex and age.

Acoustic properties of stop consonants were investigated by Fischer-Jørgensen (1954) and HALLE, Hughes and Radley (1957); stress, by Fry (1955) and LEHISTE and PETERSON (1959); glides and diphthongs, by Lehiste and Peterson (1961); voice onset time, by LISKER and ABRAMSON (1964); and intonation, by Lieberman (1967). In the case of some categories, however, the analysis provided by the spectrograph was inadequate and special filtering was necessary, as in the case of stop bursts (Halle et al., 1957) and fricatives (Hughes and Halle, 1956). Besides these studies of particular categories, the coarticulatory effects were studied by House and FAIRBANKS (1953), Peterson and Lehiste (1960), and House (1961).

H. K. Dunn at Bell Laboratories and Gunnar Fant at MIT were responsible for the final demise of the Helmholtzian account of vocal resonance. Dunn (1950) argued that Helmholtz resonators were an oversimplification, given the frequencies and cavity dimensions involved. A distributed rather than a lumped treatment was called for, taking shape as well as size into consideration.¹ This could be accomplished by regarding the cavities of the vocal tract as a series of connected tubes of different lengths and areas or equivalently, in the most striking electrical analogy so far, as segments of a telephone transmission line. Though in certain cases a particular resonance might be chiefly dependent on a single cavity, the resonant frequencies specified by the transmission characteristic of the tract depended

in general on the entire configuration. Dunn ignored damping effects to simplify his discussion, but Fant (1950a,b; 1952) demonstrated that if damping is taken into account, a tube model of the transmission characteristic (or "transfer function"), together with appropriate assumptions concerning source and radiation characteristics, could specify the complete acoustic signal, rather than merely its resonant frequencies. This was the essence of the Acoustic Theory of Speech Production, elaborated later in Fant (1960).

To test his calculations, Dunn had constructed a primitive transmission-line synthesizer, in which the vocal tract was modelled as two uniform tubes connected by a constriction of variable location and area. Soon after, STEVENS, Kasowski and Fant (1953) built a more elaborate synthesizer in which the areas of 35.5 cm tube segments in cascade could be independently varied, allowing any desired vocal-tract area function to be approximated. By defining a fairly naturalistic configuration and varying only lip opening and location and degree of tongue constriction, Stevens and House (1955) demonstrated that the connection between tongue position and vowel formant frequency was not straightforward; because of compensatory articulation, the F1-F2 patterns PETERSON and Barney (1952) had reported could be produced by many different area functions. This synthesizer, supplemented with a nasal circuit, was also used to investigate nasalized vowels (House and Stevens, 1956) and nasal consonants (House, 1957).

Computers began to become available to speech researchers in the 1960s, taking over tasks previously done manually, such as the editing of speech signals (COOPER and MATTINGLY, 1969), or electronically, such as terminal analog synthesis (Kelly and Gerstman, 1961; FLANAGAN, Coker and Bird, 1963), vocal-tract synthesis (Kelly and Lochbaum, 1963), and modelling of the voicing source (Flanagan and Landgraf, 1968).

Other tasks performed by the computer had not previously been practical at all. One such was "synthesis by rule". LIBERMAN, Ingemann, LISKER, DELATTRE and COOPER (1959) had presented rules for synthesis from a phonemic input for the Pattern Playback, but hand-painting spectral control patterns by rule was extremely tedious, and only a few sentences had actually been synthesized. Kelly and Gerstman (1961), however, programmed a computer to derive control functions for their formant synthesizer according to rule. Thus ample amounts of speech could be readily produced and evaluated, and the rules could then be improved.

The computer also made possible a research strategy inspired by the Acoustic Theory of Speech Production: "Analysis by synthesis" (Bell, Fujisaki, Heinz, STEVENS and House, 1961). Fant (1950a,b; 1952) had pointed out that the transfer function could be factored into pole and zero components in the complex plane. This suggested that the transfer function of a natural speech sound could be estimated, given reasonable assumptions about the contributions of the excitation source and radiation, by assembling, with the aid of a computer, the best matching spectrum from an inventory of such components. Bell et al. analyzed vowels in this way and the method was applied to voiceless fricatives by Heinz and Stevens (1961) and to nasal consonants by FUJIMURA (1962).

¹ Chiba and Kajiyama in Japan had made this point in *The vowel - its nature and structure* (1941/1958). But most copies of this book were lost during the war (Flanagan and Rabiner, 1973, p. 92), and it did not become known to Dunn until after he had submitted his paper for publication (Dunn, 1950, p.741).

1970-PRESENT

In recent times, although the number of investigators and the amount of research in acoustic phonetics have greatly increased, there has been no theoretical development as remarkable as the Acoustic Theory of Speech Production, and no technical advance as dramatic as the sound spectrograph. Nevertheless, substantial progress has been made in a number of different directions, which there is space to sketch only briefly, citing some representative papers.

Sophisticated computer procedures for speech analysis, such as the Fast Fourier Transform (Oppenheim, 1970), and Linear Predictive Coding (Atal and Hanauer, 1971) have been developed, and are now packaged for use on PCs and the Macintosh (e.g., Keller, 1994).

Some topics investigated earlier have been profitably revisited, as exemplified in the studies of stop consonants carried out by KLATT (1975), BLUMSTEIN and STEVENS (1979), and Kewley-Port (1982) and in the studies of the acoustic effects of coarticulation by, e.g., SOLI (1981), REPP and MANN (1982), MANUEL (1990) and MAGEN (1997). Stevens (1989), in an influential paper drawing on the Acoustic Theory of Speech Production, has argued that speech is "quantal": Ranges of articulatory variables in which the signal changes rapidly relative to articulatory change, and ranges of acoustic variables where auditory perception changes rapidly relative to acoustic change, provide the basis for phonetic distinctive features.

Other topics, previously given little consideration, have now received more attention. Thus, substantial effort has been devoted to prosodic features, especially intonation, e.g., KUTIK, COOPER and BOYCE (1983) and LIBERMAN and PIERREHUMBERT (1984); duration, e.g. Crystal and House (1988a, b); and the effects of syntactic structure on both (Cooper, 1976; Cooper and Sorensen, 1977). The pronunciation of non-native speakers has been studied by FLEGE, MUNRO, and SKELTON (1992) and by CROWTHER and MANN (1992). The speech of infants and children has been considered by several investigators from a developmental standpoint. Thus, GILBERT (1970) has examined vowel formants; KEATING and BUHR (1978), F₀; SMITH (1978), timing; and RAPHAEL, DORMAN and GEFFNER (1980), durational differences conditioned by voicing.

In a laudable effort to bridge the divide that seems to separate phonetics from linguistics (see OHALA, 1990), some investigators have employed the methods of acoustic phonetics to address phonological questions. Labov (1963) had measured formant frequencies to demonstrate a sound change in progress on Martha's Vineyard. Later, Ohala (1974) showed that certain puzzling historical sound changes could be accounted for in acoustic terms. Most recently, the Experimental Phonology movement has demonstrated that experimental phonetics can contribute to both synchronic and diachronic phonology (see the papers in Ohala and Jaeger, 1986; Kingston and Beckman, 1990; and succeeding volumes in the Laboratory Phonology series).

Acoustic phonetics has also been applied to questions of linguistic evolution. Lieberman, Crelin and Klatt (1972) have argued that while the superlaryngeal tract in non-human primates, human neonates and, arguably, Neanderthal man is essentially a single tube with a limited sound repertoire, there has evolved in the adult human a "bent two-tube" superlaryngeal tract whose shape can be varied by tongue movement to produce a far more extensive repertoire. Hauser and Fowler (1992) have provided

evidence that primate vocalizations have some of the prosodic properties of human speech.

There has been considerable work on the determination of vocal-tract configuration from spectral information. MERMELSTEIN (1967) had already shown that vocal-tract area functions for vowels cannot be recovered unambiguously unless they are required to be anti-symmetric. Atal, Chang, Mathews and Tukey (1978) have generated an inventory of formant-frequency patterns by vocal-tract synthesis and have confirmed the many-to-one articulatory-to-acoustic relation observed by STEVENS and HOUSE (1955). But LADEFEGED, HARSHMAN, Goldstein and Rice (1978) have found that for unrounded vowels, formant frequencies are highly correlated with dynamic factors known to specify tongue shape, Papçun et al. (1992) have used a neural network trained on x-ray microbeam data for Cə syllables to determine vocal-tract gestures with considerable success, and Hogden, Rubin and Saltzman (1996) have shown that a computer can be trained to determine articulator positions from synthetic speech by exploiting continuity restrictions on articulator movement.

In speech synthesis work, highly intelligible speech can now be generated from a phonemic input, and indeed from conventionally-spelled text (see KLATT's 1987 review of text-to-speech systems) and attention has turned to the voice source. Ishizaka and FLANAGAN (1972) have synthesized voiced sounds from their "two-mass" model, elaborating on the earlier "one-mass" model (Flanagan and Landgraf, 1968), and Klatt and Klatt (1990) have demonstrated the importance of breathiness for the synthesis of natural-sounding female speech.

CONCLUSION

Clearly, our understanding of acoustic structures and their relation to vocal-tract configurations has vastly increased since A. G. BELL's 1879 paper. On the other hand, the relation between acoustic structures and linguistic units, despite much research and discussion, remains clouded and controversial. It is especially in this direction that further progress is to be hoped for.

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A GUIDE TO THE HISTORY OF AMERICAN DIALECTS WITH SPECIAL REFERENCE TO PRONUNCIATION

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As regional and social varieties of the national language, American dialects emerged from the primary settlement areas of the Atlantic and Gulf States, spreading west and north to establish the rural and urban patterns of today. The study of pronunciation, grammatical forms, and words outlines the history of American dialects. And, although the following guide concentrates on phonetic and phonemic evidence, American dialect history finds reinforcement in the geography of forms and words, as well as in the ever-enlarging corpus of syntactic, semantic, and pragmatic evidence. Like a language, a dialect realizes a system of signs, modified by its social history. Regional and social dialect studies unite in their study of speech in its historical context.

The following guide concentrates on four developments in the history of American dialects as it relates to pronunciation study. First, the study of literature and commonplace social documents illustrates the philological origins of the research, an extension of Germanic philology formulated by Rasmus Rask, Jakob Grimm, and others. Next, the formation of the American Dialect Society (ADS) demonstrates progression from the written to the spoken word, an extension of Franco-Swiss dialectology as established by Jules Gilliéron, Karl Jaberg, Jakob Jud, and others. Then, the establishment of American dialect lexicography records the regional vocabularies of the nation, an extension of the model established by Joseph Wright. Finally, the emergence of social dialectology illustrates an American creation that grew from native scholarship.

American pronunciation study necessarily begins with colonial texts, from the occasional spellings in William Bradford's *History of Plimmoth Plantation* (1630-51) to the rhymes of Philip Freneau (1771-1795). Mathews (1931) gathers the most interesting of these, and McDavid and Blair (1983) record the best of American dialect literature, from colonial time to the present. Apart from Orbeck (1927), little has been done with colonial texts, but Downer (1958), Ives (1954), and others have produced interesting, phonologically based, literary dialect study.

Founded in 1889, the American Dialect Society had begun with the same national interest and one year earlier began publication of Joseph Wright's *English Dialect Dictionary* (EDD, 1898-1905). Wright's belief, expressed in the EDD "Preface", v, reflects an early notion: "pure dialect speech is rapidly disappearing from our midst", a sentiment shared by many American dialectologists at that time. Even now, many students take the word *dialect* to mean nonstandard speech, despite the accepted understanding that it means "patterned variety", whether reflecting the speech habits of the elite, the upper class, the middle class, the working class, or the indigent. Early work in the first ADS journal, *Dialect Notes*, included George Hempl's phonological study (1896) that sketched the national incidence of

greasy and *greazy*, based on replies to 1600 questionnaires, and E. H. Babbitt's study of lower-class speech in New York City (1896). In the 1930s, *American Speech* and the monograph series, *Publication of the American Dialect Society*, replaced *Dialect Notes*, becoming journals of record for American dialect study. More recently, the *Journal of English Linguistics* has begun to share their responsibilities.

Since then, the American Linguistic Atlas Project (LAP) has conducted linguistic surveys of more than 3000 representative American speakers east of the Mississippi; fieldwork continues today in the Western states. In each of the autonomous regional surveys, speakers responded to approximately 1000 items, all recorded in narrow phonetic notation, based on the IPA. The University of Georgia now archives most LAP records, with many responses available in digital form on the LAP Internet site (<http://us.english.uga.edu>) and the rest proposed for completion by Kretzschmar. Allen (1977) and Pederson (1977) record the history of LAP research, and McDavid (1984) and Linn (1993) identify the contents and locations of project archives. Basic LAP publications include regional surveys of New England (LANE) Kurath et al. (1939-43), the Upper Midwest (LAUM) Allen (1973-76), the Gulf States (LAGS) Pederson et al. (1981, 1986, 1986-92), and the Middle and South Atlantic States (LAMSAS) Kretzschmar et al. (1993). From LANE and LAMSAS data came three important interpretive studies: Kurath (1949), Atwood (1953), and Kurath and McDavid (1961), all of which are elaborated effectively in McDavid's collected essays (1979, 1980).

Such works outline three major dialect areas in the Eastern states. Northern dialects emerge from New England, dividing as Eastern New England and Inland Northern, which extends from Western New England and Upstate New York to Chicago and beyond. Midland dialects originate in Pennsylvania with eastern (Philadelphia) and western (Pittsburgh) divisions. The former became a staging area for the South Midland dialects that extend across the Southern Highlands, Plains, and Piney Woods (Pederson, 1996). The latter became the source of the North Midland dialects of the Ohio River Valley to St. Louis and westward. From the Atlantic Coast, Southern dialects move westward out of Virginia and the Carolinas, across the Piedmont through Georgia, and into the Atlantic and Gulf Coastal Plains; from the Gulf Coast, Delta Southern dialects move north east, and west out of New Orleans, through the alluvial plains of the Mississippi, Atchafalaya, Yazoo, Arkansas, and Red rivers. Today, with computers, statistical analysis of LAP data confirms the essential conclusions of Kurath's *Word Geography*, while demonstrating distributional complexity among particular items (Kretzschmar, 1992, 1996a, 1996b; Kretzschmar and Schneider, 1996). And technical interpretation of LAP phonological data have validated the earlier conclusions of Kurath and McDavid

(Troike, 1986), as the non-technical phonology in the atlas projects of Allen and Pederson offer unqualified confirmation.

Within nine years of Wentworth's *American Dialect Dictionary* (1944), FREDERIC G. CASSIDY, with Audrey R. Duckert, published *A Method for Collecting Dialect* (1953), a plan to realize the ADS goal, the composition of a dialect dictionary comparable in scope to Wright's work. Under Editor-in-Chief Cassidy, the first volume of the *Dictionary of American Regional English* (DARE; 1985-) demonstrated the results of extensive field work in a national network of 2000 speakers and a reading program. The DARE questionnaire aimed at a more comprehensive inventory of forms than did the LAP instruments. It sought all possible regional or "folk" terms; whereas, LAP work sheets concentrated more narrowly on variation in the everyday vocabulary. Hartman (1985) offers an important overall and contemporary characterization of sound changes in American pronunciation.

Hartman's work provides a context for phonological generalization before it and since. He classifies major American regional variants under four headings: postvocalic *r*, weakened variants of diphthongs, diphthongized variants of monophthongs, and vowel alternations (*op. cit.*, lvii-lxi). Not usually retroflex in Eastern New England, as well as in the Southern Coast, Piedmont, Delta and Interior Plains, postvocalic *r* provides a source of great phonological complexity as realized in the eastern states. For example, Kretzschmar and Johnson (1993) tracked eight classes of phonetic realization in LAMSAS data from the Atlantic Coast. The latest information from Labov's case studies (see below) suggests that the pronunciation of postvocalic *r* on the Atlantic Coast demonstrates the same pattern first recognized by Raven McDavid (1948). Whether realized as a weakened glide or lengthened monophthong, as in *ice* [a^hs] and *eyes* [a:z], respectively, weakened variants characterize the South and the South Midland regions, with the latter typically extending the monophthong to both contexts. Diphthongized variants of lax vowels [ɪ ɛ æ ʊ ɔ ə] may recur anywhere in the country, but most frequently in the South Midland and Southern subregions. Another basic pattern concerns front vowels preceding heterosyllabic *r*, as in *Mary*, *merry*, and *marry*. During the first half of this century, a tripartite phonemic contrast (/e ~ ε ~ æ/) endured east of the Appalachians, from Maine to Alabama. Elsewhere, the binary contrast /ε ~ æ/ in *Mary* and *merry* against *marry* prevailed across most of the interior, except the urban Inland Northern (Chicago, Pederson, 1965), where all three become homophonous /ε/ and which seems to be the trend today. The /a/-/ɔ/ contrast, as between *cot* and *caught*, had already been lost in Eastern New England and Western Pennsylvania before the Second World War, and has now been lost in the Midland and Western portions of the country, as well as in Canada. A parallel development in the former contrast /hw/ and /w/ has rapidly disappeared, as in *which/witch*, *white/Wight*, and *whale/wail*. In this instance, the simplex (/w/) typified Atlantic Coastal speech and, reinforced by urban Northern pronunciation, became the dominant American form.

As important secondary sources, the best resources for description of American pronunciation have strong empirical bases, such as the work of C. M. WISE (1957), C. K. Thomas (1958), ARTHUR J. BRONSTEIN (1960), and William Labov

(1991). Through eleven editions (1924-1997), KENYON's *American Pronunciation* remains the most influential work of its kind, without the scholarly authority of the foregoing inductive studies. As a corrective, case study work has gone on since the 1960s including acoustical phonetic analysis by William Labov and his associates, as well as by a number of students who independently apply his methods (Labov, Yaeger, and Steiner, 1972; Labov, 1981, 1989, 1991, 1994). Now, as a work in progress, Labov's Phonological Atlas of North America will add over 700 case studies to his inventory. Although the database for this work remains unpublished, their interpretive publications offer reliable and recent witnesses. Labov's most recent work can be reviewed on the Internet, at http://www.ling.upenn.edu/phono_atlas/home.html.

Such work proceeds from early developments in American sociolinguistics, pioneered by McDavid (1946) and codified by Labov (1966). For applied phoneticians, this development offers a return to substance (-etic) elements instead of form (-emic) units, which have been the central preoccupation of linguistics since the advent of American structuralism. From Henry Sweet forward, phonetic study has required empirical research grounded in the scientific method. Today, the evidence of sociolinguists leads American students of speech back to their roots (see Pederson, 1995; Kretzschmar, 1995), back to the evidence documented by Kurath and McDavid, reinforced by the authority of systematic sampling and statistical projections.

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AMERICAN DICTIONARIES IN THE HISTORY OF AMERICAN ENGLISH PRONUNCIATION

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In the English speaking world there is an impressively large market for books that document or recommend the pronunciation of words. This is no less true in the United States than in the U.K. In terms of the number of individuals directly affected, this may be the most direct contact that the population as a whole has with the phonetic sciences. How the pronunciation is coded phonetically and which dialect(s) or styles of speech are represented constitute the principal differences between the various dictionaries that provide this information.

Noah Webster's dictionaries (*The Compendious Dictionary of the English Language*, 1806, and *An American Dictionary of the English Language*, 1828) were the first strong attempts to incorporate the current pronunciations of American English in the 19th century lexicographical compilations. His respellings reflected pronunciations of the times and, as mentioned elsewhere in this handbook, he was strongly influenced by BENJAMIN FRANKLIN's efforts to revamp the spelling system. His chief lexicographic opponent, Joseph Worcester, entered pronunciation respellings in his dictionaries (*Comprehensive Pronouncing and Explanatory Dictionary of the English Language*, 1830 and *Dictionary of the English Language*, 1860) that were reflections of British (rather than American) forms on the assumption that British usages were "better", "more accurate", "more harmonious and agreeable" than American usages. (A strange assumption, indeed!)

It was during this century that the first pronouncing dictionaries appeared in America: R. S. Coxe's *A New Critical Pronouncing Dictionary of the English Language*, 1813 and B. Allison's *The American Standard of Orthography and Pronunciation and Improved Dictionary of the English Language*, 1815. The pronunciation respellings in both of these dictionaries were based on British orthoepists rather than on the editors' impressions of American usages of the time. Still later, D. Smalley issued his *The American Phonetic Dictionary of the English Language* (1855) and D. Bolles edited his *A Phonographic Pronouncing Dictionary of the English Language*, in 1846. None of these dictionaries were in widespread use and their influence was negligible.

The first major work of this type was the *Pronouncing Dictionary of American English* (1944), edited by JOHN S. KENYON and Thomas A. Knott, the only dictionary of American English using IPA symbols for all its entries, including variant regional pronunciations (e.g. "class" as [klæs] with a special note of the New England forms [klas, klas]; and the entry for "farm" as [fɑ:m], with a note about Southern and Eastern forms [fɑ:m]; and variant pronunciations in common use, such as the entry for "news" as [njuz, niuz, nuz]). The Kenyon and Knott dictionary contained an extensive introductory section detailing the phonetic

alphabet used — based on the IPA symbols then adopted, with a discussion of what each symbol represented, plus sections on stress, and accent, the order of variant entries, geographic labels, regional pronunciations, how some variant pronunciations were to be interpreted, and the Anglicizing of foreign pronunciations. Kenyon and Knott was (is) a model phonetic/pronunciation dictionary, providing American readers with the only detailed "pronouncing dictionary" of American English. It made a clear statement (in its Preface, p. vii) that this was a "dictionary of colloquial English, of the everyday unconscious speech of cultivated people — of those in every community who carry on the affairs and set the social and educational standards of those communities". It was, therefore, a vastly different record from the standard dictionaries of its time, including the Second Edition of *Webster's New International Dictionary*, published by the same G. and C. Merriam Company, whose general editor was Thomas A. Knott. That dictionary carefully noted for its readers, on p. xii (at least for those who read prefaces to dictionaries) that "In this edition, the style adopted for representation is that of formal platform speech — and this must be clearly remembered by consultants of the pronunciations here given. The omission of less precise pronunciations of familiar words does not, of course, indicate that those pronunciations do not exist or that the editors of the dictionary refuse to recognize them".

The KENYON and Knott Dictionary provides the United States with a source similar to Daniel Jones' *English Pronouncing Dictionary for Received Pronunciation* (British) speakers. The EPD has gone through numerous revisions; the PDAE has not. (Note: The EPD, first published in 1917 was revised by A. C. Gimson in a 14th edition in 1991, and in 1997 it was re-edited by Peter Roach and James Hartman in a 15th edition. In that edition, Roach and Hartman abandoned the term "Received Pronunciation", which they called an "archaic name", and substituted therefore the term "BBC English" — the pronunciation of professional speakers employed by BBC as newsreaders and announcers...). The American pronunciations in the dictionary are described by them as "'General American', which refers to a geographically-socially based set of pronunciation features". (Page v of the preface).

Certain other pronouncing dictionaries of American English should be noted. *World Words*, edited by W. Cabell Greet was first issued in 1944 (with a second edition in 1948) by the Columbia University Press. It contained the "recommended pronunciations" for approximately 12,000 place names and words. Greet prepared it for the radio announcers of the Columbia Broadcasting System who couldn't (easily) locate

pronunciations of places throughout the world that suddenly began to appear in the news during World War II. The respelling system was a diacritic (not a phonetic) one. It also contained pronunciations of such alternative forms as “chiefly British” *aeroplane* and chiefly American *airplane*, plus variant pronunciations of certain place names like *Aegina* as [ɪdʒamə] and Greek [əʃjɪnə].

James F. Bender published his *NBC Handbook of Pronunciation* for the National Broadcasting System (the other major radio broadcasting system in the country) in 1944 (Harper and Row). He used both a diacritic and phonetic alphabet system for entering pronunciations of about 20,000 entries. It included geographical and biographical names as well as words “commonly mispronounced”. Its 4th revision, in 1984, by E. Ehrlich and R. Hand Jr., removed the IPA phonetic respellings. This dictionary, unfortunately, did not include variant pronunciations, reflecting “the belief rather than justification for a particular pronunciation”. Both the Greet and Bender dictionaries used an alphabetic respelling system: but both used the IPA schwa [ə] symbol for unstressed vowels.

A small volume to accompany the Second Edition of *Webster's New World Dictionary* (Simon and Schuster, 1984) appeared as *Webster's New World Guide to Pronunciation* in the same year. It was edited by William S. Chisholm Jr., and contained pronunciations for “over 13,000 words”, using a diacritic respelling system. The introduction, pp. ix - xxvi, contained brief discussions of earlier English (Old and Middle English), the Great Vowel Shift, sound change, “correctness”, social dialects, and variant forms.

Numerous dictionaries published in the United States have appeared with excellent frontispiece sections that deal with the pronunciation of the language in the U.S. as a guide to the respellings of the entries in the diacritic system used. None of those to be mentioned in this section uses the IPA phonetic alphabet system, except for the use of the schwa [ə] to represent fully unstressed vowels. Thus the 3rd edition of *Webster's New International Dictionary of the English Language* (1961) contains an extensive section on “A Guide to Pronunciations” by Edward Artin, pp. 33a-46a of the frontispiece section. (The Second Unabridged edition of this dictionary, first issued in 1934, contained an extensive introductory essay on the pronunciation of American English, authored by JOHN S. KENYON. This was a complete revision of an essay on the same subject by Paul Carhart for the previous edition). The 9th edition of *Webster's New Collegiate Dictionary*, an abridgement of the above Unabridged version, contains a briefer frontispiece section on pronunciation, on pp. 32-36. *The American Heritage Dictionary of the English Language*, 3rd edition, 1992, includes a frontispiece essay by Lee Pederson on “A Natural History of English”, pp. xv-xxiii, in which he discusses the evolution of dialects in American English and the pronunciation details involved. *The Random House Dictionary of the English Language*, 2nd edition, Unabridged, contains a lengthy, 3-page-

frontispiece essay on American English by ARTHUR BRONSTEIN. *Webster's New World Dictionary*, 2nd College edition, 1980, contains a lengthy frontispiece essay by Charlton Laird (pp. xv-xxx) including a section on American English dialects and dialect geography and on “pronunciation and the dictionary”.

Two other phonetic dictionaries (containing pronunciation data about American English) are authored by British lexicographers. J. Windsor Lewis' *The Concise Pronouncing Dictionary of British and American English*, London, 1972 enters British RP pronunciations and “recommended American pronunciations”. John C. Wells' *Longman's Pronunciation Dictionary*, 1990, includes RP pronunciations and “General American English” variants as well. Pronunciations in both these dictionaries are entered in the IPA alphabet.

We should make special mention of the first major dictionary in this country to assign a recognized academic phonetician to its editorial staff — the Second Unabridged Edition of *Webster's New International Dictionary* (1934) when JOHN S. KENYON of Hiram College, Ohio, joined its staff and wrote the extensive introductory essay on pronunciation for that edition. Similarly the *American College Dictionary*, published in 1947 by Random House and edited by Clarence Barnhart hired W. Cabell Greet of Columbia University to head a pronunciation staff of two other academic phoneticians for similar purposes. No major dictionary today would appear without access to such specialists on American pronunciation and usage.

Finally, the recently issued volumes of *The Dictionary of American Regional English* (which, at the time of writing this essay has issued three of its five planned volumes — Volume 1 was issued in 1985) contains an essay, in the first volume of the series by James Hartman, pp. xli-lxi, that discusses pronunciation variation and American English pronunciation history from the 17th century to the present. *DARE* uses IPA pronunciation symbols for its pronunciation entries. *DARE* does not include in the body of the dictionary pronunciations for words with little or no variation (e.g. “slap”), nor for entries with expected variations (e.g. words with postvocalic /r/) nor for entries for which the *DARE* database doesn't contain pronounced forms (e.g. “caballero”). But words like “bronchial”, “Carolina”, and “carry” are entered with regional variations, as pertinent. And there are discussions that note spelling or rare pronunciations, pronunciations used by older speakers, or those used by speakers with little formal education, where pertinent.

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A GUIDE TO THE HISTORY OF CLINICAL PHONETICS IN THE UNITED STATES

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INTRODUCTION

This article will address the organizational history of ASHA, prominent academic research and training programs, their cadres of clinical phoneticians, their academic lineage, and some broad lines of research. Clinical phoneticians study disordered speech using acoustic, physiologic and perceptual methods. Clinical phonetics has been informed by the instrumentation, experimental paradigms, data and theories of basic experimental phonetics (labeled "speech science" when the phonetician is trained in or works in a department of speech pathology, as expounded by FAIRBANKS and PETERSON, in Fairbanks (1966)). Many linguistically trained phoneticians and most speech scientists have engaged in both basic and clinical research. The preeminent consumers of clinical phonetic research are speech pathologists and audiologists who are members of the American Speech, Hearing and Language Association, a society which has 91,507¹ enrolled members (there may, in addition, be as many as 30-40,000 unaffiliated speech pathologists), of whom .007% or 640 members, claim that research is their major vocational preoccupation. ASHA's five refereed journals published 230 articles in 1996, making them the largest, but far from exclusive, source of clinical phonetic research.

Clinical phonetics is a relatively new discipline in the United States and like most health-related disciplines, has been strongly influenced by the socio-economic conditions in society. The decade of the 1920s saw speech pathology established with a largely female membership followed by the near demise of the discipline during the Great Depression. After the onset of the civil rights movement, women and minorities made a strong reappearance on the clinical phonetic research scene. World War II brought tens of thousands of casualties to military hospitals in need of speech and hearing rehabilitation and spurred research to justify treatment protocols (Wallace, 1954). Wounded veterans, the GI Bill, and the post-war economic boom prepared the way for a mass expansion of undergraduate and graduate programs in speech pathology. Federal mandates and rising tax revenues led to a demand for public school speech services that paralleled the demand for medical speech pathology services. The research scene bloomed as never before as Sputnik and the Eisenhower's era NDEA act and subsequent Kennedy-Johnson Great Society largesse to Federal health and research agencies led to lavish research and training support. After post Vietnam economic stringencies, Federal mandates for early education led to a boom in positions for school speech pathologists followed by present-day growth of medical speech pathology vocations to deal with aging populations. Thus, social-political imperatives have driven the expansion of clinical phonetic training and research.

¹ Personal communication, ASHA Offices of Membership and Publications.

The ultimate decentralization of clinical phonetic research from a handful of major comprehensive universities to many dozens of programs has been materially assisted by revolutionary development of computer hardware, software, and peripheral equipment devoted to sophisticated phonetic analysis.

ANTECEDENTS

After the turn of the Twentieth century, clinical phonetic research was desultory, primarily a European import. Klingbeil (1939) noted that clinical phonetic topics such as fluency, aphasia, articulation and vocal problems and their treatment were reported by Greek authors as early as the 5th century BCE. In the mid 19th century German and Austrian physicians such as Gutzmann, père et fils, Nadoleczny, Klencke, and Kuzzmaul were in the vanguard of clinical research and treatment of speech disorders, with English (e.g., Hunt and Bristowe) and French (e.g., Chervin and Guillaume) participants. American clinicians and scientists apprenticed themselves at European universities and clinics with such scholars. By the early 1920s, a cadre of European trained and influenced American professionals and amateurs such as ALEXANDER GRAHAM BELL, Elmer Kenyon, EDWARD SCRIPTURE, John Fletcher, Isadore Coriat, Carl Seashore and others were conducting training, therapy and research on speech disorders in the United States (see Paden, 1970, pp. 2).

Institutional support for speech pathology stirred with the hiring of speech pathologists by public schools: Chicago and Detroit in 1910, Boston, 1913, and with city-wide hiring in New York City and San Francisco in 1916 (Paden, *ibid*). Smiley Blanton opened the first speech clinic on a college campus at the University of Wisconsin in 1914, followed shortly by E. W. SCRIPTURE at Columbia and E. B. Twitmayer at the University of Pennsylvania, and the Speech Clinic at the University of Iowa. The Big Ten land grant universities were the first and remain the major bastion of speech pathology and clinical phonetics in the United States. The first Ph.D in speech pathology was granted to Sara Stinchfield in 1926 at Robert West's nascent training program at the University of Wisconsin.

Professionally organized speech pathology arose from a cadre of incipient speech pathologists and speech scientists who were members of the National Association of Teachers of Speech (NATS). They delivered several clinical papers on stuttering at the 1915 NATS convention (Paden, *ibid*), and commenced publication in the NATS house journal, *the Quarterly Journal of Speech*. Through 1921-1923, 23 papers were published on clinical topics including 7 on phonetics/phonology (Paden, *ibid*). In 1925, Carl Seashore, University of Iowa, Dean of the Graduate School, Chair of Psychology, director of the Speech Clinic, sometimes musician and general polymath (Seashore, 1942), created the first PhD program (in Psychology) with a

specialization in speech pathology under the direction of his protegee, the psychologist Lee Edward Travis (Moeller, 1975).

Although advanced degrees were granted at Iowa until 1956 under the rubric of psychology or speech and theater or medicine, the program was the first integral BA/MA/PHD program in speech pathology in the United States. Travis was an inspirational, wide-ranging scientist who crossed a half dozen disciplines and led a decade of exciting (Moeller, *ibid*), free wheeling seminars and dissertations which defined whole areas of research and practice in speech pathology and audiology.

At an early Iowa conference on speech research called by Seashore and Travis in 1925, Robert West, G. OSCAR RUSSELL, Smiley Blanton, James Muyskens, Lee Travis and others issued a call for a scholarly organization to propagate basic and clinical speech research. The call was heeded. Matters came to a head when eleven NATS members at the 1925 NATS convention drew up a provisional charter for a new American Academy of Speech Correction (AASC). In their charter, the six women and five men laid plans to "promote scientific, organized work in the field of speech correction." It is significant, given women's drive toward vocational freedom, that female professionals had a leading role in the genesis of the profession. The provisional charter mentions foreign accent, stuttering, and the phonetics of normal and disordered speech as prime areas for research (Paden, *ibid*). At the 1926 NATS meeting, 22 organizers wrote and adopted an official charter for AASC. The pedigree of the participants is significant. The three physicians included the future director of Central Institute for the Deaf, Max Goldstein, MD, and the director of Rush Presbyterian Medical School, Elmer Kenyon, MD. Four participants were professors of Spoken English at universities such as Smith and Mt. Holyoke, and included the well known Professor of American dialects and phonetics at Cornell, C. K. Thomas. Three were directors of schools for the deaf or speech clinics, four were professional speech pathologists, and two were directors of the first two PhD-granting programs with a specialization in Speech Pathology — Robert West of Wisconsin and Lee Travis of Iowa. The 6-point charter emphasized professional organization and leadership along with establishment of a firm research base as their primary objectives. NATS underwrote and supported the eventual breakaway of the group and held joint conventions with the American Speech and Hearing Association (ASHA) until 1951 (Paden, *ibid*). In fact, at Iowa, E.C. Mabee supported clinical phonetic work with the Department of Speech for several decades (Moeller, *ibid*), and warned about the peril to strong interdisciplinary roots when departmentalization arrived at Iowa in 1956.

These cross-disciplinary roots of the AASC have persisted throughout the 77 years of organized speech pathology and clinical phonetics with the eventual addition of theoretical linguistics, physics, anthropology, biology, computer science and engineering.

In 1927 the group changed their title to The American Society for the Study of Disorders of Speech. With the onset of the depression, the society faltered, dropping to 15 members in attendance at the 1929 NATS convention. Despite this, at the 1930 NATS meeting, 18 members attended the society's first scientific symposium (on stuttering), the results of which were sold under the title, "Proceedings of the American Speech Correction Association" (Paden, *ibid*). The first scientific publication of the society, the *Journal of Speech Disorders*, was

inaugurated in 1937 under the editorship of G. OSCAR RUSSELL, a clinical phonetician at Ohio State University. For five years he patiently built a readership single handedly, appointing an exclusively European editorial staff, and focusing on European research to the chagrin of domestic scientists. In 1942, the by then renowned Iowa expert on dysfluency, Wendell Johnson, assumed editorship for 6 years, turning published research toward available domestic scientists, and toward more clinically oriented research. This trend shifted yet again when the psychologist and clinical phonetician, GRANT FAIRBANKS, assumed the editorship, 1947-1956. He introduced irreversible statistical, mathematical and linguistic rigor into the editorial process, and passed the editorship on to GORDON PETERSON, a student of GILES GRAY of the LSU Department of Speech. Peterson was subsequently a Bell Labs phonetician and director of the Communication Science Research Laboratory at the University Michigan, who completed the process of introducing rigorous phonetic, linguistic and psychological methodology and theories as key ingredients for clinical research in speech pathology. Subsequent splits into a *Journal of Speech and Hearing Research* and *Journal of Speech Disorders* ultimately led to creation of five edited ASHA journals being published today as major venues for clinical research, much of it phonetic in nature. Other popular domestic venues for clinical phonetics are the *Journal of Communication Disorders*, the *Journal of the Acoustical Society of America*, and the *Journal of Fluency Disorders* as well as *Ear and Hearing* and a half dozen other audiological journals.

FOUNDERS AND UNIVERSITY DYNASTIES

Stetson; Russell

Scientific disciplines have founders and dynastic research institutions; clinical phonetics-speech pathology is no exception. Some of the scientists to be discussed performed normative, developmental and theoretical studies of verbal communication, other performed clinical phonetic research, and many others, both.

In the late 1920s and 1930s, R. H. STETSON at Oberlin, G. OSCAR RUSSELL at Ohio State, and Lee Travis and Carl Seashore at Iowa were trailblazers. Russell used x-ray techniques to chart normal and disordered articulation including labial, lingual and velar articulation in normal and cleft palate subjects. Stetson (1928/1951) used methods pioneered by L'Abbé Rousselot in France to study breathing, vocal, and articulatory dynamics, deriving a theory of the respiratory/articulatory syllable as the basic unit of articulatory and vocal motor coordination and production. Commencing in the late 1920s, for more than three decades, Harvey Fletcher directed a speech research unit at Bell Laboratories responsible for publishing benchmark studies in acoustic phonetics including descriptive acoustics, perception, and psychoacoustics of speech and nonspeech signals. He and his scientists and successors — Potter, Kopp, Green, Crandall, Dunn, PETERSON, Flanagan, RABINER, Atal, et al. inspired clinical phonetic research based upon their work. Fletcher's early and influential normative data and his experimental paradigms are well summarized in various editions of his book (Fletcher, 1929).

The Iowa orbit: Iowa, Illinois, Wisconsin, Washington

At Iowa, Dean Seashore, and his director of the Speech Pathology subprogram and clinic, Lee Travis, and their newly minted graduates, GRANT FAIRBANKS and Wendell Johnson,

trained dozens of PhDs, in the 30s and early 40s. Laryngography, acoustic analysis, electromyography, voice disorders, stuttering, articulation disorders, handedness, encephalography, professional voice, language impairment, audiology, etc. were explored in a great creative outburst of clinical phonetic research. Dozens of dissertations with clinical phonetic roots were launched. After Travis's departure before the war, Fairbanks and Johnson trained a group of major pathologists cum clinical phoneticians in the 1939-1945 period — among the most notable were Frederick Darley (neuromotor disorders, articulation), James F. Curtis (acoustic phonetics), and Duane Spriestersbach (cleft palate speech) who became Iowa faculty upon graduation. Early, distinguished graduates such as Mack Steer, Robert Milisen, JOHN BLACK, Charles Van Riper and dozens of others joined or founded other important university programs.

Many phoneticians (FAIRBANKS, Curtis, Spriestersbach, BLACK, Steer and others) were drafted into the armed forces during WWII, participating in basic and clinical phonetic and psychoacoustic research at DOD labs (like Harvard's Psychoacoustic Labs) or at military bases such as Pensacola, Waco, San Diego, or in VA hospitals. Their efforts led to establishment of speech and hearing clinics in most post-war VA hospitals. An important cadre of VA research phoneticians such as Thomas Shipp, Tom Murray, Kryztof Iszdebski, James Till, Leonard LaPointe, Jay Rosenbeck, Robert Wertz, Bruce Gerratt, and others produced an abundance of important clinical phonetic research. This was paralleled by establishment of NIH laboratories dedicated to speech research in the 1970s which include phonetic scientists such as Christy Ludlow, Maureen Stone, Barbara Sonies, Sheila Stager and others.

In the postwar period, Mack Steer (Purdue), JOHN BLACK (Ohio State), GRANT FAIRBANKS (Illinois), and Wendell Johnson, James Curtis (Iowa) oversaw burgeoning research programs. At the University of Iowa, Johnson and Curtis trained and then hired Frederick Darley, Duane Spriestersbach, Dorothy Sherman, KENNETH MOLL, James Hardy, and Hughlett Morris, who in turn and in various combinations trained William Tiffany, Harris Winitz, Harry Hollien, FRED MINIFIE, Robert McGlone, James Lubker, Harry Cooker, Ron Netsell, Sumiko Sasanuma, Thomas Hixon, Thomas Shriner, Raymond Daniloff, RAYMOND KENT, Dave Kuehn, Ehud Yairi and dozens of other scientists who would publish important clinical phonetic work. Of particular clinical phonetic importance were the x-ray motion picture studies of KENNETH MOLL and his students which set internationally influential standards for the investigation of articulatory dynamics. The Iowa group was immensely strengthened by collaborative training and research with the Departments of Otolaryngology/Maxillofacial surgery and Neurology. To the present day with the work of John Folkins, Gerald Moon, Bruce Tomblin and the trailblazing laryngeal modeling research of Ingo Titze, Iowa remains a strong presence in basic and clinical phonetic research.

A second training program which for a time rivaled Iowa in quality was instituted at the University of Illinois by GRANT FAIRBANKS, 1948-1965, a proponent of a servo theory of speech production, an investigator who produced detailed studies of phonetic space for vowels and diphthongs, an originator of time and frequency compressed speech and various vocoding schemes so on. His phonetics research program attracted considerable student talent, most of whom became clinical phoneticians, and

many of whose dissertations were outstanding. They included Tony Holbrook, Murray Miron, Newman Guttman, Mary Mann, Dorothy Huntington, Robert Brubaker, Arthur House, Patti Grubb, etc., students of both psychology and speech pathology. Fairbanks collaborated with electrical engineering (Everett, Jaeger) in developing and explaining time and frequency compression of speech, and influenced the outstanding psycholinguist, Charles Osgood, his students and others in linguistics (Wallace, 1954). Fairbanks had just assumed a position at Stanford Research Institute's program in speech research in 1965 when he perished accidentally. Fairbanks had a subtle but powerful influence on the future of American clinical phonetics through his training of the initial Iowa cadre of scientists (Curtis, Darley, Spriestersbach and many others) and later, at Illinois, many other scientists, including Arthur House, who became a research associate of KENNETH STEVENS at MIT and later professor at Purdue. He advocated experimental and theoretical rigor, using paradigms from all ancillary sciences with an ease and freedom, much as his confrere, GORDON PETERSON would do at Michigan and Santa Barbara (before his equally untimely death) with the assistance of faculty such as June Shoup, ILSE LEHISTE, David Broad, Steve Davis and others. Fairbank's clinical phonetic research was carried forward at Illinois by Lee Hultzen, Willard Zemlin, John Locke, Ray Daniloff, Thomas Shriner, Frank Silverman and later by Peter Alfonso, David Kuehn and Ehud Yairi. The earlier group trained such active researchers as Robert Mason, Daniel Beasley, James Amerman, Gordon Schuckers, Tanya Gallagher and others.

At Wisconsin, in the mid 1960s, FREDERICK MINIFIE and David Yoder along with Thomas Hixon, Ronald Netsell, James Abbs and later Jesse Kennedy, Eric Mueller, RAYMOND KENT and Gary Weismer established a powerful clinical phonetics research program which garnered substantial grant support through the Waisman Center for almost two decades, while training dozens of important clinical phoneticians such as Gary Weismer, Steve Barlow, Vince and Carol Gracco, Susan Shaiman, etc. Ray Kent is perhaps the single most prolific and influential single clinical phonetician at work today. Minifie later replaced the phonetician Theodore Hanley at the University of Washington, and established an extremely active clinical phonetics research program there. It would graduate, employ, or influence phoneticians such as Jesse Kennedy, J. W. Folkins, Carole Stoel-Gammon, and the extremely prolific and important clinical phoneticians/phonologists, Patricia Kuhl, Kim and Rebecca Oller, and Jim Hillenbrand whose subsequent work with language and speech development has been profoundly influential.

Outside the Iowa orbit

Outside the powerful Iowa-Wisconsin-Illinois orbit, after the war, Northwestern University mounted an impressive Ph.D program which would employ G. Paul Moore, a protean voice/phonetic, scientist/pathologist, Gerald Canter, a phonetically inclined aphasiologist, and Hilda Fisher, a phonetician of some repute, and later, as a psychoacoustician, Lois Elliott and the speech scientist, Bruce Smith, who have done excellent clinical phonetic work in timing and perception. In the early 1960s, Moore joined Harry Hollien at the University of Florida, establishing a superior training program in clinical-vocal phonetics, numbering Bud Wendahl, Samuel Brown, Howard Rothman, Doug Childers, Bob McGlone, James Flege, and Patti Hollien among its research-

productive faculty and graduates. At the University of Michigan Don Sharf and students of his such as Ralph Ohde and Tom Hemeyer produced a considerable body of meritorious clinical phonetics. At Southern Illinois University, Herbert Koepp-Baker, Martin Schultz, and Dennis Molfese have published widely in anatomy, acoustics, evoked potentials, etc. in a clinical phonetic framework.

Mention must be made of JOHN BLACK's, 1950-1970s, powerful graduate training program at Ohio State University. This indefatigable scientist trained dozens of clinical-phonetically influenced graduates such as Sadanand Singh, Bruce Mahaffey, Arthur Compton, Oscar Tosi, Robert Peters, Yukio Takefuta, Tom Murray, Courtney Stromsta, Don Morehead and many others in his rigorous research-oriented training program. Later on, Robert Fox, OSAMU FUJIMURA, Mary Beckman and ILSE LEHISTE published much important basic and applied phonetic research.

At the University of Minnesota, Clark Starr, Gerald Siegel, Charles Speaks, Diane VanTassell and nearby at Mayo Clinic, Frederick Darley and Arnold Aaronson produced an abundance of important clinical phonetic research. At the Indiana University, Martin Schultz, Gary Weismer, Mary Elbert, Dan Dinnsen, Judith Gierut, Gordon Schuckers, Robert and Diane Kewley Port and David Pisoni produced several decades of highest quality basic and clinic phonetic research, training clinical phoneticians such as Paul Hoffman and Elaine Stathopoulos, and Tom Powell. Purdue's long standing chair and departmental founder, Mack Steer, returned from the armed forces, and set about reproducing the Iowa program at Purdue. With the hiring of Arthur House, the presence of George Hughes (MIT-RLE) and a number of speech researchers in electrical engineering such as Kung Sung Fu, numerous clinical phoneticians were trained such as: Robert Ringel (later chair after Steer), L. Jay Platt, Norman Lass, Brian Walden, Robert Prosek, Alan Montgomery, Irene Stephens, John Saxman, Andy Leeper, Yoshiyuki Horii, and many others. Later phoneticians such as Ray Daniloff, George Allen, Rachel Stark, Ann Smith and Robert Ringel have trained graduates such as Peter Alfonso, Akira Hasegawa, Charles Healey, Lori Ramig, Kim Wilcox, Joan Sussman, Dennis McFarland, and many others with strong records of accomplishment in clinical phonetics. Finally, Kathy Harris and HARRY LEVITT and others have operated a strong graduate training program focused upon basic and clinical phonetics at the City University of New York-Graduate Center. As the single most widely published phonetician in the area of basic phonetic theory and a clinical phonetician, Harris rivals RAYMOND KENT in stature and has mentored one of the largest cadres of Ph.D. trainees in phonetics as well. Some of the alumni of the program are listed in the section on Haskins Laboratories.

Clinical phonetics in smaller, more recent programs

Smaller programs hosted such important phoneticians as: DONALD WARREN and his elegant aerodynamic research at the University of North Carolina; Randall Monson's elegant acoustic and perceptual analyses of deaf speech at the Central Institute for the Deaf; Harris Winitz's pioneering speech perception and child phonology work at the University of Missouri-Kansas City with the assistance of Conrad LaRiviere; William Diehl, Ralph Shelton and lately Kim Wilcox's noteworthy research into the phonetics of disordered articulation at the University of Kansas/University of Kansas Medical Center program; Sandra

Hamlet's substantial body of work on somatosensory factors in articulatory control at Maryland and Wayne State; Harvey Sussman and PETER MACNEILAGE's research efforts at the University of Texas include decades of highest quality, basic and clinical phonetic research which has had major influence on current theories of language development and perception; Robert Orlikoff and Joel Kahane's physiological-anatomical work at the University of Memphis; at Columbia, Ronald Baken's pursuit of a long course of interesting clinical phonetic research related to breathing, voice and articulation; At Syracuse-Upstate Medical Center, Ray Colton, Janina Casper, and John Saxman's publication of a wide variety of clinical phonetic work, primarily physiological in nature; Robert Hillman's strong program of clinical phonetic research on voice at Boston University; at the Medical College of New Jersey, Paula Tallal has generated exciting new clinical phonetic and neurophysiological accounts of disordered speech perception and rehabilitation with the collaboration of Michael Merzenich of UCSF Medical School; Kim and Rebecca Oller at the University of Miami Mailman Center produced decades of distinguished clinical phonetic and phonological research on disordered and normal development; at the University of Connecticut, Harry Cooker and subsequently Peter Alfonso trained clinical phoneticians of note, including in particular, Ben Watson and Joseph Kalinowski, who have produced important work in stuttering; during a 40 year career at Penn State, Eugene McDonald published widely on misarticulated speech and was followed by the able phoneticians Robert Prosek and Deborah Rekart. James Lubker, an extremely able phonetician worked both at Iowa with MOLL and in Sweden with workers such as Lindblom and Fritzell, producing truly distinguished clinical phonetic work for decades before returning to the University of Vermont.

More recent programs and laboratories

A number of smaller and newer programs have developed which have also produced influential basic and clinical phonetic research. Among them is Brown University which for a period in the 70s-early 90s produced a barrage of interesting studies of normal and disordered phonetics under the tutelage of SHEILA BLUMSTEIN and Philip Lieberman. Active phoneticians produced there include Shari Baum, Aditi Lahiri, and William Katz. Similarly, Samuel Fletcher, Marvin McCutcheon and James Flege established a powerful clinical and basic/applied phonetics research program at the University of Alabama Medical Center which has explored palatography, deaf speech, developmental speech and second language phonetic learning. Similarly, Thomas Hixon created a phonetic research program at Arizona which now is part of a neurosciences institute (largely through his inspiration), which has trained dozens of pre and post doctoral students in the areas of normal and clinical respiration, voice, singing and phonetics. The department also profited from the contributions of Ralph Shelton to research efforts in clinical phonetics. JAMES PICKETT established a research program in phonetics at Gallaudet University specialized in the acoustics of deaf speech and speech prosthetics which has grown and prospered with Sally Revoile and James Mahshie. Under the leadership of James Gould, Ingo Titze and Ronald Scherer, the National Center for Voice and Speech at the Denver Center for the Performing Arts in Denver has become a center of excellence in vocal dynamics and pathological conditions of voice and allied

articulation with such workers as Titze, Scherer, Lorraine Ramig, visiting scientists and pre/post doctoral students, and faculty at Iowa, Utah and Wisconsin-Madison. Similarly, the Boystown Institute for the study of speech and hearing has functioned as an important center for clinical phonetic research using both in-house, visiting, postdoctoral and other young phonetic scientists.

Three centers of theoretical influence on clinical research

Three laboratories have provided more than forty years of strong theoretical influences upon clinical phonetics as well as some direct research in the area: 1) MIT-Research Laboratories of Electronics, KENNETH STEVENS presiding; 2) UCLA Phonetics Laboratory — led by PETER LADEFOGED; and 3) Haskins Laboratories — led principally by FRANKLIN COOPER, Katherine Harris and MICHAEL STUDDERT-KENNEDY. Haskins Laboratories exerted immense influence by defining entire theoretical methodologies and measurement systems, and generating dozens of theoretical claims and models as they explored the structure of speech perception and production, both normal and disordered. Theories such as motor theory, modular phonetic perception, parallel processing for speech production, tier models of articulatory coordination, accounts of coproduction and coarticulation etc. have permeated clinical phonetics and set paradigms and research goals for many decades. Katherine Harris was especially influential in clinical research. The list of house scientists and trainees at Haskins is stupendous: Franklin Cooper, AL LIBERMAN, Kathy Harris, Phil Lieberman, MICHAEL STUDDERT-KENNEDY, Larry Raphael, Gloria Borden, Mike Dorman, Frederika Bell-Berti, Thomas Baer, BRUNO REPP, Louis Goldstein, Betty Tuller, Jim Hirose, Minoru Hirano, Frances Freeman, Emily Toby, Susan Nittrouer, Peter Alfonso, Thomas Gay, Vince and Carole Gracco, Elliott Saltzman and many dozens of others — truly, it is the crossroads of phonetic research, as influential through its graduates and scientists as any major union or guild.

The MIT group under KENNETH STEVENS began work in the 1950s with Arthur House and later, DENNIS KLATT as collaborator(s). The lab systematically explored the acoustic theory of speech production as well as acoustic structure of vowels, consonants, and syllables in a series of publications of profound importance for theories of speech production and perception and distinctive features; later the laboratory added physiological studies of articulation undertaken with Joseph Perkell. Among the important coworkers in this engineering and acoustics based laboratory were Dennis Klatt, Victor Zue, William Cooper, Thomas Baer, Stefanie Shattuck-Hufnagel, Mario Svirsky, Christine Shadle, and dozens of others. The laboratory began its decades-long exploration of distinctive features, phonetic space, and quantal theory under the influence of theories enunciated by eminent MIT faculty and visiting fellows: Gunnar Fant, ROMAN JAKOBSON, MORRIS HALLE, (cf. their monograph: *Preliminaries to Speech Analysis: The Distinctive Features and Their Correlates*), Noam Chomsky and Morris Halle, (authors of *The Sound Pattern of English*), and Gunnar Fant, (author of *Acoustic Theory of Speech Production*). The MIT auditory research hearing group also began to do clinical phonetic work in conjunction with research on clear speech. It is difficult to underestimate the theoretical and practical influence of this group, which has recently offered

postdoctoral training to many speech pathologists and audiologists.

From a phonetic standpoint, beginning with his earliest work on breathing, perhaps no single investigator has more crucially influenced phonetic theory in all aspects, and few have produced as much empirical data, trained as many linguistic phoneticians and linguists who have to a greater or lesser degree performed clinical phonetic research, than PETER LADEFOGED — who led the UCLA Phonetics laboratory for more than 30 years. Graduates and colleagues include VICKI FROMKIN, Ralph Vanderslice, JOHN OHALA, Harry Whitaker, PATRICIA KEATING, Theo Venneman, Ian Maddieson et al. The laboratory's impact on clinical linguistics has been enormous, provoking numerous tests of claims and extensions of work in all areas of phonetics to clinical populations.

CONCLUSIONS

Currently, even greater dispersion of clinical phonetics is well underway; clinical phonetic research is being performed by psychologists, linguists, educators, engineers, medical personnel, computer scientists and many others for a multitude of reasons, one of which is using pathological phonetic performance to inform and criticize normal research and theory. A second is that speech and language are windows into developing theories of mind and of brain function. New techniques such as neuro-imaging, refinements in cognitive psychology and its methodology, neural network theories, advances in neuroanatomical and neuropharmacological techniques, and biology have spread speech research into domains unforeseen a half dozen years ago. Furthermore, speech recognition and low-bit synthesis schemes as well as near real-time transcription and translation of speech and vocoding and low-bit telecommunications have led to an explosion of commercial research across the world and bids fair to preempt much basic and applied phonetic work in conventional academic settings. Another driving factor has been the dramatic increase in longevity, and in many cases, healthy longevity, so that geriatric communication disorders have come to the fore; similarly, neuroscience research has demonstrated that developing brains and aging developed brains both fare poorly when normal language usage is handicapped. It is unfortunate that clinical phonetics offers few areas of research as profitable as let us say, genetics or neuropharmacology, or we would otherwise find that the market would drive research forward much more rapidly. Presently, basic and clinical phonetic research in Europe and Japan have drawn abreast of and surpassed domestic research in certain areas. One can anticipate an international school of clinical phonetics in the 21st century as embodied in the International Society for Phonetic Sciences, The Association for Clinical Phonetics and Linguistics, and the International Association for Logopedics and Phoniatrics. Let us hope so, because truly humane treatment of communication disorders must be early, immediate and effective to rehabilitate spoken language, the crown jewel of human social behavior.

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FIELD PHONETICS IN AMERICA

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The indigenous languages of America were studied from the first European contact, first by the explorers, conquerors and early settlers. They wrote as best they could the indigenous peoples' words for the plants, animals and cultural items that were new to the Europeans. The next group to try their hand at such transcriptions of were the missionaries and priests, who settled among the Native Americans to preach the gospel, and teach Western ways. But it is primarily beginning in the 19th century that the languages began to be studied purely for the sake of linguistic science. [See JOHN ELIOT, THOMAS JEFFERSON, JOHN PICKERING, PETER DU PONCEAU, EZRA STILES, ROGER WILLIAMS.] The tremendous linguistic diversity of the New World posed a great challenge to linguists, who had the tasks, first, of determining linguistic relationships in this complex situation, and discovering if there were any relationships between these and languages elsewhere in the world, and then of documenting their structures, so very different from the languages of Europe. Linguists "went to the field" to work with the speakers of American Indian languages. And a first step for any scholar going to the field to study languages was to write down the sounds with accuracy.

The early scholars mentioned above — those involved in exploration, religious expansion, and education — had attempted various solutions to the problem of transcription. Most frequently, attempts were made to transcribe languages using the writing system and spelling rules of Spanish or English or French. Since Spanish has a spelling system that is fairly close to the phonetic rule of "one symbol, one sound", it was not all that difficult to develop writing systems for the languages of Hispanic America, though certainly the history of phonetic writing for Meso-American and South American languages had its pitfalls. But in North America, the spelling rules of English were and are so complicated that most transcriptions based on English spelling are highly inadequate. French orthography also did not lend itself well to phonetic spelling.

When linguistic scholarship began to focus on the American languages, phonetic systems for transcribing them abounded. Each scholar developed his own system for phonetic transcription, usually based on some system learned in Europe, modified and expanded for transcribing the very non-European sounds that were prevalent in the indigenous languages of America. Only rarely did the early scholars develop transcription systems that faithfully represented all the distinctions present in the Native American languages they studied. A number of 19th century transcription systems (as well as later transcriptions by linguistically-untrained scholars) use English spelling rules. For example, post-vocalic 'r' was written as an indicator of vowel quality, by scholars from the East Coast who had r-less dialects. Thus, the Havasupai root for "water", phonetically [hɑ], would be rendered 'har' (Hinton, 1998).

The first person who had the power that it took to begin to unify the phonetic writing systems for Native American languages was John Wesley Powell, the talented geologist, explorer, anthropologist and linguist who became the director of two important government organizations: the Bureau of Ethnology and the Geological Survey. The eastern languages of the US were relatively well documented when Powell began to gather linguistic information, but the West was still new to our country, having been purchased or won through war in the 19th century. Powell took on the task of determining the linguistic classification of the American languages. To do so, he collected everything he could of previous documentation, but beyond that, he provided linguistic training to anyone going into the field in the west. He trained the military personnel that headed west in great numbers to manage the Indians who were being disenfranchised by the westward movement of the United States. Geologists and naturalists going to the field to study natural history were also given training in phonetic transcription, as were, sometimes, their wives. Thus the Powell system of transcription became the first wide-spread orthography in field phonetics in America, and vast numbers of extensive word lists were collected during the Powell era.

Powell attempted to produce a linguistic classification of New World languages and so was primarily interested in word lists which would provide the basis for their comparative study. While the good rendering of phonetic distinctions was valuable, even a rough transcription could be well utilized for classification purposes so long as it could be more or less accurately interpreted. The Powell system was lacking in a few important symbols — it had no way to distinguish uvulars from velars, for example (the symbol 'q' was used to stand for a velar fricative, not a uvular stop); nor did it have a symbol for glottal stop. The next generation of scholars, such as FRANZ BOAS and his student EDWARD SAPIR, were interested in much more intensive study of the languages themselves, even though classification remained of great interest as well. The linguists of the early 20th century wanted to do accurate and detailed phonetic transcription in order to represent truly the sounds of American Indian languages. Rich documentation of linguistic structure and oral literature was also considered of great importance. Many thousands of pages of mythology and ethnographic texts were transcribed phonetically and translated. Phonetic transcription became a fine art: having a "good ear", capable of noting fine phonetic distinctions, was valuable, and being able to write both clearly and speedily was essential in the transcription of texts. As it was, linguistic informants had to be trained to tell a story slowly, one sentence at a time, so that the linguist could take it down; but being asked for frequent repetition would disrupt the telling, and so a linguist needed to have a sharp ear and an excellent short term memory. The normal method of transcribing a text was to have the speaker tell it in the Indian language while the linguist wrote it; then the

linguist would read it back a sentence at a time and ask for a translation and explanation. Therefore, the linguist also had to have a good ability to pronounce the phonetic transcription of unfamiliar languages well. The two linguists most noted for their great abilities at accurate transcription in the field were EDWARD SAPIR and J. P. Harrington. Another great linguist, A. L. KROEBER, was not such a great phonetician as the other two (being partially deaf in one ear), and in fact did not see great value in narrow transcription, as shown by a critique he wrote once of Harrington's phonetics:

He is as keen and well informed on the subject as anyone in the country, but perhaps because he is a young man has shown a riotous inclination to indulge in the expressions of fine shades of sounds in the symbols used for them. (Letter to Edward Sapir, Jan. 6, 1913; Golla, 1984: 76).

Powell's system was inadequate in many ways, and also out of step with systems being developed in Europe. As his power over the field waned, linguists continued to use disparate systems of their own or of their teachers. In 1912, EDWARD SAPIR wrote to ALFRED KROEBER:

I have been instrumental in having a committee appointed at the Cleveland meeting of the AAA [American Anthropological Association] which is intended to propose a new practical system for phonetic rendering of Indian languages. Chairman: Boas; other members: you, J. P. Harrington, Goddard, and myself. ... This system, which should be adequate, yet not cumbrous, would naturally try, where possible, to adhere to what may be considered general consistent usage in America, and should also aim, at least in part, to approximate current European usage. ... Powell's system to be definitely abandoned. (Golla, 1984: 72).

KROEBER's criticism of Harrington cited above was in response to Sapir's letter. The committee, ultimately without the membership of Harrington, met several times at the meetings of the American Anthropological Association and drew up recommendations for "Phonetic Transcription of Indian Languages" (Sapir et al, 1915). Citing the different needs of the "specialist who wishes to analyze and discuss the sounds of a language" vs. the necessity of a relatively simple system for the use of students without thorough phonetic training, and for the recording and printing of large bodies of texts, the committee recommended two systems, one "simpler" and one "more complete" (now usually known as "broad" and "narrow" systems of transcription). The main goal was to create a unified system, but the committee made many compromises. They recommended that "where a uniform and fairly adequate system has already been employed in the recording of a particular language, it will usually be best to continue its use in further work with that language to avoid confusion". The final recommendations changed some of Powell's less popular symbols (for example, for the interdental fricative, the AAA recommendations replaced Powell's [ç] with [θ], and Powell's

[q] with [x]), and added symbols that had been developed for sounds the Powell system did not distinguish.

Vowels were one of the big problems: beyond the five vowels of the Roman alphabet, there was a debate around whether to use diacritics or special characters for other vowel sounds. The committee recommended the use of Greek characters, but also said: "since these are not always available and present other difficulties in their use, Roman characters with a diacritical mark above the letter ... may also be used". (SAPIR et al, 1915, p. 2.)

As SAPIR and his students refined the developing methodology of phonemic analysis, they developed new ideas about orthography and how it related to the analysis (Goddard, 1996, p. 49). So a new set of recommendations were created by a self-constituted committee consisting of Sapir and prominent members of the next generation of linguists — George Herzog, Stanley Newman, Mary Haas, Morris Swadesh, and Charles F. Voegelin (Herzog et al, 1934). All these linguists were together at Yale University at the time. The recommendations of this committee brought phonetic practices to the approximate system used commonly today by people studying American Indian languages. BOAS himself was opposed to the changes instituted in the second set of recommendations, because he believed that phonemic transcription would result in too much loss of phonetic information. Certainly even today, good field practice is to write phonetically in the field, and introduce phonemic writing only in subsequent analyses.

The various scholarly traditions and attempts at unification described above represent the development of the "Americanist system" of phonetic transcription. It is interesting to question why the International Phonetic Alphabet, first developed in 1886, was paid so little attention during these deliberations about Americanist transcription. It is clear that although European scholarship played an important role in the education and phonetic preferences of American scholars, America was nevertheless on a separate path. The SAPIR recommendations, which attempted to bring phonetic transcription closer to European usage, were nevertheless bound in part by long previous scholarship in an Americanist tradition. The IPA, in any case, did not have the prominence in the early days that it does now. Still, at least a few of the changes wrought by the two committees definitely brought Americanist usage closer to the IPA. For example, the first committee introduced [θ] to the Americanist alphabet, and the later committee introduced the glottal-stop symbol [ʔ] used also by the IPA. On the other hand, with regard to the transcription of affricates, the second committee actually took the Americanist system further away from the IPA, by using single letters with diacritics, rather than digraphs. The Americanists who developed the final orthographic recommendations had actually consciously pitted themselves against the IPA in how affricates should be analyzed. Sapir and his students believed that affricates needed to be analyzed phonemically as single segments, [č], [j]. The IPA represents them as two segments (a stop plus a fricative) [tʃ], [dʒ], respectively. It is in keeping with the principle of phonemic analysis that Sapir and his students decided to use the Americanist single-symbol transcription of affricates instead of the IPA-style digraphs. The use of symbols with diacritics for the

affricates also goes against the IPA, which prefers the Greek symbols instead. I believe it is the result of this dispute between the Americanists and IPA that led to the IPA's development of ligature forms of affricate digraphs. I still remember Mary Haas telling me that she prefers using the Americanist system over IPA because the IPA has too many shortcomings, and she cited the representation of affricates as an example.

The Americanist tradition of phonetic transcription has had no real governing body. The two committees described above were voluntary and temporary. The IPA, on the other hand, had an association formed around it at the outset, and has been overseen for over a hundred years now by a governing body that meets regularly. Thus the Americanist tradition has remained without real unity, and changes not by consensus but by individual choice. Almost any linguist using the Americanist system probably uses a few symbols that differ from usage by others also claiming to use the Americanist system. Perhaps largely due to this lack of governance, the Americanist orthography has slowly assimilated to the IPA over the years, so that there are now fewer than a dozen common symbols used by present day Americanists that are really different from the IPA. The main distinction between the two systems is that while the IPA eschews the use of diacritics and prefers using Greek symbols or other single-component letters, the Americanist tradition uses diacritics fairly liberally. Interestingly, for one sound IPA has adopted the Americanist usage: in 1989 the symbol [ɔ] was replaced by [u]. The main symbols that differ between the two systems are these:

AMERICANIST	IPA
λ	ḏ
λ̃	ḏ̃
k ^y	c
g ^y	j
c	ts
č	tʃ, c
ʒ	dʒ
ž, ĵ	dʒ̃
ü	y
y	j

Table 1. Main differences between the Americanist and IPA transcriptions.

While most Americanist introductory textbooks in linguistics still use the Americanist system, the IPA has been gaining ground. Transcription of data in actual fieldwork is less

central to linguistic training than it used to be, and intensive training in transcription as preparation for fieldwork is available in fewer programs. Laboratory phonetics is now the dominant phonetic training for students, and laboratory phonetics brings with it the IPA traditions. Phoneticians such as PETER LADEFOGED, J. C. CATFORD, and JOHN OHALA lobby for universal use of the IPA, and more and more graduate students in America are trained to use the IPA instead of the Americanist system. The field notes of students trained in the 80's and 90's often display IPA symbols in place of Americanist symbols. Nevertheless, the Americanist system is still solid in American Indian linguistics. For example, the recent volume on *Languages of the Handbook of North American Indians* (Goddard, 1996), designed to be a major reference on the study of Native American languages, still uses the Americanist system.

Lest the reader is led to believe that the slow convergence between IPA and the Americanist system means field phonetics might finally be on its way to unification, another wrinkle is leading to increasing diversification in transcription systems. The Native Americans themselves have a very different attitude now toward linguistic work done in their communities than they did in previous generations. A growing movement toward language revitalization is in progress, and linguists wanting to work with Native Americans often find that if they want entry into the community, they must give back to the community with linguistic projects of use to the Indians themselves. We see, then, the flowering of practical alphabets in American Indian communities, usually designed with consultation with linguists. Where both the IPA and the Americanist systems use special symbols, and where the Americanist system uses diacritics, the practical systems aim toward digraphs and typeable or computer-friendly symbols. Thus 'ch' and 'sh' are often used instead of either the Americanist or IPA version; long vowels are written as double vowels or with a colon rather than a raised period. Much linguistic work, including the fieldwork itself as well as the later development of articles and teaching materials, is now written using these practical alphabets. The *Handbook*, for example, while preferring scholarly systems in general, concedes to Navajo practice by using the Navajo practical orthography.

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A BRIEF HISTORY OF SPEECH PERCEPTION RESEARCH IN THE UNITED STATES

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INTRODUCTION

A hundred and fifty years ago, Alexander Melville Bell (1849) prefigured an insight that has come to shape research on speech perception only in recent decades: There is a powerful link between the way we perceive speech and the way we produce it. Bell's system of transcription, his "visible speech" (Bell 1867), reportedly allowed speakers who knew the system to reproduce exactly any utterance not only in languages they knew, but in languages they did not. Thus, by the intermediary of a phonetic script, Bell unfolded the imitative capacity implicit in every untutored child who automatically recovers from speech the articulatory gestures that shape it, and so learns to speak a native language.

Yet, curiously, modern studies of speech perception and speech production have generally followed separate paths at laboratories where only one or the other topic was of interest. Only quite recently have researchers begun to argue that a viable theory of speech perception must be grounded in a viable theory of speech production, and vice versa. The reaction to this stance, either for or against, defines much of the field of speech perception today.

EARLY WORK

Telephonic Communication

Early work, in the years after World War II, was largely guided by the demands of telephonic communication. Its aim was to estimate how much distortion (by frequency-bandwidth compression, amplitude peak-clipping, filtering, noise, and so on) could be imposed on the speech signal without seriously reducing its intelligibility (for a review, see Miller, 1951). Three general conclusions were surprising and important. First, speech is so resistant to distortion that we can throw away large parts of the signal without seriously reducing its intelligibility. Second, intelligibility does not depend on naturalness. These first two facts have enabled us to learn a great deal about the important information-bearing elements of speech by stripping it to its minimal acoustic skeleton.

A third conclusion, confirmed in many later studies, was that when speech perception breaks down in noise, it tends to do so along the dimension, or features, of traditional articulatory phonetics. English consonants, for example, are more likely to be confused within than across manner (stop, fricative, nasal) and voicing classes (Miller and Nicely, 1955). By corollary, place of articulation is the feature most susceptible to damage by noise; fortunately for the hearing-impaired, it is also the feature most easily seen on a talker's lips.

The Sound Spectrograph

Study of the auditory bases for articulatory perception became possible with the development of the sound spectrograph at Bell Laboratories during World War II (Koenig, Dunn, and Lacy 1946). The spectrograph provided a visual record not of the physical signal as it impinges on the ear, but of its time-varying Fourier transform as it is assumed to be represented at the output of the cochlea. Strictly, then, the representation is auditory (psychological), not acoustic (physical), and it was originally hoped that the spectrograph would enable deaf persons to use the telephone (Potter, Kopp, and Green 1947); but this proved impracticable because spectrograms are formidably difficult to read.

The difficulty arises from the astonishing variability of the speech signal, both within and among speakers. JOOS (1948), in a monograph still well worth reading, first described the variability. But experimental investigation awaited development of the Pattern Playback at Haskins Laboratories in New York.

The Pattern Playback

The playback reconverted the visual pattern of a spectrogram into a speech sound sequence with a constant fundamental frequency (COOPER 1950; Cooper, LIBERMAN, and Borst 1951). Experimenters laid a transparent acetate loop over a spectrogram and traced the formant pattern with white paint. The pattern was then rolled at a constant speed, matched to the time scale of the spectrogram, beneath a strip of frequency-modulated light. The light was reflected from the painted portions of the pattern to a photocell that drove a loudspeaker, thus reproducing an approximation to the original sound. The Playback (and its more flexible computer successors at Haskins and elsewhere) permitted experimenters to manipulate the speech signal systematically, by pruning, deleting or exaggerating portions of a spectrographic pattern until they had isolated those pieces that determine the perception of a particular utterance.

One broad conclusion from the first perceptual studies has stood, and has guided research, for over 40 years: Information in the speech signal is not conveyed by an acoustic alphabet. The invariant phonetic segments of the perceived message do not correspond one-for-one to segments in the acoustic signal (LIBERMAN, COOPER, Shankweiler, and STUDDERT-KENNEDY 1967). Due to coarticulation, that is, due to the overlapping actions of articulators engaged by successive segments, segment boundaries become interleaved, and the acoustic pattern specifying a given segment varies with its context. Thus, in a typical consonant-vowel-consonant syllable, acoustic information for all three segments may be distributed, both temporally and spectrally, over the entire syllable. This lack of isomorphism

between signal and message has been, and continues to be, the central puzzle of speech perception.

ACOUSTIC FEATURES

Categorical Perception

Early work with synthetic speech revealed that tokens of syllables contrasting on a single phonetic feature could be constructed by manipulating a single acoustic variable. For example, by varying the direction of the second formant (F2) transition at the onset of a CV syllable, an experimenter could construct a continuum of a dozen or so items, separated by acoustically equal steps, ranging from /bæ/ to /dæ/ to /gæ/. If listeners were then asked to identify tokens from the continuum, they typically divided them into clear-cut categories, despite the absence of obvious acoustic boundary markers. Moreover, asked to discriminate between tokens two steps apart, say, on the continuum, listeners did little better than chance if they had assigned them to the same category, but performed very well if they had assigned them to different categories. The phenomenon was dubbed "categorical perception" (LIBERMAN, HARRIS, HOFFMAN, and GRIFFITH 1957) to distinguish it from the "continuous perception" typical of non-speech continua, such as tones varying in pitch or loudness, for which discrimination is equally good across the entire continuum (see HARNAD 1987, for a collection of articles).

Many experiments eventually established that the level of discrimination within categories varies with experimental method (e.g. PISONI 1973; CARNEY, WIDIN and VIEMEISTER 1977; MILLER, CONNINE, SCHERMER and KLUENDER 1983), and that categorical perception is not confined to speech (e.g. PASTORE, AHROON, BAFFUTO, FRIEDMAN, PULEO and FINK 1977), or even perhaps to humans (e.g. KUHL and MILLER 1978). Nonetheless, the phenomenon does characterize speech, and widespread use of the identification/discrimination paradigm has proved fruitful in establishing phonological differences among languages (e.g. MIYAWAKI, STRANGE, VERBRUGGE, LIBERMAN, JENKINS and FUJIMURA 1975), infant capacity for speech perception (e.g. EIMAS, SIQUELAND, JUSCZYK and VIGORITO 1971) and the distinction between auditory and phonetic perception (e.g. MANN and LIBERMAN 1983).

Quantal Theory

Among the offshoots of work on categorical perception was the quantal theory of speech (STEVENS 1972; 1989). Stevens attributed the lack of acoustic category boundary markers in synthetic speech studies to the fact that categories were there defined by articulatorily impossible variations in a single acoustic variable (e.g. F2 formant transitions) rather than by the whole-spectrum properties (e.g. grave-acute, compact-diffuse) of distinctive feature theory (JAKOBSON, FANT and HALLE 1951/1963; CHOMSKY and HALLE 1968). Stevens' goal has been to derive the articulatory and acoustic properties of the postulated features by applying the acoustic theory of speech production to an idealized model of the vocal tract. The acoustic properties selected are those few that are both easy to articulate (because they are centered in regions of acoustic stability where large changes in some articulatory parameter have little acoustic effect) and easy to discriminate (because they are bounded by regions of acoustic discontinuity where small articulatory changes have a large effect).

Quantal theory thus rejects the claim that speech is not an acoustic alphabet. The theory proposes, rather, that the speech signal is a sequence of discrete spectral patterns, invariant across context, each integrated perceptually over brief intervals by property detectors characteristic of the mammalian auditory system. Note that temporal properties are explicitly excluded from the description of a feature; this omission has proved to be the central weakness of the theory's account of perception. A series of experimental studies of the acoustic structures that support stop consonant perception both by STEVENS' colleagues (e.g. BLUMSTEIN, ISAACS and MERTUS 1982; LAHIRI and BLUMSTEIN 1984) and by others (e.g. KEWLEY-PORT, PISONI and STUDDERT-KENNEDY 1983; WALLEY and CARRELL 1983) have come down clearly in favor of dynamic, context-dependent formant patterns rather than of the gross, static spectral invariants postulated by quantal theory (for critiques of the theory, see the special issue of *Journal of Phonetics*, Volume 17, July, 1989).

ACOUSTIC CUES

Unlike features, cues are empirically defined properties of spectrally and temporally limited portions of the signal that have been shown (usually by manipulation of a synthesized syllable) to contribute to perception of a standard articulatory dimension. The invention of the Pattern Playback opened the way to systematic description of the acoustic cues for phonological categories. Within less than a decade of the initial work, a preliminary set of "minimal rules for synthesizing speech" was proposed (LIBERMAN, INGEMANN, LISKER, DELATTRE and COOPER 1959).

Perhaps the most surprising discovery of this and later work was that virtually every phonetic contrast is carried by several spectrally and temporally distributed cues. The critical importance of time was first recognized by LISKER and ABRAMSON (1964) who showed by analysis of natural utterances, that the several spectro-temporal properties specific to perception of the voicing, aspiration or "tensity" of homorganic stops in many languages reflect the timing of laryngeal action relative to consonant release (voice onset time, or "VOT").

Other work showed that place of articulation is signaled in syllable-initial English stops by spectral properties of the release burst and of formant transitions at vowel onset (LIBERMAN, DELATTRE and COOPER 1952; DORMAN, STUDDERT-KENNEDY and RAPHAEL 1977); in syllable-initial fricatives by spectral properties of the frication noise and of its formant transitions into the vowel (e.g. HARRIS 1958; WHALEN 1981); in the unaspirated stops of English [s]-stop clusters by duration of the stop closure, by spectral properties at the offset of the [s], and by the relation between those properties and those of the following vowel (Bailey and Summerfield 1980). Even for vowels, sometimes taken to be relatively static formant patterns (PETERSON and BARNEY 1952), critical information in a CVC syllable is carried not only by the nucleus, but by onset and offset transitions (e.g. LINDBLOM and STUDDERT-KENNEDY 1967; STRANGE, VERBRUGGE, SHANKWEILER and EDMAN 1976).

In all these examples, cues do not occur in "simultaneous bundles", as posited for distinctive features, but in temporal sequences that reflect the course of articulatory action. Many studies of reciprocal relations among cues, as in so-called "trading relations" (e.g. REPP 1983; KLUENDER 1991), and of multiple cue function (e.g. Bailey and Summerfield 1980) have

indeed demonstrated that cues are *additive* components of a coherent pattern of sound, and that their coherence is intrinsic to the speech signal itself, imposed not by perception, but by the speaker's articulations. Further support for this conclusion comes from studies of sinewave speech and of lipreading.

SINE WAVE SPEECH

Sine wave speech is generated from a radically reduced copy of a spectrogram in which only the center frequencies of the formants are preserved. Intelligible speech can be constructed for semantically implausible, and therefore unpredictable, utterances from which all information about source (voicing, friction, plosive release), nasality, harmonic spectrum, and fundamental frequency has been removed, so that the listener hears no more than a crude approximation to the peak resonances of the changing cavity shapes and volumes of the vocal tract (REMEZ, Rubin, Pisoni and Carrell 1981; Remez, Rubin, Berns, Pardo and Lang 1994). Most listeners come to hear such bizarre combinations of whistles as speech after brief instruction and little or no practice. We do not infer from this work that the diverse acoustic properties of natural speech, eliminated from sine wave speech, have no function. We infer, rather, that these properties are integral components of the dynamic patterns of spectral change to which listeners are demonstrably sensitive.

LIPREADING

Studies of lipreading in recent years have taken on a new theoretical importance, largely precipitated by the well-known McGurk effect (McGurk and MacDonald 1976), in which mismatches between what is seen and what is heard can lead to speech perception that is based on portions of each modality. At issue is the question of whether the listener/viewer combines phonetic features extracted independently from the two channels (MASSARO 1987), or integrates optic and acoustic information into a continuous, time-varying, precategorical event structure (Summerfield 1987). Studies in which one or other signal is ambiguous if presented alone, but the combination is not (e.g. Green and Miller 1985; FOWLER and Dekle 1991) support the latter interpretation, as do studies in which prelinguistic infants prefer an acoustic-optic match to an acoustic-optic mismatch (MacKain, STUDDERT-KENNEDY, Spieker and Stern 1983; Kuhl and Meltzoff 1984). Such studies corroborate the conclusion, independently drawn from work on cue function and sine wave speech, that the information-bearing elements of speech are articulator movements, or gestures.

PROSODY

Prosody refers to the suprasegmental melody, amplitude and timing of speech (LEHISTE 1970; Martin 1972). A central concern has been its perceived isochrony, seemingly absent from the signal (Morton, Marcus and Frankish 1976). FOWLER (1979; 1980) has argued, however, that the perceived regularity is based on acoustic information about articulatory timing, concealed in the signal by gestural overlap. The onsets of gestures overlap, and so the acoustic output can be confusing. Others (Howell 1987; Pompino-Marschall 1989) have argued for an articulation-free acoustic basis, but their work seems to ignore the effects of later occurring information (Cooper, Whalen, and Fowler 1988). The competition between articulatory and acoustic explanations continues to inform this research.

SPECIALIZATION FOR SPEECH PERCEPTION?

The question of whether speech perception engages general auditory or specialized phonetic mechanisms first arose from attempts to devise an acoustic alphabet to substitute for the optic alphabet in a reading machine for the blind (LIBERMAN, et al. 1967). Despite innumerable attempts, no one was able to devise an acoustic alphabet that listeners could follow faster than Morse code, that is, a rate of some 10-15 words per minute, roughly a tenth of a typical English speaking rate. What accounts for our ease in following speech?

The answer hangs on the nature of the speech percept. On one view, perhaps the most widely held, the percept is auditory, an amalgam of cues that we have learned to associate with linguistic dimensions, or features (e.g. Diehl and Kluender 1989). Perceptual coherence then emerges from spectrotemporal diversity according to the Gestalt "laws" of visual perception, adapted to audition by Bregman (1990). (But see also the arguments in REMEZ, et al. 1994.) On this account, we follow speech with peculiar ease because of its Gestalt structure and because we have been hearing it continually since infancy.

On a second view, the direct realist view (FOWLER 1986; Best 1995), the percept is articulatory. Whether by ear, by eye, or by hand, we perceive the gestures that structure the energy in the signal. We follow speech with ease because speech has evolved to match our perceptual systems, and our perceptual systems have evolved to pick up information about objects and events in the world (Gibson 1979).

On a third view, the motor theory of speech perception (LIBERMAN and MATTINGLY 1985), the percept is again articulatory, but is achieved by a specialized computational device that has evolved to recover discrete phonetic gestures from the intricately shingled articulatory and acoustic structures that make rapid speech possible. Evidence consistent with a specialized mode of phonetic perception has come from studies of dichotic listening (Kimura 1967; STUDDERT-KENNEDY and Shankweiler 1970; Zatorre, Evans, Meyer and Gjedde 1992) and of so-called "duplex perception". In the latter, listeners are led to hear a synthetic sine wave transition as simultaneously a non-speech glissando and an integrated phonetic component of a stop-vowel syllable (e.g. Xu, Liberman and Whalen 1997).

DEVELOPMENT OF SPEECH PERCEPTION

A large and still growing body of work on infant speech perception began with a demonstration of categorical perception in one- and four-month-old infants (EIMAS, et al. 1971). Within a few years, research had shown that infants could discriminate virtually any speech contrast from any language during the first six months of life (e.g. Kuhl 1976), but that over the second half of the first year, they gradually lose the capacity to discriminate non-native contrasts (Werker, Gilbert, Humphrey and Tees 1981), especially those that are close to, but not the same as, native contrasts (Best 1995). Over this period, infants also become sensitive to recurrent word patterns, to phonotactic constraints in the surrounding language, and even to prosodic markers of clausal units. (For a comprehensive review, see Jusczyk 1997).

CURRENT TRENDS AND FUTURE DIRECTIONS

The past 10-15 years have seen a shift away from the segment and the invariance issue toward the word, and even longer stretches of the signal, where the goal is less to discover invariants than to understand how listeners master and exploit variability (e.g. Perkell and KLATT 1986). Among the growing points in the area are studies of word recognition, both in isolation (Elman and McClelland 1984; Pisoni and Luce 1987; Luce and Pisoni 1998) and in running speech (e.g. Marslen-Wilson 1973). Such work and continued research along older lines, revitalized perhaps by the new techniques of brain imaging now emerging, should make for an interesting history at the 25th International Congress of Phonetic Sciences in 2043.

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THE HISTORY OF PHYSIOLOGICAL PHONETICS IN THE UNITED STATES

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INTRODUCTION

Prior to the emergence of Phonetics as an academic discipline within the United States, most of the interesting developments in the study of physiological aspects of voice and speech production resulted from investigations by independent scholars widely separated in time and dispersed throughout the world. The landmark accomplishments of those early investigations have been well chronicled in Elbert R. Moses, Jr.'s book *Phonetics: History and Interpretation* published in 1964. Suffice it to say that the awakening of interests in the United States during the early 1900s to the importance of scientific study of speech physiology comes relatively late in the history of phonetics. The early development of research interests in physiological phonetics within the United States can be found in two sources: *Speech Pathology and Audiology Iowa Origins of a Discipline* (Moeller 1975), and *A History of the American Speech and Hearing Association 1925-1958* (Paden 1970). Studies of the anatomy of the voice and speech production mechanisms, including the respiratory, laryngeal, and articulatory systems, had been well established during the 1800s. During the twentieth century scientists in the United States have played a major, if not dominant, role in describing the physiological aspects of normal and disordered human communication. Thus, it is the purpose of this chapter to chronicle the contributions of many of the physiological phoneticians from the United States during the 20th century. The work of these scientists will be discussed collectively by topic and in relation to major research laboratories.

THE EARLY AND THE MODERN ERAS

The history of physiological phonetics in the US can be said to extend from Raymond to Raymond to Raymond. The early period starts with the pioneering work by RAYMOND WEEKS (1893) of Columbia University and the modern era from the work of RAYMOND H. STETSON of Obelin College in Ohio in the 1920s and 30s (see his *Motor Phonetics* 1928, 2nd ed. 1951) to the publication of RAYMOND D. KENT's book *The Speech Sciences* in 1997. Weeks constructed a device that worked with a kymograph to show the movements of the soft palate during connected speech, however, he did not publish any large-scale systematic studies using the apparatus. In 1896 Charles Hall Grandgent of Harvard published a study of tongue positions for different vowels determined by wire probes inserted into his mouth. One of the most ambitious early programs for instrumental study of speech was undertaken by EDWARD W. SCRIPTURE of Yale. Starting in 1893 Scripture, working under the banner of the "New Psychology" (which he opposed to speculative, "armchair", psychology), studied many aspects of

normal and disordered speech, including respiratory, glottal, and supraglottal articulations using palatography and the kymograph driven by Marey tambours transducing a variety of speech movements. This culminated in his monumental and subsequently quite influential book *Elements of experimental phonetics* (1902). Carl Seashore, the experimental psychologist famous for his work on hearing and music, including singing, was one of Scripture's students.

STETSON, who had trained with Abbé Rousselot, promoted a novel view of speech. In *Motor Phonetics* he wrote that "speech is rather a set of movements made audible than a set of sounds produced by movement". He defined motor phonetics as "the study of skilled movements involved in the process of handling articulatory signals". Motor phonetics deals with the organization of a series of actual syllables or nonsense syllables" (p. 45). Thus he defined what has become known as the discipline of physiological phonetics. In the mid 1930s there was a strong tie between the research being done by Stetson and his colleague, physician C.V. Hudgins, and the emerging interests in physiological phonetics in Europe. Hudgins worked with LOUISE KAISER in Amsterdam. Hudgins and Stetson published their work on "Voicing of consonants by depression of the Larynx" in the *Archives Néerlandaises de Phonétique Expérimentale*, and of course, the 1951 version of *Motor Phonetics*.

Much of the research in the 1920s was focused on understanding speech articulation for vowels and consonants. G. OSCAR RUSSELL, Ohio State University, used lateral head x-ray films to study speech articulation, his work appearing in 1928 and 1929. However, without head stabilization techniques he could not specify regular lingual articulatory positions for vowels. Obviously, gravitational forces influenced tongue position during head flexion and extension adjustments. HOLBROOK and Carmody published a more complete description of vowel articulation in 1937 by using the concept of central tendency to provide articulatory templates for the various vowels. Harlan Bloomer of the University of Michigan devoted substantial efforts to monitor the contact phase of consonant articulation through the use of palatography. Bloomer believed that important information could be obtained by comparing palatograms and lateral head x-rays to describe consonant articulation. The colorful history of palatography is well described in Moses (1964) and will not be repeated here.

PHYSIOLOGICAL MODELS OF SPEECH PRODUCTION

The early attempts at describing the vocal tract and articulatory positioning during vowel production were rather crude by today's standards. Homer K. Dunn (1950) at Bell Telephone Laboratories developed an electrical model simulating four

resonance tube sections of the vocal tract. Amazingly, his model produced rather acceptable sounding vowels. Dunn compared the output of his model with the results of Bell Lab colleagues GORDON PETERSON, Harold L. Barney, R. K. Potter, J. C. Steinberg and Lawrence Kersta who were investigating acoustical patterns of vowels measured via the newly developed sound spectrograph. KENNETH N. STEVENS, Kasowski and Fant (1953) developed a more elaborate model of the vocal tract with 35 LC sections each of which simulated a 1/2 centimeter length of the vocal tract. By 1955 Kenneth Stevens and Arthur House published their classic paper on the development of a quantitative model of vowel articulation, specifying the dynamic interrelationships between place of articulation, degree of vocal tract constriction and degree of lip rounding and protrusion. Their model provided a solid foundation for description of the relationships between vocal tract shapes and acoustical resonances during speech production.

Much of the history of physiological phonetics can be traced by noting the research activities in a select group of research laboratories.

Haskins Laboratories, New Haven Connecticut

Under the leadership of FRANKLIN COOPER and ALVIN LIBERMAN, the research team at Haskins Laboratories made significant contributions to the study of physiological phonetics. Katherine Harris stimulated and guided much of the physiological research on speech production from the 1950s until the 1990s. She and her many students and protégés, including Fredericka Bell-Berti, Gloria Borden, Betty Tuller, Lawrence Raphael, and Peter Alfonso, conducted many studies on the dynamics of speech movement and on aerodynamics of speech production. That research team was one of the few to take advantage of the x-ray microbeam equipment in Japan and at the University of Wisconsin to track articulatory movements during speech production. Their coordinative systems approach to understanding of speech motor control helped focus research interest on the interactive effects of motor control within articulatory subsystems used in speech production.

Vocal tract modelers and modelers of the motor control systems used in speech production have been abundant at Haskins Laboratories during the second half of the 20th century. Among notable physiological modelers whose careers have passed through Haskins Laboratories have been PAUL MERMELSTEIN, Thomas Baer, Thomas Gay, Scott Kelso, Betty Tuller, Louis Goldstein, Melissa Bowerman, Eliot Saltzman, Kevin Munhall and CAROL FOWLER. The development of a dynamic model of gestural patterning during speech production by Saltzman and Munhall is leading to even more comprehensive models of speech production being undertaken by Joseph Perkell and his colleagues at MIT.

University of Iowa

Research interests in physiological phonetics has had a long history at the University of Iowa (see Moeller 1975), beginning with the hiring of Psychologist Carl Emil Seashore in 1897. Seashore's vision for the need of individuals prepared to study normal and disordered human communication caused him to recruit Lee Edward Travis as a doctoral student. Travis's interests during the late 1920s and 30s had been on psychological factors influencing communication. His special focus was on

cerebral dominance and its effects on stuttering. Travis, who chaired the program at Iowa until 1938, was instrumental in the education of Wendell Johnson, Charles VanRiper, GRANT FAIRBANKS, Charles Strother, JOHN BLACK, and several others. From those early beginnings stemmed a powerful research focus on physiological phonetics exemplified by the work of James F. Curtis, Frederick L. Darley, Duane C. Spriestersbach, Dorothy Sherman, James Hardy, Hughlett Morris and their many academic progeny. Frederick Darley left the University of Iowa in 1960 to head up the newly established medical speech pathology program at Mayo Clinic. Darley's subsequent influence on the study and treatment of neurogenic speech and language disorders as a clinical phonetician is unparalleled. It is fair to say that the University of Iowa has played a dominant role in the discipline of physiological phonetics in the United States during the 20th century. John Black at Ohio State University, Grant Fairbanks at the University of Illinois, Mack Steer at Purdue University, Mildred Berry at Rockford College in Illinois, Harry Hollien at the University of Florida, and Harlan Bloomer at the University of Michigan all had Iowa beginnings and all launched research programs to study the physiological aspects of speech production.

The 1960s saw the continuing development of the research team emphasizing physiological phonetics at the University of Iowa. Strongly influenced by the research orientations of Duane C. Spreistersbach and James F. Curtis and supported by the National Institute of Dental Research, KENNETH L MOLL led a research team in analyzing the results of cineradiographic films obtained during speech production. By dint of their work, the emphasis in speech research shifted from static studies of articulation to articulatory dynamics during speech production. Kenneth Moll collaborated variously with Raymond Daniloff, RAYMOND KENT, and David Kuehn to publish a spate of papers on the dynamics of articulation during speech production, the effects of rate of speech on the timing of articulatory movements, and coarticulation. Two of the five films produced at Iowa in the 1960s as part of the Speech Pathology series provide the best perspectives of normal articulation and velopharyngeal function ever made.

University of Wisconsin

Between 1925 and 1950 Robert West at the University of Wisconsin had a significant influence on the study of physiological phonetics by applying medical terminology to descriptions of normal and abnormal speech production. During the 1960s three Iowa graduates, FRED MINIFIE, Thomas Hixon and Ronald Netsell, were recruited to Wisconsin where they developed a speech science laboratory that has continued to contribute significantly to knowledge in the area of physiological phonetics during the last half of the 20th century. Drs. Hixon and Netsell developed a well-equipped laboratory for the study of the aerodynamics of speech by normal and disordered talkers. (See research discussed below under the headings of respiratory physiology and articulation).

MINIFIE and Hixon collaborated with radiological physicists Charles A. Kelsey and James Zagzebski to pioneer the use of diagnostic ultrasound in the monitoring of laryngeal and pharyngeal movements during speech production. Their use of a doppler velocity monitor to track movements of the vocal folds, b-mode time motion displays of pharyngeal displacements during speech production, and b-scans to plot the shape of the tongue

during sustained vowel productions were all pioneering adaptations of ultrasound technologies. Later computer controlled and computer enhanced displays made by Barbara Sonies, Maureen Stone and their colleagues at NIH, and work by Kenneth Watkin at McGill University further advanced the use of diagnostic ultrasound in physiological phonetics.

Minifie, Hixon, and Netsell educated James Abbs, Harvey Sussman, Harvey Gilbert, John Bernthal, David Buekelman, and Diane Bless, among other physiological phoneticians, before all three professors were recruited to other universities: Minifie to the University of Washington, Hixon to the University of Arizona, and Netsell to Boystown Research Institute in Omaha. In their places at the University of Wisconsin came RAYMOND KENT, Gary Weismer, Jay Rosenbek, and Malcome McNeil, who along with Diane Bless and Lawrence Shriberg created the premier research program in the United States focusing on motor speech disorders, particularly the dysarthrias.

In the mid 1970s James Abbs returned to the University of Wisconsin, where he, OSAMU FUJIMURA and RAYMOND KENT helped established the only x-ray microbeam facility in the United States for monitoring specific articulator movements during speech production. That facility, the previously established speech physiology laboratory, and the collective talents the large and productive faculty mentioned above made for an enriched environment for the study of physiological aspects of speech production in normal and disordered populations. That group produced a large number of scientists who have assumed significant leadership roles in studies of speech production. Among them are: Steven Barlow (University of Indiana), Vince Gracco (Haskins Laboratories and City University of New York), Scott Adams (University of Western Ontario), Edythe Strand (University of Washington), Susan Shaiman (University of Pittsburgh), and Michael Kimelman (Duquesne University). The work at Wisconsin during the 1980s and 1990s has stimulated research on motor speech disorders at many other universities, including that by David Buekelman (University of Nebraska), Katherine Yorkston (University of Washington) and Lorraine Ramig (University of Colorado in Boulder).

University of Washington

In 1971 Fred Minifie and James Abbs moved from the University of Wisconsin to University of Washington where they established an active speech science laboratory. James Abbs, Eric Muller, Gerald Eilenberg, John Folkins, Jesse Kennedy, Michael McLean, and others employed bio-mechanical models to account for active and passive properties to describe control of lip and jaw motion during speech production. Erick Luschei, a physiological psychologist worked with this team and was a primary influence on the development of John Folkins (University of Iowa), Charles Larsen (Northwestern University), and Anne Smith (Purdue University) during their predoctoral and/or postdoctoral experiences at Washington. The innovative use of strain gage technologies, force feedback, optical tracking of articulatory movements, concurrent monitoring of electromyographic and aerodynamic events, and use of simultaneous recordings of multiple articulator movement established this laboratory as a major contributor to the development of physiological phonetics. Catherine Yorkston and Edythe Strand have devoted their careers to descriptions of motor speech disorders in dysarthric

populations. Christopher Moore, a Purdue University graduate trained by Anne Smith, has taken over the directorship of the speech physiology laboratory at Washington, where he has emphasized the development of physiological control of speech articulation by infants and young children.

University of Texas at Austin

At the University of Texas PETER MACNEILAGE and Harvey Sussman developed a strong physiological research laboratory within a Linguistics Department. MacNeilage and J. L. DeClerk's 1967 paper on "motor control of coarticulation in CVC monosyllables", MacNeilage's paper on "Motor control and the serial ordering of speech", the paper by Harvey Sussman, Peter MacNeilage and Robert Hanson (1973) on "Labial and mandibular dynamics during the production of bilabial consonants" are exemplary of the productivity of the Texas team. Their work was complemented by Thomas Marquardt's work on acquired neuromotor speech and language disorders.

UCLA Phonetics Laboratory

PETER LADEFOGED and his students JOHN OHALA, Richard Harshman, Louis Goldstein and many others have contributed significantly to the history of physiological phonetics in the United States. Since the work in applied phonetics at the UCLA Phonetics Lab will be discussed elsewhere in this volume, it will not be repeated here.

ANATOMY AND PHYSIOLOGY OF THE RESPIRATORY SYSTEM

Based upon a strong foundation of knowledge about the anatomy of the respiratory system collected during the 19th century, speech scientists Roy E. Eblen 1963, and Willard Zemlin 1968, added significant information about the importance of anatomical structure in the assessment of respiration during speech production. The importance of their anatomical work has been well chronicled in textbooks on speech anatomy written by GILES GRAY 1950; Willard Zemlin 1968 and 1988; H. L. Kaplan 1971; Joel Kahane and John Folkins 1984; William Perkins and RAYMOND KENT 1986; John Palmer 1993; J. A. Seikel, D. W. King and D. G. Drumright 1997; and Kent 1997.

With the advent of modern technology, increased emphasis was placed on physiology of speech production — on function, rather than on structure. In no area of physiological phonetics is this emphasis more evident than in research on respiratory function during speech production. The classic paper by Draper, Ladefoged and Whitteridge (1959) from Edinburgh, on the role of respiratory muscles during speech production provided the first attempt at description of functional differences in the use of the respiratory system for speech production as contrasted to respiration for biological survival. By the late 1950s James F. Curtis at the University of Iowa had developed a sophisticated speech physiology laboratory and trained several speech scientists with interests in respiratory function during speech production. Among them were Herbert Arkebauer, Harry Cooker, Roy Eblen, James Hardy, Thomas J. Hixon, LaVern Kunze, Robert McGlone, Kenneth Moll, Ronald Netsell, Alan Reich, and Bud Wendahl. Kunze's doctoral dissertation reported a serious methodological flaw in the paper by Draper et al. (1959) showing that the esophageal pressures used by the Edinburgh team as estimates of intratracheal pressure would have to be

adjusted to account for where the talker was in terms of percent vital capacity. Peter Ladefoged, who was by that time head of the Phonetics Laboratory at UCLA, readily acknowledged the flaw uncovered by Kunze.

No other physiological phonetician has written as extensively about speech respiration as has Thomas Hixon. In the late 1960s Hixon took a leave of absence from the University of Wisconsin and did post-doctoral research with internationally renowned respiratory physiologist Jere Mead at the Harvard School of Public Health. Hixon's applications of the solid foundation in scientific theory and technology for the study of human respiration, gained during his years at Harvard working under the tutelage of Jere Mead, have virtually transformed the knowledge of respiratory function needed for speech production. Hixon's papers with Goldman and Mead (1973, 1976) provide the scientific foundation for current models of respiratory function during speech production. Hixon, who later established a speech physiology laboratory at the University of Arizona, and Gary Weismer, from the University of Wisconsin co-authored an important letter to the editor of JSHR, critiquing virtually every assumption in the classic paper by Draper, LADEFOGED and Whitteridge paper. That tutorial review provides in bold relief a distinction between the days of trial-and-error empiricism and the theory-driven, data-based, focused research on respiratory function employed today. Hixon and Weismer present data to show that the abdominal muscles are nearly continuously active during speech production, providing a platform of activity that optimizes the expiratory activity of the rib cage during speech and providing for efficient inspiratory action. JOHN OHALA from the University of California at Berkeley argued that the force applied to the lungs is constant for a given voice intensity, and that short time aerodynamic variations are related to variations in airway resistance and the inertia of the respiratory system. The quality of Hixon's research mission continues after establishment of a National Center for the Study of Neurogenic Speech and Language Disorders at the University of Arizona, for which he serves as director.

Other significant contributors to knowledge of respiratory function during normal and disordered speech production include DONALD WARREN, a dentist from the University of North Carolina, Elaine Stathopoulos from SUNY Buffalo University, Christine Sapienza from the University of Florida, Christopher Moore at the University of Washington, and Jenny Hoit and Peter Watson from the University of Arizona. Applications of current research methodologies for the study of speech respiration by talkers from several disordered populations have been undertaken by Vicki Hammon from Purdue University and by B. E. Murdoch and colleagues from Australia.

ANATOMY AND PHYSIOLOGY OF LARYNGEAL MECHANISM

Interest in the structure and function of the larynx during voice production continued unabated throughout the 20th century. The major contributors to knowledge of the anatomy of the larynx have been Willard J. Zemlin from the University of Illinois, David Dickson and Wilma Maui from the University of Pittsburgh, David Broad at the Speech Communications Research Laboratory, and Joel Kahane the University of Memphis. Kahane has published extensive histologic studies of changes within the larynx as a function of aging.

In the late 1930s high speed photography became available and was applied to studies of laryngeal vibrations by P. Moore in 1938, and by Farnsworth at Bell Telephone Laboratories in 1940. The remarkable physiological phonetician G. Paul Moore from Northwestern University and his colleagues Hans von Leden and Rolf Timcke provided a quantitative description of laryngeal vibrations in 1958 and 1959 as a consequence of their analysis of high speed laryngeal motion pictures. Their papers were published at about the same time that Janwillem van den Berg published his classic paper on the myoelastic aerodynamic theory of voice production. Thus began serious scientific study of laryngeal function during voice and speech production. In the early 1960s Harry Hollien, a University of Iowa product, moved to the University of Florida and established a laboratory devoted to the speech sciences, but with a particular focus on the study of laryngeal function. Harry Hollien and G. Paul Moore began a research collaboration at Florida that yielded significant fruit. They installed two innovative tools in addition to high-speed laryngeal photography. The first was a stroboscopic laminograph to obtain motion picture x-ray simulations of vocal fold vibration in coronal section. These films allowed investigation of factors such as the thickness of the vocal folds during changes in fundamental frequency and intensity of sound production. Secondly, they developed a fundamental frequency indicator (FFI) to automatically extract measures of fundamental frequency from acoustic signals. Although crude by today's standards, the FFI allowed Hollien and his many students and colleagues to report changes in fundamental frequency of sustained vowels as a function of age, gender, and many different demographic populations. Among the many voice scientists influenced by the Florida program were: Sam Brown, Robert McGlone, John Michel, Robert Coleman, Thomas Murray, and Thomas Shipp.

A major compendium of methods for the clinical assessment of voice disorders is Ronald Baken's *Clinical Measurement of Speech and Voice*, 1996. The methods described by Baken are used at centers for the clinical treatment of voice disorders located throughout the country. Physiological phoneticians with strong research emphases in treatment of voice disorders include Janina Casper, SUNY Health Science Center in Syracuse; Rebecca Leonard, California Davis Medical Center; Diane Bless, University of Wisconsin; Alex Johnson at Henry Ford Hospital in Detroit; Joseph Duffy at Mayo Clinic; Robert Orlikoff, New York University Hospital; Ed Stone, Knoxville, Tennessee; and Bruce Garrett, Jody Kreiman, and James Till at the Longbeach VA hospital.

MODELS OF LARYNGEAL FUNCTION

JAMES FLANAGAN, an electrical engineer trained at MIT who headed a research team at Bell Labs, developed a quantitative explanation of laryngeal function in his 1958 paper, "On the nature of the glottal sound source". Flanagan's quantitative physiological model for sound production was followed by the development of other engineering models of laryngeal function, including: Gunnar Fant's (KTH, Sweden) model of glottal airflow, KENNETH STEVENS (MIT) models of laryngeal aerodynamics, Martin Rothenberg's (Syracuse University) inverse filtering technique for deriving the glottal airflow waveform during voicing, K. Ishizaka and Flanagan's (Bell Labs) two-mass model of the vocal folds, and Ingo Titze's (University of Iowa) three-mass model of the vocal folds. The most

significant development in physiological studies of vocal function during the last half of the 20th century have come as a result of establishment of the National Center for Voice and Speech Research under the directorship of Ingo Titze at the University of Iowa and incorporating the work of such scientists as Ronald Scherer and Lorraine Ramig at the Wilbur James Gould Voice Research Center in Denver Colorado, and of Diane Bless and RAYMOND KENT at the Waisman Center at the University of Wisconsin.

VELOPHARYNGEAL CLOSURE

Investigations of velopharyngeal closure during speech production have been undertaken at a number of laboratories throughout the United States. At the University of Iowa in the 1950s and 1960s Duane Spriestersbach, KENNETH MOLL and Hughlett Morris used cineradiography to monitor v-p closure. More recently Mitchell Carnell and Gerald Moon at Iowa have employed a multidimensional monitoring system to compare movement dynamics, aerodynamic and acoustic factors associated with v-p closure. Robert Shprintzen and colleagues at Montefiori Hospital in New York City relied on videofluoroscopic and nasendoscopic views of v-p closure; Minifie, Hixon and Kelsey at the University of Wisconsin used diagnostic ultrasound, and Skolnick and McCall at the University of Maryland used oblique cinefluoroscopic views of the velopharyngeal port, and Thomas Hixon (Arizona) and Ronald Netsell (Boystown Research Institute) used aerodynamic methods for assessing the degree of closure between the oral and nasal cavities. More clinical applications of physiological studies of velopharyngeal closure have been made by Duane Spriestersbach, Hughlett Morris and Mitchell Karnell at the University of Iowa, Robert Mason at the University of Kentucky Medical School, and by Ralph Shelton at the University of Arizona.

ARTICULATORY TIMING AND COARTICULATION

Much could be written about research in this important area of physiological phonetics. Seven key papers provide the theoretical substrates for the many data based papers published in this area.

--First was famed physiological psychologist K. S. Lashley's 1951 paper "The problem with serial order in behavior".

--William Henke's 1966 "Dynamic articulatory model of speech production using computer simulation".

--In 1970 PETER MACNEILAGE at the University of Texas wrote "Motor Control and the Serial Ordering of Speech".

--A 1972 article in *Psychological Review* by James Martin "Rhythmical (hierarchical) versus serial structure in speech and other behavior.

--In 1977 RAYMOND KENT and Fred Minifie wrote "Coarticulation in recent speech production models".

--Also that year, CAROL FOWLER wrote "Timing control in speech production".

--And in 1980 Carol Fowler from Haskins Laboratories wrote "Coarticulation and theories of extrinsic timing control".

In addition to the foregoing think pieces, there has been a spate of articles dealing with evidence of coarticulation during speech production by normal and abnormal talkers. LEIGH LISKER and ARTHUR ABRAMSON's studies of voice onset time, George Allen's many articles on the nature of speech timing and the "internal

clock" of the talker, and the series of papers by Thomas Crystal and Arthur House on articulation rate and the duration of syllables must be mentioned in this section.

ELECTROMYOGRAPHIC STUDIES OF SPEECH ARTICULATION

Since the publication of J. V. Basmajian's book *Muscles Alive* in 1962 there has been considerable interest in the use of electromyographic recordings of muscles during speech production. For example: Roy Eblen (University of Northern Iowa), Michael Hoshiko (University of Southern Illinois) and Willard Zemlin (University of Illinois) and each studied the role of respiratory muscles during speech production; Thomas Shipp (Human studies at the University of California at San Francisco and the Veterans Hospital in San Francisco), JOHN OHALA and Minoru Hirano (UCLA), William Vennard (University of Southern California), Hajime Hirose and Thomas Gay (Human studies at Haskins Research laboratories), and Charles Larsen (Animal studies at the University of Washington) each recorded EMG activity from several intrinsic and extrinsic laryngeal muscles during changes in fundamental frequency and intensity; Fred Minifie and colleagues at Wisconsin studied the pharyngeal muscles during production of voiced and voiceless consonants in low, mid and high vowel contexts and showed evidence of coarticulation in the pharyngeal structures; Michael McClean, and Fredericka Bell-Berti and Katherine Harris, monitored velar activity associated with velopharyngeal closure; PETER MACNEILAGE and Harvey Sussman (University of Texas at Austin) used concentric electrodes to monitor single unit recordings from lingual muscles during speech production; Tim Smith (UCLA) used hooked wire electrodes to study the function of tongue muscles; and James Abbs, John Folkins, Jesse Kennedy, and Michael McClean used hooked wire electrodes to monitor EMG activity in lip and jaw muscles during voiced-voiceless contrasts in low and high vowel environments. At various times VICTORIA FROMKIN, Raymond Daniloff and KENNETH MOLL, Harvey Sussman and John Westbury, and Fredericka Bell-Berti and Katherine Harris studied temporal patterns in EMG signals during lip rounding resulting from anticipatory coarticulation. Clearly, the most advanced work in the use of EMG during speech production has been done by Anne Smith, a graduate of the University of Iowa who heads the speech physiology lab at Purdue University, and her students Christopher Moore, Christine Weber Fox, and Margaret Denny. The primary factor that sets their work apart has been the use of sophisticated mathematical processing strategies to describe the role of active muscle contractions during speech production. Timing, coordination, and development of control of speech movements have been primary foci of their research activities. Drs. Smith, Denny and Fox have been particularly interested in the identification, and description of, differences in the EMG patterns employed by normal talkers and talkers who stutter. Christopher Moore and his students Jacki Ruark (Pittsburgh) and Jordan Green (University of Washington) have made significant contributions to the literature regarding the development of neuromotor control for speech articulation by infants and young children, and evidence showing that speech movements do not stem from more basic biological movements like those used in chewing.

It is likely that any attempt to provide a historical account of the development of physiological phonetics will be incomplete, and important contributors to this discipline will be overlooked, the foregoing account reflects but this writer's recollections. I take full responsibility for the errors and omissions. The following reference books house references to all of the material cited above.

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SPEECH TECHNOLOGY

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INTRODUCTION

Speech technology can be defined as any artificial means that enhances the communicative functions of speech. Obvious examples are a) speech communications at a distance, b) automatic speech recognition c) speech synthesis and d) medical treatments for deficiencies in human speech and hearing. With this definition, we see that speech technology has a long history.

THE TELEPHONE

The most important event in the history of speech technology in the United States was the invention of the telephone by ALEXANDER GRAHAM BELL in 1876. By the turn of the century, downtown New York City was already clogged with telephone lines. Many of the subsequent U.S. contributions to this area were made at Bell Telephone Laboratories, the research arm of Bell Telephone.

SPEECH CODING

Homer Dudley pondered the problem of transmitting the relatively wide band speech signal over the existing lower bandwidth telegraph lines. Here is one of his thoughts, written in his research notes.

"If I could determine what there is in the very rapidly changing complex speech wave that corresponds to the simple motion of the lips and tongue, if I could then analyze speech for these quantities, I would have a set of speech defining signals that could be handled as low frequency telegraph currents with resulting advantages of secrecy, and more telephone channels in the same frequency space as well as a basic understanding of the carrier nature of speech by which the lip reader interprets speech from simple motions" (Homer Dudley, 1935).

Dudley's insight (Dudley 1939) was that the intrinsic information content of speech was much less than indicated by the bandwidth, and this insight led to the invention of the channel vocoder, the first speech processing system to implement bandwidth compression.

Dudley pointed out that vocoders could enhance secrecy systems. World War II was the first arena where the vocoder was used to transmit secure speech (Bennett, 1983). Good security required that the signal be digitized and this increased the transmission bandwidth, making it possible to communicate by speech over a wide variety of channels. The bit-saving ability of the channel vocoder opened many such channels. Based on channel requirements, vocoder users eventually converged on a standard 2400 bits per second (bps) rate for secure vocoded speech.

Unfortunately, the 2400bps format resulted in speech quality that was not acceptable to most of the users, who were typically high-ranking military officers. Thus, after the war, there were quite a few funded research efforts to improve vocoder intelligibility and quality. (A good part of this work involved improved methods of analyzing and synthesizing vocoder excitation models (David et al., 1962; Dolansky, 1955; Duifhuis et al., 1982; Gill, 1959; Gold, 1969; Moorer, 1974; Noll, 1967; SCHROEDER, 1968; Seneff, 1976).) This research gathered momentum during the 1960s. As computer technology increased in sophistication, economically feasible systems of greater complexity evolved. In the late 1960s and early 1970s, a radically new algorithm using linear prediction came to the fore, and by the mid 1970s became the U.S. government's standard 2400bps algorithm.



Fig. 1. Homer Dudley (Kyoto, 1968).

Several factors accounted for the acceptance of LPC vocoders as the system of choice. By the 1970s, it was clear that future vocoders would be implemented as real-time computer programs. The LPC algorithm required less computational power (by a factor of about three) than the channel vocoder. Also, many research workers felt that LPC offered the opportunity for new (and not yet exploited) research.

Standardization of a 2400bps vocoder did not end vocoder research. It is still true, today, that 2400bps systems, whether LPC or channel vocoder, are not wholly satisfactory in quality and robustness. Also, modem technology advanced greatly during this same period, so that 2400bps became unnecessary in many cases. Increased bit-rates raised expectations of building *transparent* systems, where the output sounded as good as the raw speech.

Currently, the most fertile market for vocoder systems is cellular telephony, where bandwidth is restricted by nature. So, as the number of users grow, sophisticated speech coding research should play an increasing role.

SPEECH SYNTHESIS

Everyone is familiar with the various voice-answer-back systems, on the telephone and in many cars. These systems store spoken words and then employ various algorithms to generate a response to a specific inquiry. As the vocabulary of such a system grows, it is reasonable to study the tradeoff between increasing the memory capacity as opposed to including a device that uses a speech synthesizer to reduce the memory requirements.

Mechanical synthesis of vowels and some consonants — using organ pipes — was reported by D.C. MILLER (1922) and synthesis via electrical circuits by Stewart (1922).

For the past few decades there has been a great deal of speech synthesis research. The original inspiration was the 1939 demonstration, by the telephone company at the San Francisco exposition and the New York World's Fair, of the Voder (Dudley, 1939a). The Voder could "speak" semi-intelligibly when controlled by a trained operator using a keyboard for spectrum, a wrist bar for voicing, a foot pedal for intonation and special keys for the plosive and affricate sounds. A speech synthesizer is, of course, a major vocoder component and this motivated researchers to experiment with improved quality and lower parameter information content. COOPER et al (1952) built the *Pattern Playback* synthesizer to perform speech perception experiments. Kelly and Gerstman (1962) implemented the first computer program to synthesize speech, using a digital simulation of the vocal tract¹. They supplied the parameters to the program by intuition, trial and error. Some years earlier, Rosen (1958) had implemented an analog version of an articulatory model. Later, MATTINGLY (1968) (following Holmes, Mattingly and Shearme 1964) demonstrated a system that generated segmental and prosodic parameters from a supplied phoneme string (*Synthesis by Rule*). This was an important step in the evolution towards text-to-speech systems, since it reduced the problem (not an easy one) to that of a grapheme-to-phoneme translator.

In the late 1970s and during the 1980s, a large scale effort was undertaken at MIT to develop a complete text-to-speech system (Allen et al. 1979; Allen et al. 1987). From this work

¹ The Kelly and Lochbaum phoneme-based synthesis was demonstrated to the world by a recording which highlighted the "to be or not to be" soliloquy from Hamlet as well as the song "A bicycle built for two". The latter was the inspiration and explanation for the bizarre behavior of HAL, the talking computer in Stanley Kubrick's film "2001, a space odyssey". When HAL was being disassembled by the surviving astronaut, it "reverted to its childhood" and started singing that song. (Kubrick had heard this demo synthesis before making his film.)

came a practical outgrowth; the evolution of speech synthesizers culminating in the commercial DECtalk is described in detail by KLATT (1987). An interesting application of this device, by Sachs and coworkers (Miller and Sachs, 1984), was the collection of physiological data from cats' auditory systems when presented with a speech signal. To collect such data reliably, it was necessary to have a perfectly controlled stimulus presented to the cat's ear; Klatt's synthesizer created the desired stimuli.

Stephen Hawking, who had lost the power of speech, could make himself understood using KLATT text-to-speech device.

SPEECH TECHNOLOGY IN MEDICAL PROBLEMS

Cochlear Implants

A sizeable portion of the world's population is either totally deaf or in need of a hearing aid. Special attention must be paid to the hearing of speech. Thus, the manufacture of hearing aids is an important function. Within the past several decades, cochlear implant prosthesis has assumed increasing importance, primarily among adults who have damaged hair cells (but reasonably intact auditory neurons) caused by sickness or accident. These adults, who had normal hearing to begin with and are now deaf, are the best candidates for implant surgery. This is a very skillful surgical procedure; once done, sounds can reach the electrodes via a transcutaneous microphone. The resultant field excites the auditory neurons and in many cases the subject can recognize speech.

In early procedures, a single electrode was surgically implanted into the patient's cochlea (House 1976) with accompanying primitive signal processing to deliver the speech to the electrode. Later efforts led to multiple electrodes and relatively sophisticated signal processing (Chouard and MacLoed, 1976; Eddington et al., 1978; Kiang et al., 1979; Eddington, 1980; Tierney et al., 1994).

Speech technology enters into this process because great variations can result from different signal processing operations on the speech before reaching the electrodes. For example, if the surgeon inserts four electrodes into the cochlea, external hardware can be adjusted to get optimum results. The best temporal, frequency and wave shape patterns need to be experimentally (and perhaps, theoretically) found.

Hearing Aids

Most present-day hearing aids are algorithmically simple; a tiny microphone collects the speech and amplifies and frequency shapes the signal before applying it to a tiny loudspeaker located close to the outer ear. Research workers are experimenting with microphone arrays.

Artificial Larynx

Victims of throat cancer often lose the use of their vocal cords. An artificial larynx can imitate a "buzz" sound so that the speaker can often be understood by holding the artificial larynx near his or her throat and mouthing the phrase. The result is monotone speech.

AUTOMATIC SPEECH RECOGNITION

Conceptually, the development of speech recognition is closely tied with other developments in speech science and engineering, and as such can be viewed as having roots in studies going back to the Greeks (as with synthesis). However, the history of speech

recognition per se in the 20th century began with the invention of a small toy, Radio Rex (David and Selfridge, 1962a). This was a toy dog, manufactured in the 1920s, which responded to 500 Hz energy using a mechanical coupling; if the user said "Rex" the dog came out of its house. It is likely that the toy responded to many other words than "Rex", or even to many non-speech sounds that had sufficient 500 Hz energy. However, this inability to reject out-of-vocabulary sounds is a weakness shared by most recognizers that followed it. While quite simple, it embodied a fundamental principle of speech recognizers for many years: store some representation of a distinguishing characteristic of the desired sound, and implement a mechanism to match this characteristic to incoming speech.

While much of the work in vocoding and related speech analysis in the 30s and 40s were relevant to speech recognition, the next complete system of any significance was developed at Bell Labs in the early 1950s. In particular, a system built at Bell Labs and described in Davis et al. (1952) may have been the first true word recognizer, as it could be trained to recognize digits from a single speaker. It measured a simple function of the spectral energy over time in two wide bands, roughly approximating the first two resonances of the vocal tract ("formants"). The system achieved 2% error for a single speaker uttering digits that were isolated by pauses.

By 1962, quite a few word recognizers existed with very limited vocabulary (usually the 10 digits) and restricted to single speakers (Forgie and Forgie, 1959); (Hughes, 1959); (DENES, 1959; Keith-Smith and Klem, 1961).

ASR research continued, and by the 70s several major advances had been achieved. As with synthesis and vocoding, linear predictive techniques were found to be quite useful for the signal processing representations used for storage and recognition of speech. Dynamic programming, an optimal search technique, was successfully applied to speech in order to compensate for nonuniform time variability over speech — in other words, different parts of the speech signal changed their length in different ways when talkers spoke at different rates, so that simple linear time compressions and expansions do not provide a good match between incoming speech and stored representations. Dynamic programming as applied to the time normalization problem is generally referred to as *dynamic time warp* (DTW) technology, and this approach (along with linear predictive features) was the dominant ASR technology by the mid-70s (Bellman, 1952; White, 1976; Sakoe and Chiba, 1978; Ney 1984).

In the 1970s, a new technology was beginning to surface, e.g., at CMU (Baker, 1975) and IBM (Jelinek, 1976). In this class of approaches, statistical models were used to represent speech sounds, and the parameters for these models were learned in a set of iterative mathematical procedures. At any given point in the process, the actual identity of the speech sound or "state" at any given time was not entirely known, but probabilities for these identities were learned in a way that maximized the probability that the data had been produced by such a sequence. Since the actual state sequence associated with the sequence of acoustic observations was unknown, it was called "Hidden". In order to make the mathematics tractable, the probabilities depended only on the previous state, which is called a Markov assumption in statistics. Consequently, the statistical representations used in

these approaches have commonly been called Hidden Markov Models, or HMMs.

By the mid 1980s, HMMs were used in some form by many researchers, and by the mid 1990s essentially every system used some variant of this approach. In retrospect most of the earlier approaches could be seen as specific forms of HMMs in which there were strong implicit assumptions — for instance, DTW systems using a Euclidean distance between stored and new speech sounds could be viewed as being based on HMMs with an assumption of uncorrelated features with unity variance. However, the new mathematics provided a unifying set of abstractions, as well as powerful learning techniques. Given these tools, researchers and developers in the 1980s and 1990s were able to develop many complete systems for ASR.

Some further development has also been seen for the signal processing end of speech recognition. It is now standard to use some representation that has a few "auditory" properties, such as a spectral analysis that has greater resolution at low than at high frequencies; primary examples of these approaches are referred to as the mel cepstrum Davis and Mermelstein, 1980 and PLP (Hermansky, 1990). Additionally, researchers have made some progress in reducing the sensitivity of ASR systems to variability in the frequency response of the channel (telephone line, microphone, hand set); typically the mean of the cepstrum or log spectrum is removed via some filtering or average removal (Hermansky, and Morgan, 1994). However, robustness of ASR systems to variability in the environmental acoustics is one of the key weaknesses of current systems.

Some commercial applications of ASR

In recent years speech recognition has reached a level of development so that many effective commercial devices can be used. Dictation systems for PC users are now widespread, for instance. While most of these use isolated word technology (pauses required between words), some of the newer systems permit continuous speech input. Some systems in automobiles permit dialing using a key utterance chosen by the user ("call Mom"), while other voice dialing systems use digit strings as input. Stock quotations can now be obtained by telephone using an ASR system. There are organ transplant voice response information systems where isolated voice recognition allows the database to focus on the specified organ. Voice control of X-Ray microanalysis equipment allows the user to continue to observe the X-Ray while adjusting the equipment by voice. Automatic recognition of destinations allows for automatic routing of warehouse packages. Wheelchairs, radios and car windows are examples of items that can be controlled by physically handicapped people using their voices.

Thus, the current ASR technology is sufficient for many purposes, and engineers are actively involved in building commercial systems. As the technology improves, however, users will have greater flexibility (for instance, to speak more naturally or to use the system in a situation with degraded acoustics).

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SPELLING REFORM AND THE HISTORY OF PHONETICS AND PRONUNCIATION IN THE UNITED STATES

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The subject of spelling reform, which is, and was, an attempt to change the written language so that it reflects the spoken forms more accurately, is indeed an important, if small, part of language use in this country. Such reforms were tried occasionally during, and since, the eighteenth century. They all stemmed from the desire to bring the spelling system then in use in this country closer to the phonetic character of the spoken language. Some few of these attempts became part of the written language. This is a brief review of some of those attempts.

Perhaps the earliest contributor to such spelling reform attempts was BENJAMIN FRANKLIN — statesman, scientist, inventor, printer — who lived from 1706 to 1790. His interest in spelling reform led to his *A Scheme for a New Alphabet and a Reformed Mode of Spelling*, written when he was in London in 1768. That *Scheme* suggested such changes as: eliminating the letters “c”, “q”, “x” and “y” as redundant or unnecessary; introducing a modified “a” for the sound of the vowel in “hall”; an upside down “h” for the initial vowel of “unto”; combining “s” and “i” for the initial sound of “shame”; the use of “y” with a tail (that curved) for the final “ng” sound of “sing”; a variation of the letter “h” for the initial “th” sound of “thin”, and a different variation of the letter “h” (with an appendage) for the “th” of “then”. Franklin also proposed that short and long vowels appear as single or double letters so as to differentiate the vowels of “hat” and “hate” or “sit” and “site”. Franklin’s recommendations were considered “extravagant” or “inconvenient” even by some of his contemporaries, phonetically insightful as they were. They were not to become the printers’ choices.

FRANKLIN was not alone in those early attempts at spelling reform. One such proposal, by Ezekiel Rich (born in 1784) was sent to the 28th Congress of the United States in 1844. That proposal was discussed at length by the members of Congress and then tabled! His proposal contained 12 pages of “phonetic text”. A few years later, in 1849, a similar proposal was made by Henry Martin Parkhurst (born in 1825).

Both Rich and Parkhurst were New Englanders and their suggested spelling reforms included such requests as: the use of the sound /a/ for /æ/ in words like “last”, “advance” — a sound then developing in New England in the nineteenth century; the shorter (monophthongal) “o” for words like “stone”, “throat”, and “whole” (vs. “hole”, “soap”, etc. — which retained the longer diphthongal forms). (This was a “new sound” — as it was called by Rich who lived in the Connecticut Valley in the 1840’s — and it is common to today’s speakers in Eastern New England); the spelling of “hw” for words like “which” and “when”; and three differently spelled forms to differentiate the vowels in words like “Mary” or “vary” from “merry” or “bury”, and from “marry” or “carry”; the distinction between the New England vowels in “hoarse” vs. “horse”, or “fourth” vs. “form”, where the former word in each pair was heard with the vowel of

“boat” and the latter word of each pair with the vowel of “bought”. Rich further suggested the deletion of such silent letters as the first “g” of “suggest” and a different vowel to represent the weakened initial vowels in “abut” and “about” from the stressed vowels in each of the second syllables of those words. One might compliment both men for their attempts, but they were unsuccessful in convincing their contemporaries to make such changes.

FRANKLIN’s influence on Noah Webster, the most influential lexicographer of 19th century America, and on England’s Sir Isaac Pitman (the creator of the Pitman system of shorthand writing who proposed the idea of “phonetic printing” in 1841) has been widely noted. Webster acknowledged that debt by including a transliteration of Franklin’s letters on the subject in his *Dissertations on the English Language*, in 1789. Webster, however, stated his preference for a more simplified spelling system within the framework of the conventional alphabet.

Noah Webster has been called “the real father of the simplified spelling movement”. He authored *The American Spelling Book* in 1783, *Blue Back Speller* in 1790 and *The Elementary Spelling Book* in 1829. His *Blue Back Speller* was the most widely used book of the 19th century (if one excluded the Bible). Both it and the Bible were reported to be the two books that accompanied many of the settlers who moved from the eastern part of the country on their westward march during that century. Thus a large percentage of children were educated by Webster’s *Blue Back Speller*, found in almost every classroom of that century’s westward migrations. It is to Webster that we are indebted for such uniquely American spelling innovations as: the deleted “u” in words like “honor” and “favor”; the single “l” of “traveler”; the single “g” of “wagon”, the inverted “er” in words like “fiber”; the “s” vs. the “c” in words like “defense”; the “z” vs. the “s” in words like “realize”; “whisky” for “whiskey”; “connection” for “connexion”; the loss of the final “k” from words like “frolick” and “physick”.

Others of Webster’s proposals did not become part of our spelling habits. These recommendations included the omission of certain silent letters (such as the “a” of “bread”, dropping certain consonant and vowel combinations for which more common sounds were available (e.g. “tuf” and “ruf” for “tough” and “rough”) and introducing certain diacritics to distinguish the ways of pronouncing the same letter, in such words as “tap”, “tart”, “tame”, and “tall”.

As we know, too many spelling changes didn’t make much progress, even if “catalog(ue)” and “program(me)” are now part of standard spelling in this country. Such other changes as “thru”, “tho”, “wisht”, “giv”, “ar”, and “gard” never made it into widely accepted print and they are not part of our spelling system today.

At the end of the 19th century (in 1898) the National Education Association presented a list of proposed spellings:

“tho” (*though*), “altho” (*although*), “prolog” (*prologue*), “pedagog” (*pedagogue*), “bild” (*build*), “laf” (*laugh*), and “leag” (*league*). And in the early 20th century a number of other spelling reform supporters entered the “fray”. The Simplified Spelling Board, whose members included such persons as Andrew Carnegie (steel magnate and philanthropist), Samuel Clemens (the author Mark Twain), Melvil Dewey (founder of the library decimal system), Brander Mathews (theater personality), CHARLES H. GRANDGENT and Thomas Lounsbury (eminent linguists), had their own special preferences. Their recommendations included omitting the silent letters in words like “dumb”, “psalm”, “wrong”; changing the spelled “a” of “father” to “ah” to represent the “broader vowel”; and changing the spelling of the /u/ sound in words like “mood” and “do” so that it varied from the spelled form in words like “so”, “done”, and “gone”.

Opponents to spelling reform argued for the retention of the spelled system as it has come down to us in modern times. John Algeo made such a point in his introductory essay of *Webster's New World Dictionary* (Simon and Shuster, 1988): “The writing system of Modern English... tends to be a force for standardization and unification because recorded language creates a precedent for future language use... This conservative effect is one reason why spelling reformers have, so far, met with but modest success in their efforts” (p. 26a). Even more

provocatively stated are a number of points made by Wayne O'Neil in his front matter essay in *The American Heritage Dictionary of the English Language* (Houghton Mifflin, 1981, pp. xxv-xxxvii). Among these are such comments as: “... it is false to assume that the orthography bears little relationship to the phonology of English”. He argues that “English orthography is, at an abstract level, a psychologically significant level from which pronunciations can be predicted”. Thus English phonological rules will predict how the added suffixes “-ic” and “-y” will reassign the stress pattern of “telegraph” to “telegraphic” or “telegraphy”. And the orthography also helps the user to predict the phonetic forms and stress patterns speakers use in such derived words as *morality* from *moral*, *personify* from *person*, *resignation* from *resign*, and *parental* from *parent*. O'Neil concludes his essay with an elucidating remark that spellings “are represented by alphabetic writing systems (that) are themselves quite resistant to change” (p. xxxvii).

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AMERICAN ASSOCIATION OF PHONETIC SCIENCES

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A number of meetings were held by American Phoneticians between 1970 and 1972; their purpose was to consider the possibility of forming a national society. These discussions were lively with many individuals outlining the unmet needs of Phoneticians in America and the success of many nationally or regionally organized groups abroad. Others argued the converse, suggesting that the International Society of Phonetic Sciences, the International Phonetics Association, the Acoustical Society of America, the American Speech and Hearing Association and the Linguistic Society of America could meet the cited needs and provide a venue for relevant activities. The problem faced, however, was that the first two of these societies were international in nature and the primary focus of the other three was on disciplines other than Phonetics. For example, Phoneticians were bunched into a Speech Communication section in ASA and with the "speech" and "voice" scientists in ASHA. Since the preponderance of opinion favored incorporation, a working group was formed. It consisted of W. S. Brown, H. Hollien, L. LISKER, R. E. McGlone, J. F. Michel and T. Shipp. This committee established the association, wrote a set of By Laws, held elections, instituted a newsletter and scheduled the first annual meeting — which was held in 1973.

The initial set of officers were: President: H. Hollien, Vice President: L. LISKER, Secretary: K. Harris, Treasurer: W. S. Brown, Councilors: P. DENES, P. LADEFOGED, P. MACNEILAGE; committee chairs were: Membership: I. LEHISTE, Nominating: A. Malecot, Program: P. MacNeilage, Constitution: A. BRONSTEIN and Publications: J. Michel. Since that time, nearly 150 American Phoneticians have served as officers and/or chairs of various committees/functions; they have done so for over the 25 years of AAPS's existence. For example, the AAPS Presidents (two-year terms each) have been H. Hollien, L. Lisker, P. MacNeilage, T. Shipp, J. Shoup, D. Beasley, R. KENT, G. Allen, R. Baken, R. Colton, J. Folkins, R. Orlikoff and J. Hoit. And, as may be seen, AAPS enjoyed its 25th Birthday in 1998.

The role of AAPS is primarily that of a clearing house for Phoneticians residing in America. It supports three principal functions: 1) annual meetings, 2) a newsletter and 3) group/individual services. The first of these — the annual meetings — originated during the formation year of the Association; for convenience, it is usually held in conjunction with the Fall meetings of the Acoustical Society or with the annual ASHA convention. By this means, AAPS members can attend, and participate in, the activities of a second organization. The AAPS program varies from a single evening to two days in length and includes scientific papers on Phonetics, laboratory reports and especially presentations on the nature, problems and future of Phonetics. The annual AAPS program is always followed by a social hour, one where Phoneticians can interface directly with their colleagues.

One of the more important AAPS activities is the publication of a *Newsletter*. As such, it is aptly named for it provides American Phoneticians with current information about many facets of their field. The AAPS *NL* also is variously a repository of 1) abstracts of relevant papers; 2) programs at various laboratories and universities (with reports on both research and teaching), 3) information about new equipment, books and relevant computer programs, 4) necrology, 5) databases of references of interest, and 6) lists of meetings. While very few scientific articles have been published in the AAPS *NL*, a number of essays about Phonetics can be found among its pages. The debate about the nature and importance of the Phonetic Sciences was initiated by H. Hollien in only its second issue. This effort was expanded greatly in the early and mid 1980's by position papers authored by J. M. PICKETT, R. KENT and K. N. STEVENS. The excitement was soon intensified by a lively exchange about the need for major Phonetics units and university departments in the U.S. The primary interchange took place between P. LADEFOGED (departments are not needed) and J. Flege (departments are badly needed) and continued on from there. The publication of essays provided by members has continued over the years. Some involved the State-of-the-Science as did R. Kent's reviews of those speech processing systems available in 1990; other efforts focused on the future of Phonetics (J. Folkins: *Exploding/Imploding*; H. Hollien: *Phonetics 2000*). Published twice a year, the *Newsletter* also provides cross-discipline contacts for the AAPS membership.

The general services provided by the association have been a little limited but still are of importance. A modest amount of Phonetics research has been supported (mostly by use of facilities) and a number of Phonetics conferences have received support — that is, when they were held in the United States. One of the more important services AAPS provides its membership involves an open forum — one where Phoneticians, Speech Scientists and relevant Engineers can exchange ideas, argue philosophy and negotiate relationships either on a face-to-face basis or via the Internet. Members J. Mahshie and T. Bunnell have established an AAPS Home Page at the following address: <http://www.gallaudet.edu:80/~aapsjm/index.html>, and, yet more important, a list server for rapid and useful interchange (listproc@gallux.gallaudet.edu).

The American Association of Phonetic Sciences now looks to its second quarter century of service. It is hoped that during the next millennium it can continue to assist American Phoneticians in their research, teaching and leadership.

PART II. INSTITUTIONS

PHONETICS RESEARCH AT BELL LABORATORIES *

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INTRODUCTION

The history of phonetic and acoustic research at Bell Laboratories reflects a strong tradition of interdisciplinary inquiries. Phonetics research is inseparable from many related fields such as hearing, acoustics, speech coding, speech transmission, and speech synthesis. Generations of physicists, engineers, linguists, psychologists, mathematicians, and computer scientists joined forces to solve fundamental problems in the study of human speech. In the process, they often needed to design tools and to develop methodologies, which had a profound impact on the field, and will continue to influence speech research in the future.

BEGINNINGS: BELL'S TELEPHONE

ALEXANDER GRAHAM BELL, the founder of the Bell Telephone Company, grew up with, first, a deep awareness of the needs of the deaf community (his mother and his wife were hard of hearing) and, second, a solid training in phonetics. His father Alexander Melville Bell designed a feature-based phonetic alphabet called *visible speech*¹, published first by the father (Bell, 1867; Bell 1881), and later by the son (Bell, 1916) with detailed notes on articulatory phonetics. The decomposition of phones into features and their consistent usage made the system easy to learn, especially for the deaf. The combinatorial possibilities of the features and an additional set of symbols for non-speech sounds gave the system the capability to transcribe different languages, accents, and non-speech sounds.

EARLY 20TH CENTURY AT BELL LABS

While ALEXANDER GRAHAM BELL was exploring methods to capture the visual image of sound waves as a teaching aid for the deaf, he realized that if he could convert sound waves into electric currents, then he could transmit speech over a long distance. He made several attempts to obtain graphical records of speech sounds but the results were not satisfactory. Bell's waveform display in 1874 was weak and lacked discernible details. Meaningful phonetic/acoustic study from waveforms was achieved 50 years later with an improved oscillograph, made possible with the advancement of sound amplification by vacuum tubes (H. D. Arnold), distortion control (Irving B. Crandall), and their incorporation in a condenser-type microphone (E. C.

Wente). Crandall and Sacia (1924) and Crandall (1925) presented the waveforms, energy, and spectrum characteristics of English vowels, semivowels, and consonants from 4 male and 4 female speakers. The study was among the first to define spectral properties that differentiate one speech sound from another. Around the same time, Fletcher (1922) established the perceptually salient frequency band of each English speech sound using filtered speech as stimuli. He also studied extensively the interaction of intensity level and listener's recognition rate of each English sound.

THE SOUND SPECTROGRAPH & ACOUSTIC ANALYSIS

BELL's dream of visualizing sound waves was finally realized in the sound spectrograph, invented in the early 1940s. It soon became an indispensable tool for phoneticians. Today, 50 years later, while the generation of spectrograms is done digitally rather than by analog circuitry, the principle and even the display of spectrograms remain the same. Work on the sound spectrograph at Bell Laboratories intensified during the Second World War due to potential military applications, including speech-encryption and speaker identification — since the voices of radio operators could reveal information on troop movement. Because of that, all publications were held back until the war ended (Dudley and Gruenz, 1946; Koenig et al., 1946; Kopp and Green, 1946; Riesz and Schott, 1946; Steinberg and French, 1946). A year later, the *Visible Speech* (Potter et al., 1947) was published — a namesake of Melville Bell's phonetic alphabet. This book is simultaneously a historical account of the spectrograph project and a technical manual for spectrogram reading. Visual cues to the interpretation of spectrograms were exemplified with ample explanation on their correlations to acoustic properties. The idea of *hubs*, target formant values of sounds, was developed to explain coarticulation effects and the resulting variations in spectrograms. The authors even designed a set of phonetic symbols derived from formant structures to facilitate speed reading of spectrograms.

Bell Labs continued its efforts to study speech sounds, production and perceptual cues, acoustic and articulatory models (French and Steinberg, 1947; Potter and PETERSON, 1948; Potter and Steinberg, 1950), and pattern playback synthesis (Schott, 1948). Peterson and Barney (1952) reported results from a database of 76 speakers, including men, women, and children, speaking English words with 10 different vowels in the *h d* context, such as "heed", "hid", and "head". Auditory identifications of all stimuli from 70 listeners were also obtained. The paper included informative figures of the formant space of all sounds, the average F0, F1, F2, and F3 values of all vowels by men, women, and children, and explored factors that lead to

*We would like to thank Mohan Sondhi, Joe Hall, Lloyd Nakatani, Bernd Mobius, and Richard Sproat for helpful discussions in the process of writing this paper.

1. For example, the consonant signs were open circles with the direction of the opening reminiscent of the place of articulation. Manner of articulations were indicated by embellishments on the open circle, such as using a bar for voicing and a wavy line for fricative.

vowel misidentification by listeners. Dunn (1950) calculated vowel resonances from vocal tract dimensions, compared them to measurements from natural speech, and tested them with an electronic vocal tract model.

In 1940, Farnsworth succeeded in taking high speed motion pictures of vocal cords during speech (Farnsworth, 1940) providing a valuable source of information for the study of vocal cord movements. Miller (1959) devised an electronic inverse filter that removes the vocal tract resonances, thereby revealing the glottal waveform.

THE VODER AND SPEECH SYNTHESIS

The understanding of the principles of human speech naturally leads to a desire to simulate human speech. Speech synthesis, and the later text-to-speech system, is another research topic that has been carried out in tandem with phonetics research at Bell Laboratories. The creation and the improvement of a speech synthesizer requires all aspects of phonetic and acoustic knowledge. At the same time, a working synthesizer is a good testing ground for phonetic and acoustic hypotheses. The first electronic speech synthesizer, the *Voder* (Dudley et al., 1939), was developed by Homer Dudley at Bell Laboratories, and was demonstrated at the World's Fair in 1939 in New York. The *Voder* was a keyboard-like instrument with keys, switches, and pedals controlling variations in vowel resonance, sound source, and pitch. The picture of the *Voder* can be found on the Bell Labs Archive web site <http://www.lucent.com/museum/1936scs.html>. A sample of the *Voder* speech (as well as many other speech synthesis samples up to 1987) was collected in the synthesizer archive of DENNIS KLATT (1987) and can be downloaded from <http://www.icsi.berkeley.edu/eecs225d/klatt.html>. Soon after the *Voder*, Dudley developed the *Vocoder* which can play back speech from phonetic specifications (Dudley, 1939). Dudley also contributed to an interesting article reviewing the early history of phonetic alphabets, speech acoustics, and mechanical speech synthesis (Dudley and Tarnoczy, 1950).

Digital synthesizers were developed soon after the introduction of the digital computer. Kelly and Gerstman (1961) implemented a digital formant synthesizer, which takes phonetic input and computes three formant resonators and pitch. Kelly and Lochbaum (1962) described the first articulatory synthesizer, replacing the earlier formant models with vocal-tract models. Later articulatory synthesis include Coker (1968) and FLANAGAN et al. (1975).

SPEECH ANALYSIS & TEXT-TO-SPEECH SYNTHESIS

FUJIMURA employed fiberoptic and x-ray microbeam techniques (Fujimura, 1977; Fujimura et al., 1979; Fujimura, 1980) to take measurements and to construct articulatory models of vocal cords, nasal and stop consonants, larynx, and the tongue. The microbeam research was extended to allophonic variations of English /l/ (Sproat and Fujimura, 1993).

The first text-to-speech system at Bell Labs was developed by Coker et al. (1973). English text was converted to phonetic input by the use of a dictionary, the output was then sent to a formant synthesizer. The idea of concatenative speech synthesis — connecting segments of stored real speech to create new sentences — was proposed in the fifties by PETERSON et al. (1958). The idea was tested with magnetic tapes. A digital

concatenative synthesizer was implemented by OLIVE (1977) when computers had gained enough memory and processing power. This system was the predecessor of the current Bell Labs text-to-speech system. Duration models (UMEDA, 1975; Umeda, 1977), FO models (Olive, 1975), pronunciation variations (Umeda and Coker, 1974), and glottal flow models (ROSENBERG, 1971) were developed and were used in the text-to-speech systems. At the same time, studies by Nakatani et al. (Olive and Nakatani, 1974; Nakatani and Dukes, 1977; Nakatani and Schaffer, 1978; Nakatani, 1981) established the role of prosody in production, comprehension, and the naturalness of synthetic speech. They showed speech concatenation may improve the intelligibility of synthesized speech, but the naturalness of the system lies in better understanding and modeling of prosody.

PROSODIC MODELING & SYNTHESIS

Pierrehumbert (1980) developed a formal grammar of English intonation. Intonational contours were represented as tonal sequences, and were classified into pitch accents, phrase accents, and boundary tones. Liberman and Pierrehumbert (1984) explored several factors affecting the phonetic implementation of pitch accents, such as foreground and background reading, downstep, and final lowering. Hirschberg (1992) linked the pitch accent predictions to discourse structure. The model was generalized to Japanese (Pierrehumbert and Beckman, 1988) and to Chinese (Shih, 1988). An implementation of this model for the English text-to-speech system is described in Anderson et al. (1984), and the implementation for Chinese, Navajo and Japanese in Sproat (1998).

The current text-to-speech system of Bell Labs includes the following languages/dialects: English, German, Chinese (Mandarin and Taiwanese), Spanish (Latin American and Castillian), French, Russian, Italian, Japanese, Romanian, and Navajo. Many of these systems are accessible on the web: <http://www.bell-labs.com/project/tts/>.

Behind each language there is an extensive research effort, including the collection of speech databases, typically of thousands of sentences, containing multiple instances of all possible phone-to-phone sequences and many triphone sequences in the language. The databases offer valuable information on phone inventories and coarticulation effects. OLIVE et al. (1993) provides detailed discussions of all sound transition patterns in English with illustrations of waveforms and spectrograms. Sproat (1998) reported F1/F2 space of vowel inventories of a few languages, and Shih and Sproat (1996) reported the Chinese data.

The current duration models and a set of tools for analysis were developed by Jan van Santen for English (van Santen, 1992; van Santen, 1994), and applied successfully to other languages (Shih and Ao, 1996; Möbius and van Santen, 1996). Many interacting factors affecting duration were considered, and greedy algorithms were employed to choose text materials for the duration database that provide maximum coverage of desired factor combinations. A central idea of the theory, with support from multilingual data, is that most of the durational effects are *monotonic* in nature — the relative durational scale of members of phone classes, such as voiceless fricatives, tends to be preserved under different contexts — therefore the durational variation in speech can be captured by additive or multiplicative models. In cases where factors interact, duration can be predicted by sums-of-products models (van Santen, 1993).

The current intonation model, with precise alignment of accent curves with the segmental material, was developed by van Santen (van Santen and Möbius, 1997; van Santen et al., 1998). The model has been successfully applied to Germanic and Romance languages, as well as Russian.

PHONETICS AND TELECOMMUNICATIONS

We have often been asked in the past why a telecommunications company is interested in phonetics research, and what the current direction is. The application of phonetics research has taken many unexpected turns over the years. In the early days, the understanding of speech and hearing was vital to the design of telephone equipments, which must convert and amplify speech with minimum distortion in the frequency range that is important to human speech production and perception. There is also a continuous quest for a cost-efficient method for speech compression for the purpose of data transmission. Dudley's vocoder was conceived as such a system: speech was converted into phonetic specifications and could be synthesized from such specifications. Only the specifications, not the speech, needed to be transmitted over the phone line, at a much narrower bandwidth. As new technologies evolved, the scope of phonetics research has widened to include high quality text-to-speech systems and speech recognition systems (Riley and Ljolje, 1991, Giachin et al., 1991) as a service within today's communication network.

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FURTHER READINGS

For readers who would like to delve into the subject more deeply, we highly recommend the following books: *A History of Engineering and Science in the Bell System: The Early Years (1875-1925)*, and *A History of Engineering and Science in the Bell System: Communications Sciences (1925-1980)*. These are two volumes of a set of five, which summarize Bell Labs research up to the eighties. The chapters were written by experts in the fields, with fascinating technical and historical details that are accessible to general readership.

Fletcher (1953) presented work on phonetics, acoustics, loudness, and hearing as integral components of the human communication network, and how the advancement of these areas impacted telecommunications. The book gave detailed summaries of works by Crandall et al., Potter et al., and Farnsworth. The 1997 reprint by the Acoustical Society of America makes this valuable resource available again. For easier reading on the same subject, there are two popular books, also from Bell Labs researchers, *Man's World of Sound* (Pierce and David, 1958), and *Speech Chain* (DENES and Pinson, 1963).

FLANAGAN (1972) gave an excellent account of speech synthesis work from the earliest records up to the seventies. Sproat (1998), written by the current members of the TTS team, describes the Bell Labs multilingual text-to-speech system, which is a modern product made possible by a tradition of speech research that goes back more than a hundred years.

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A CENTURY OF PHONETICS AT BERKELEY

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INTRODUCTION

The teaching of phonetics at the University of California, Berkeley (UCB), spans nearly a century although there are several discontinuities in the record of original phonetic research. There are approximately four periods of research. The first period, starting in 1901, saw phonetic work serving the needs of anthropologists and linguists interested in documenting, preserving, and instrumentally analyzing indigenous languages of the Americas and elsewhere. A second period occurred in the 1920s and 1930s with the x-ray studies of RICHARD T. HOLBROOK in the Department of French. The third period in the late 1940s and through the 1950s was marked by the work of YUEN REN CHAO of the Department of Oriental Languages. Chao used the sound spectrograph to help in the documentation and analysis of Chinese dialects. The fourth period, which continues to the present, started in the late 1960s with the establishment by WILLIAM S-Y. WANG of the Phonology Laboratory within the Department of Linguistics. The principal focus of the lab, now under the direction of JOHN J. OHALA, is to arrive at a general understanding of the speech code by applying phonetic data, methods, and theories to the explanation of sound change and common sound patterns in languages of the world. Additionally, research on automatic speech recognition is conducted at the International Computer Science Institute (ICSI) under the direction of Nelson Morgan and speech motor control is investigated by Richard Ivry in the Department of Psychology.

THE BEGINNINGS

From 1901 to 1906 a Department of Linguistics was established at UCB under the chairmanship of Benjamin Ide Wheeler, (1854-1927) (then president of the university — his term in that position running from 1899 to 1919). Wheeler's own specialization was classical philology, especially of Latin, however he had an interest in virtually all areas of linguistics, not excluding phonetics¹. In 1901 Wheeler also saw to the founding of the Department of Anthropology (which has flourished to the present) and hired ALFRED L. KROEBER as its first faculty member. Between Linguistics, Anthropology, and other language departments, phonetics has been taught at Berkeley in one department or another since the early 1900s — initially by Wheeler, now by OHALA. Evidence of the cross-disciplinary approach to phonetics pedagogy is the 1917 course description for Anthropology 150, taught by T. T. Waterman:

An introduction to the general principles of phonetics, with illustrations from English, French and German. Recommended for advanced students who

intend to take courses in philology, ancient or modern, or in linguistic theory.

It was through Wheeler's initiative that the Danish phonetician Otto Jespersen came to Berkeley in the summer of 1909 as a Visiting Professor in the Department of English. The Harvard phonetician CHARLES HALL GRANDGENT was another visiting professor during this period.

The original research in phonetics at this time was done almost exclusively by anthropologists. Anthropologists and ethnologists such as A. L. KROEBER, P. E. GODDARD, E. SAPIR, T. Waterman, and J. P. Harrington were driven by their interest in studying and preserving other cultures and saw language as one of the more tangible and empirically describable aspects of culture. Adopting the latest phonetic tools and instrumental techniques of the time, including the kymograph, palatography, and photography, these scholars incorporated empirical measurements and methodologies into their study of the linguistic systems of Native American languages.

ALFRED LOUIS KROEBER (1876-1960) was an outstanding anthropologist and ethnologist, not only for the quality of his work, but for the sheer quantity of languages that he documented. He contributed much to the field of phonetics up until the 1920s, and to linguistics in general until the 1950s. One of his major contributions to both Anthropology and Linguistics (inspired by FRANZ BOAS) was the use of statistical methods in the empirical documentation of the Native American languages. Out of the 33 native American languages he documented, a few incorporated detailed instrumental records from the most up-to-date speech analysis tools of the time. He used instrumental phonetics not only to accompany his descriptive documentation, but as a means to evaluate the accuracy of the phonological claims of his contemporary field workers. He showed through kymographic recordings that the variation perceived between voiced and voicelessness in intermediate stops was not due to the laziness of Native Americans, but arose through consistent, predictable allophones that simply differed from those found in English. Colleagues of his, such as T. T. Waterman and J. P. Harrington also adopted instrumental techniques but did not emphasize them nor see them as essential in the documentation of languages. Kroeber was also the first to document a Polynesian language with instrumental techniques.

An interest in the culture and language of the Native American language, Hupa, brought P. E. GODDARD to the Department of Anthropology of Berkeley in 1901, where he worked as a graduate student for Benjamin Ide Wheeler, in order to learn the formal tools of ethnology. The University acquired a Rousselot kymograph for him which he used to document both the Hupa and Kato languages. Like his mentor, KROEBER, Goddard was an excellent scholar and recognized not only the importance of the study of language for its insight into a culture,

¹ Wheeler was one of the translators — in 1891 — of Hermann Paul's influential and seminal volume on the theoretical bases of linguistics, *Prinzipien der Sprachgeschichte*.

but also the importance of empirical data and precise measurements to such ventures.

In his treatment of the Hupa language he used laboratory techniques to solve disputes about the nature of the phonemes themselves, by taking articulatory measurements from native informants, not by relying on their phonological patterning alone. His work on Kato includes a description of ejectives — derived from his kymographic recordings — that is essentially that which we hold today: stops made by compressing air in the oral cavity when supraglottal, velic, and glottal apertures are closed. He also published detailed descriptions of the tools he used in order to make these techniques public and to promote their use for language documentation. GODDARD attempted to show the importance of such mechanical aids in the study of languages by demonstrating the inadequacy of alphabets for anthropologists studying unknown languages (alphabets can only represent sounds one already knows), and by discussing the problem of relying on introspection in phonetic description (since one can't produce a new sound unless one already knows how it is articulated). Using palatography, Goddard showed that the Hupa [d] is articulated considerably further forward (dental) than the English [d] of the same, bilingual, subject.

GODDARD also recognized the importance of acoustics for phonetic measurements. But while Hermann, Bevier, and SCRIPTURE were making tracings from phonographs, cylinders, or gramophone disks — which preserved the higher frequencies — Goddard took the voice measurements directly from the kymograph tracings where only low frequencies were present. He enlarged these traces by microphotography to analyze them by means of the Le Conte curve analyzer.

The anthropological and ethnographic application of “ear” phonetics for language description continued up to the present. The work of Mary Haas (1910-1996) and Murray Emeneau (1904-), the founder of the present Department of Linguistics in 1952, with phonetic and phonological description of Asian and Native American languages, exemplifies this tradition.

RICHARD T. HOLBROOK

In 1937, *X-Ray Studies of Speech Articulations* by RICHARD T. HOLBROOK (1870-1934) and Francis J. Carmody was published. Carmody pieced this monograph together after Holbrook's death based on the latter's notes. It consisted of reports of a series of experiments that used an alarming number (by today's standards) of x-rays of subjects uttering specific speech sounds. At the time, the standard method involved subjects speaking with small chains held taut over the articulators, which would show up on the x-rays, revealing a two-dimensional outline of the articulator in question. Holbrook improved this technique by instead spraying lipiodol (iodized sesame oil) into the speaker's mouth, nose or throat, which would then reveal the three-dimensional aspects of the articulators as well as difficult-to-reach spots, such as the epiglottis.

HOLBROOK, who was professor of French from 1919 until his death in 1934, had as his primary interest in phonetics the sources of variation in the articulation of vowels. In 1929, he showed that as F0 is elevated, the larynx rises more for the high vowels ([i] and [u]) than for the low ones (like [a]) and more for the rounded front vowels than for the unrounded ones. He also showed how the tilt of the head can influence the articulation of vowels. The influence of the size of the jaw opening also played

a role in the articulation of vowels. This research — essentially similar to modern “bite block” studies — showed that the place and degree of the tongue-palate constriction is not much changed even with a highly exaggerated jaw opening. Holbrook's x-ray studies investigated the vowels and selected consonants of French, Spanish, Polish, Russian, and German. Carmody used these experiments to critique the ‘vowel triangle’ as well as other highly impressionistic labels that were in use at that time for describing vowels and other speech sounds: terms such as ‘dark’, ‘light’, ‘open’, ‘closed’, ‘mellow’, ‘metallic’. Based purely on the articulatory properties of vowels, Carmody suggested that a quadrilateral might be more in line with the data they found, and that what seems to remain constant across different speakers and different instances is not the exact location of these articulators, but their relative position.

YUEN-REN CHAO

YUEN-REN CHAO (1892-1982), educated in China and in the United States, had had prior teaching and research positions at Cornell, the National Tsing Hua University (Beijing), Harvard, Academia Sinica (Beijing), and Yale, before being appointed professor at Berkeley in 1947. There he was named Agassiz Professor of Oriental Languages in 1952 until his retirement in 1960. Chao's phonetic work was manifested primarily in his extensive work on Chinese dialects, phonetic transcription (especially of Chinese, and that exemplified especially by his phonetic dictionary of Chinese), and phonological theory. He was the inventor of the “tone letters” used in IPA for the transcription of tones and was one of the first phoneticians on the U.S. west coast to obtain a sound spectrograph, which he used, among other things, for the analysis of tone. During his time at Berkeley, Chao also produced an insightful review (1954) of JAKOBSON, Fant, & HALLE's *Preliminaries to speech analysis*.

1967 TO THE PRESENT

In 1967 WILLIAM S-Y. WANG came to the Department of Linguistics and founded the Phonology Lab. Wang was committed to applying modern empirical techniques in phonetics (and related disciplines) to the traditional questions of phonology, including the mechanisms of sound change and phonological universals. He was instrumental in recruiting PETER MACNEILAGE to the then Speech Department from 1967 to 1969, and JOHN OHALA who started at Berkeley in 1970.

OHALA became head of the Phonology Lab in 1975 at the same time that WANG established another research unit, Project on Linguistic Analysis (POLA). The research focus at POLA was diverse, including the perception of tones, the origin and development of speech and language, and neuro-phonetics. The Phonology Laboratory, which continued to be the center for the teaching of phonetics in the Department of Linguistics, continued to research sound change with special emphasis on perceptual mechanisms and speech aerodynamics. In addition, psycholinguistic aspects of phonology and ethological aspects of speech (cross-species commonalities in vocal communication) were explored. Among those who completed their dissertation research in the lab are: Matthew Chen (UCSD), Marilyn Vihman (Univ. of Wales, Bangor), Jean-Marie Hombert (Lyon II), Hector Javkin (Santa Barbara), Haruko Kawasaki-Fukumori, Jeri J. Jaeger (SUNY, Buffalo), Kazue Hata (Panasonic), Margot Peet (MITRE Corp.), Mariscela Amador (Sony Corp.), Michelle

Caisse, John Kingston (Univ. of Mass, Amherst), Kathleen Hubbard (UCSD), Joyce Mathangwane (Univ. of Botswana), and Natasha Warner (MPI, Nijmegen).

In 1988, the International Computer Science Institute (ICSI) was inaugurated with primary financial support from German government and industry, and with the active participation of the Computer Science Division of UCB. Since that time, its support has broadened to include Switzerland, Italy, and Spain, numerous U.S. government grants, and significant sponsorship from AT&T. Although a range of topics in computer science have been explored at ICSI, the computer engineering or "Realization" group ultimately focused on systems and algorithms for automatic speech recognition. This effort was led by Nelson Morgan of Electrical Engineering, who is also the current Director of ICSI. Contributions of this group to speech research included the design of multiple auditory-like transformations to be used in tandem to overcome the problems of signals degraded by noise and room reverberation, and the detailed study of spontaneous speech.

In 1991, Richard Ivry joined the Department of Psychology and established the Human Performance and Sensorimotor Control Laboratory. Ivry's research focuses on the psychological and neural mechanisms involved in motor control with a special interest in temporal information processing. With respect to speech production, Ivry and his colleagues have analyzed the speech production of patients with cerebellar disorders, given the problems these patients have in regulating the timing of voluntary movements. These studies have revealed a dissociation between the control of temporal aspects of articulation (e.g., voicing) and spectral aspects (e.g., place of articulation).

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PHONETICS AT THE UNIVERSITY OF FLORIDA

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*Institute for the Advanced Study of the Communication Processes
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The Phonetic Sciences program at the University of Florida was initiated in 1962. That is not to say that General Phonetics was not taught at this institution prior to that time. Indeed, a leading American Phonetician — C. K. Thomas — had transferred from Cornell and was on faculty; further R. E. Tew taught a number of "Speech Science" courses. Actually, however, the 1962 arrival of G. P. Moore, H. Hollien, and their primary consultant G. PETERSON, signaled the development of a larger, more complicated program than simply Phonetic Sciences alone. Their goal was to bring together those scholars and scientists who were studying virtually any aspect of human communication — and do so at a single research center. This new organization was called the Communication Sciences Laboratory (CSL). It was divided into three major components: 1) Phonetic Sciences (Experimental Phonetics, Speech/Voice Science, Communication Factors Engineering), 2) Audition (Psychoacoustics, Auditory Physiology, Audiology) and 3) Language Sciences (Linguistics, Psycholinguistics). Over the next few years, several other programs or projects were added either to these three sections or established as separate (but smaller) entities. They included: 1) Animal Communication, 2) Computational Linguistics, 3) Man-Machine Communication, 4) Underwater (Diver) Communications and 5) Forensic Communication. The initial CSL Director was G. P. Moore; he was succeeded by H. Hollien. The Academic programs were administered by CSL faculty: 1) Phonetics: D. Dew (later W. S. Brown), Audition: J. F. Brandt (later D.C. Teas) and 3) Language: P. J. Jensen (later R. Scholes). Local and national consulting boards were established with G. Peterson (chair) joined initially by J. F. Curtis, R. Rhodes and J. Wepman. After Peterson's death, this board was expanded to include G. Fant, F. HOUSEHOLDER, R. Schiefelbusch and J. Zwislöcki. In 1968, CSL was provided its own facilities in Dauer Hall and in 1974 was greatly expanded and given independent status. At that time, it was renamed the Institute for Advanced Study of the Communication Process (IASCP) and, as a STAR-2 program reporting to the Board of Regents via the UF Vice President, it served all nine State of Florida Universities. The IASCP Director was H. Hollien; he was later succeeded by W. S. Brown. Although partially supported by the State of Florida (faculty, academics) the primary financing of the IASCP research programs came from the several hundred research grants attracted by its faculty. Over the past 35 years CSL and IASCP have sponsored/supported several thousand students, graduate students, post-doctoral Fellows and visiting/sabbatical scientists.

Even though Phonetic Sciences was embedded in the (cited) larger structure, it played a key role in the overall CSL/IASCP research and academic programs. For one thing, the first formal PhD program at CSL was in the Phonetic Sciences. Approved in 1963, it was followed by the Phonetics MA program (1964) and

an undergraduate major (1966). Ultimately the advanced Phonetics degrees could be sought from either the Speech (now CPD) or Linguistics departments (plus a version through Engineering). Over the years, the structure of the Phonetics PhD has varied but little — primarily due to the upgrading and addition of new courses. It consists of a core in the Phonetic Sciences (included are acoustics and physiology) plus secondary curricular in Psychoacoustics and Linguistics. Tools are in Computer Science, Statistics and (usually) Audioengineering. On average, two individuals per year have graduated from the Phonetics doctoral program; many have gone on to develop their own organizations whereas others work as scientists and/or academics at university (and industrial) laboratories and clinics. Other features of the CSL/IASCP Phonetics program are the relatively large number of Post-doctoral students that have been trained at this site. So too have hundreds of other academics and professionals — either as visiting scholars or at the many intensive two-week seminars sponsored by this organization. Finally, several subspecialties within the Phonetic Sciences have been developed. These included the study of animal communication and the specialization in underwater (diver) communication. However, the program with the greatest impact appears to be that of Forensic Phonetics.

The research programs in Acoustic, Physiological and Perceptual Phonetics have been among the most robust at CSL/IASCP. Indeed, scientists in this one division have attracted slightly over half of all of the nearly 400 research (and research training) grants won by CSL/IASCP personnel. These projects have included research on nearly all aspects of the Phonetic Sciences except perhaps artificial intelligence; they have been awarded by NIH, NSF, ONR, NIJ, ARO, the VA and a number of foundations; a few also were awarded by Fulbright, IREX, DOC, the U.S. State Dept. and various law enforcement agencies. As would be expected, the CSL/IASCP Phoneticians proved to be among the most productive at this research center. They have contributed over half of the nearly 1000 major publications plus about one third of the books and two patents. Appropriately, a number of these specialists have received recognition — such as election to Fellow by major scientific organizations; several have received individual awards for their research contributions.

While it is difficult to single out any particular scientist for recognition, it is possible to identify certain of the contributions to the field of Phonetics which have been made at CSL/IASCP. One such breakthrough involved the development of stroboscopic x-ray of the larynx. Until the present, anyway, the system developed for this purpose is the only one by which the living, vibrating vocal folds may be seen in coronal cross-section. Another advance is a real-time F0 tracking system which permits the period of each wave (in any complex acoustic series) to be

measured. Fundamental frequency measurements, in either Hertz or semitones, are realized by means of equal tempered music scale processing. Third, only recently finalized is a voice identification system which is based on the computer processing of those features perceptually employed by humans for this purpose. The "perceived" elements of pitch level (and variability), voice quality, vowel articulation and speaking rate (or prosody) are machine determined. The protocols employed first force the system to match its own reference sample within a

field of foils, and then go on to assess the exemplar voice; the process is repeated a number of times before a match (or non-match) is attempted.

In summary, the CSL/IASCP faculty in the Phonetic Sciences — plus their students and associates — can be seen to have materially contributed to their field. They have done so both by the development of training programs and through their personal research.

NOTES ON PHONETICS AT GALLAUDET UNIVERSITY: SPEECH SCIENCE VS DEAFNESS*

J.M. Pickett

Windy Hill Lab, Surry, ME

INTRODUCTION

Gallaudet College (1864; University, 1984) is the only institution for higher education of deaf people with a traditional curriculum of arts and sciences. Scientific research has never been a major component of Gallaudet, but since World War II there has been a gradual acceleration of scientific activities.

SPEECH RESEARCH AT GALLAUDET

Beginnings

There was a glimmer of speech research at Gallaudet during the period 1953-1961 when G. OSCAR RUSSELL (1890-1962), Research Professor of "Speech Hearing, and Voice of the Deaf", was there during the last years of his professional life. Despite his very early papers on speech and deafness (e.g., Russell, 1929) I could not find any papers from his tenure at Gallaudet.

S.C.R.L. In 1964 I joined the faculty of the Department of Audiology and Speech as a Professor of Speech Communication Research. I was provided with a part-time audiologist, Robert Daly, and we called ourselves the Sensory Communication Research Laboratory (SCRL).

G.R.I. In the 1970s the Gallaudet Research Institute (GRI) was formed out of existing departmental studies in Psychology, Education, English (sign-language linguistics), and Audiology and Speech. About 1983 SCRL became autonomous as the Center for Auditory and Speech Sciences (CASS) within the GRI.

Our program of research was modeled in my studies at Oberlin College with the phonetician/psychologist, R. H. STETSON, and his student C. V. Hudgins¹. They believed in applying speech research and development for the deaf, not only to find improved methods of teaching speech to deaf speakers, but also to gain basic insights into normal motor mechanisms of speech production and perception, especially as related to Stetson's syllable-based theory of production and motor theory of speech perception (Stetson, 1951, pp. 144-149; or 1988, pp. 166-170). In addition, I had spent a 1961 fellowship year at the Swedish Royal Institute of Technology, where I studied phonetic perception of speech stimuli conveyed by a tactile speech analyzer to deaf "listeners" (PICKETT, 1995).

The Center's program studied the basic acoustic cues in phonetic perception by normal listeners and a range of hearing-impaired listeners. Numerous experiments explored the use of acoustic cues to place of articulation, voicing, nasality, and manner of consonants, often using computer-altered and synthesized syllables (Bunnell, 1990; Revoile, 1993; 1998). Other communication problems studied were tactile speech aids and cochlear implants (Pickett and McFarland, 1985). Bernstein

¹ Hudgins became the first research director in a school for the deaf, in 1936 at the Clarke School, Northampton, MA. (Hudgins, 1934).

(1995) studied tactile speech signals in combination with lipreading, using distinctive feature analyses and proposing new theoretical approaches to the problem. Pickett, Bunnell and Revoile (1995) published a theoretical review of the phonetics of consonant perception. Nabelek and Pickett (1974) did the first studies of impaired perception via hearing aids of acoustic features of consonants in reverberation of varying degrees.

Phonation for speech was studied via computer modeling of the vocal folds, when two physicists joined the CASS staff. The first, on sabbatical in 1974-5 from Brigham Young University, was W. S. Strong. He developed a model on our (old) PDP-12 computer and, when he had to go back to BYU, he recommended his student I. R. Titze to us. Titze's work on the problem, beginning in 1976, brought biomechanical parameters into the model and it is now probably the most complete model of phonation, accounting for many normal and abnormal vocal-fold phenomena (Titze and Talkin, 1979; Titze, 1994). In 1979 he left Gallaudet to establish the National Center for Voice and Speech at the University of Iowa, where he has continued work to improve the model.

Cued Speech Program. In 1966 Dr. Orin Cornett, a physicist and University Vice President, started work to develop Cued Speech, a phonemically-based system using coded hand-signals while speaking in order to completely disambiguate lipreading for a deaf viewer. The speaker supplements each consonant-vowel syllable (CV) with a unique hand shape and position at the side of the mouth. The combination of a mouth pattern together with the hand gesture defines each syllable. The system is used primarily by parents while speaking to their deaf children. The Program develops and disseminates teacher materials. Research studies demonstrate large benefits in language and speech use and in general educational progress (Quenin, n.d.). The method has also been adapted to several languages. Research at MIT seeks to develop a wearable device that would operate automatically to derive the cues and display them superimposed on the user's view of the speaker's face (Uchanski et al., 1994).

Speech Communication Lab, Department of Audiology and Speech (1982-). This research group focuses on measuring speech production and the role of sensory feedback in articulatory control and voice production by deaf speakers. Techniques used are electropalatography and electroglottography together with air-flow and pressure-indicating devices (Mahshie & Yadav, 1990; Mahshie, 1992; Mahshie, 1995). Computer processing of outputs from these sensors enables display of the speaker's articulation in speech-training sessions. Current studies employ computer voice-quality measures and training feedback. Analysis-by-synthesis is also used to model disordered speech production, in collaboration with colleagues at MIT and in Ireland.

Gallaudet's Non-experimental Contributions. Two international conferences were sponsored by the Center: the 1967 Conference on Speech-Analyzing Aids for the Deaf (PICKETT, 1968) and the 1977 Conference on Speech Technology for the Deaf. The '67 Conference described and demonstrated numerous electronic devices, of a stand-alone or wearable type, for speech training and aid to speech perception; 150 persons attended. The '77 Conference emphasized computer-based research and demonstrations, to 270 participants.

1980 saw the publication of a sabbatical project by J. M. PICKETT, *The Sounds of Speech Communication, A Primer of Acoustic Phonetics*, Allyn and Bacon, Boston. An expanded second edition of that book is now in press (Pickett, 1998).

Bunnell, now at The A.I. Dupont Institute, developed a highly useful suite of speech research programs for PC's called EDWAV beginning about 1983 and continuing to the present (Bunnell, 1999). This software can be downloaded free by request from www.asel.udel.edu/speech. In 1996 he hosted the 3rd International Conference on Speech and Language Processing held in Philadelphia.

PICKETT served as Associate Editor for Speech for the *Journal of the Acoustical Society of America* and Revoile serves on the Executive Council of the Society. They are both Fellows, as is Professor Titze.

GALLAUDET SUPPORT FOR SPEECH RESEARCH

The "Golden Age" of the Sixties. When I arrived at Gallaudet there was a new Hearing and Speech Center, already built, and flourishing in the heady enthusiasm of the President Lyndon Johnson's social program called "Great Society". The President and faculty were highly supportive (we received about 60% of our funding from the University's budget). The College funded my entire tenured salary and continued that policy for new associate researchers who might, for example, be first hired on University funds and then obtain NIH grants for their own funding increases.

A Difficult Time. In the 1970s "deaf power" attitudes became somewhat hostile to the hearing world and all researchers and faculty were required to become proficient signers. This placed a considerable burden on most non-teaching researchers who were not deaf and were already overloaded with reporting and grant writing for ever harder-to-get grants from the shrinking real budgets of federal research agencies. I stepped down as Director of CASS, in 1985, succeeded by Sally G. Revoile.

In 1988 the students successfully revolted and closed the University to force the Trustees to ask the new President, who had normal hearing, to resign and appoint a deaf President. The deaf president candidate, Dr. I. King Jordan, a professor in the Psychology Department, was well qualified except for his lack of administrative experience. But he made a fine president. However, in the 1990s the University's funding overall (c. 95% direct from the Federal Government budget) was considerably reduced.

In 1996, the Center for Auditory and Speech Sciences of the GRI was closed due to funding difficulties and a gross decline of the Institute's interest in auditory speech research and speech production. A list and copies of the Center's publications can be obtained from the Dean of Graduate Studies and Research, Gallaudet University, 800 Florida Ave. N.E., Washington, DC.

Research on speech production continues in Mahshie's Speech Communication Lab, Department of Audiology and Speech Pathology.

Thus ended the enthusiastic period of phonetically oriented research at Gallaudet. At its peak, c. 1990, the Center had seven doctoral investigators and a total staff of 14 persons. A previous 3-year grant as a "Rehabilitation Engineering Center" sponsored closely related work that is still continuing, at MIT (tactile speech), CUNY (tactile voice pitch feedback), and Johns Hopkins University (vibrator design for a wearable tactile aid).

However I'm sure that speech research will break out vigorously again at Gallaudet, perhaps as specialized research for processing by cochlear implants or tactile aids, and text-to-speech applications, if only because about 95% of the parents of deaf children have normal hearing.²

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² Other directors of speech research for the deaf are:

- Dr. Nancy Tye-Murray, Director, Research Department, Central Institute for the Deaf, 818 S. Euclid St., St. Louis, MO 63110.
- Prof. Harry Levitt, Graduate Speech Program, CUNY Graduate Center, 33 W.42 St., New York, N.Y. 10036.
- Dr. Lynne E. Bernstein, Spoken Language Processing Lab, House Ear Institute, 2100 W. 3rd St., Los Angeles, CA 90057. National Technical Institute for the Deaf, Lomb Drive, Rochester, N.Y.
- Dr. Karl-Erik Spens, Department of Speech Music and Hearing, Royal Institute of Technology, S-100 44, Stockholm, Sweden.
- Dr. H. Timothy Bunnell, Head, Speech Processing Group, Dupont Institute, Wilmington, DE.
- Prof. Nathaniel Durlach, MIT Group on Biocommunications, RLE, Massachusetts Institute of Technology, Cambridge, MA.

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*The opinions expressed in this paper are personal to the author and should not be construed as official information from Gallaudet University.

SPEECH RESEARCH AT HASKINS LABORATORIES

Carol Fowler and Katherine S. Harris
Haskins Laboratories

INTRODUCTION

In this short history of Haskins Laboratories we have emphasized the abiding themes of the Laboratories' work, and the lines of research for which they are best known, although this tends to shift the emphasis towards older studies and is done at the expense of particular investigations. This focus leaves us without a specific spot to emphasize Haskins' most significant contribution: It has been for about fifty years a place where a substantial group of investigators with expertise in different aspects of speech and language production and perception could work together, in an environment with substantial and often innovative technical resources.

BEGINNING

Phonetics research began at Haskins Laboratories (founded in 1935 in New York City, moved to New Haven, CT, in 1970) late in the Second World War as part of a program headed by FRANKLIN COOPER and ALVIN LIBERMAN, to develop aids for the recently war-blinded, in particular, a reading machine. The machine was built to produce distinct, discrete, and invariant non speech sounds each corresponding to a textual symbol. That is, an acoustic alphabet replaced the written one. When sounds were sequenced at rates fast enough to be within normal reading rates, listeners were unable to determine the order in which the sounds occurred; the rates apparently exceeded those at which the auditory system can resolve the temporal order of discrete sounds. This finding led them to ask why speech perception can occur at rates so much faster than the rates at which users of the reading machine failed. Using the sound spectrograph, then recently developed at Bell Laboratories and its complement, the Pattern Playback, (invented and built at Haskins by Franklin Cooper), Liberman, Cooper and PIERRE DELATTRE began to study the acoustic speech signal, to determine how it represents the consonants and vowels of spoken words, and to discover the acoustic structure (the "cues") essential for their identification by listeners. Spectrographic displays provided a visible indication of the structure in the acoustic speech signal; the Playback transformed either a photographic negative of a spectrogram, or, more usefully, a hand-drawn, often highly schematic, spectrogram into sound. By selectively including and eliminating elements of acoustic structure, Liberman and his colleagues could determine what bits of structure provided information for the different phonetic properties of spoken words.

They made a number of important discoveries (e.g., DELATTRE, LIBERMAN, COOPER and Gerstman, 1952; Liberman, Delattre and Cooper, 1952). Discovery of the acoustic cues for consonants and vowels, among other consequences, enabled development of rules for speech synthesis, first by Frances Ingemann (Ingemann and MERMELSTEIN, 1975) and subsequently, implemented as a computer program, by IGNATIUS MATTINGLY (1968). This advance, among its many other valuable uses, was a crucial step making possible the

development of the modern reading machine. A prototype machine was built at Haskins in a project worked on by Cooper, Patrick Nye, Frances Ingemann, Jane Gaitenby and George Scholes, but loss of funding prevented its full implementation.

MOTOR THEORY

The group realized early that speech is not represented acoustically by an alphabet; rather, owing to coarticulation in speech production, information for consonants and vowels in a word is interleaved and is highly context-sensitive. Two early findings were especially important. LIBERMAN et al. (1952) and Carol Schatz (1954) found that the same piece of acoustic structure (a burst centered at 1440 Hz) was heard as /p/ in the context of some following vowels but as /k/ in the context of others. This finding held whether natural subphonemic bits of speech were reassembled from taped natural speech, or whether highly schematized patterns were synthesized on the Pattern Playback. Complementary to this finding, two very different transitions of the second formant (a high rising transition in the context of /i/ and a low falling transition in the context of /u/) specified invariant sounding /d/s to listeners (Liberman, DELATTRE, COOPER and Gerstman, 1954).

These two findings were central to the development of a novel theory of speech perception. Both findings appear to show that the listener's percept bears a closer correspondence to the gestures that produce consonants than to the acoustic signal. Due to coarticulation, the signal provides different "cues" to the same phonetic properties in different phonetic contexts. Due to coarticulation, the only way to get a burst centered at 1440 Hz before the vowel /i/ is to close the lips; the only way to get the same burst before /a/ is to make a velar constriction. Due to coarticulation, the same alveolar constriction produces a high rising second formant transition in the context of coarticulated /i/ and a low falling one in the context of coarticulated /u/. Despite coarticulation, talkers articulate a given consonant in roughly the same way in all phonetic contexts.

The early version of LIBERMAN's motor theory (Liberman, COOPER, Harris and MACNEILAGE, 1962) proposed that the invariant percepts correspond to invariant articulations but variable acoustic signals develop when listeners learn to associate sensory feedback from their speech musculature to the consequent acoustic signals. The motor theory stimulated considerable phonetics research at Haskins Laboratories and elsewhere.

SPEECH AS A BIOLOGICAL SPECIALIZATION

Although LIBERMAN initially supposed that the motor percept was achieved by a process of associative learning, discussions with scientists who studied the communication systems of other animals helped him to develop a different idea (Liberman, COOPER, Shankweiler and STUDDERT-KENNEDY, 1967). The communication systems of other animals are evolutionary

achievements. Further, some other animals (certain birds, for example) had been found to recruit their neural systems for call production during the act of perception (Nottebohm, 1975), not unlike what Liberman proposed that human speech perceivers do. Liberman and colleagues proposed, now, that phonetic perception is no less a biological specialization of humans than is the ability to produce and understand syntactically structured sentences. One consequence of this idea was research conducted by Donald Shankweiler, Michael Studdert-Kennedy and BRUNO REPP (Studdert-Kennedy and Shankweiler, 1970; Repp, 1975) using dichotic listening to test for a left-hemisphere specialization for speech perception. Highly reliable findings were that stop consonants especially led to a strong right ear advantage in dichotic listening. (Due to the right ear's privileged access to the left hemisphere, these findings have been interpreted as evidence for left hemisphere superiority in stop perception.)

A second consequence of the idea that speech is a biological specialization of humans was a search for perceptual evidence for a distinct module of the brain (in Fodor's (1983) sense of "module") sub-serving speech perception (and production). The most compelling evidence was the finding of "duplex perception" obtained originally by Timothy Rand (1974) at Haskins but pursued further, among others, by LIBERMAN, Douglas Whalen and Virginia Mann (Mann and Liberman, 1983; Whalen and Liberman, 1987). Duplex perception is observed when all of a consonant-vowel syllable except for its third formant transition is presented to one ear, while the missing transition is presented to the other ear. Remarkably, listeners integrate the acoustic structure across the ears, hearing a syllable the identity of which is determined by the transition, but the speech-likeness of which depends on integration of the transition with the remainder of the syllable. Perception is duplex, because the listener also hears a chirp-like sound in the ear to which the isolated transition was presented; the chirp is the transition heard by itself. The important finding is that listeners hear the transition in two ways simultaneously, as part of a speech syllable and by itself. This suggests that two perceptual systems are being engaged by the stimulation; if so, one may be a special-to-speech system that renders a syllabic percept, and the other is likely to be a general auditory system that renders an apparently literal percept of the frequency glide that constitutes the transition.

ACOUSTIC CUES FOR SPEECH

While these theoretical developments were important in motivating work at the Laboratories, systematic experiments on the nature of the cues for speech perception continued, and suggested ways of tying the cues to speech perception to the details of speech production. Work by ARTHUR ABRAMSON and LEIGH LISKER showed the importance of the acoustic consequences of the timing of the burst of energy signaling stop release and of vocal fold pulsing in signaling the distinction between "voiced" and "voiceless" stop consonants. Interestingly, investigations across languages showed that the timing of these events was language specific — that is, the same interval was judged as e.g., /p/ or /b/, depending on the target language, that is, the category boundary moved around (Lisker and Abramson, 1964). Two exciting lines of work resulted. At a perceptual level, Liberman showed that discrimination of speech sounds is good at phonetic category boundaries, but quite poor within them. In languages with different category boundaries, the

discrimination peak moves correspondingly (LIBERMAN, Harris, Hoffman and Griffith, 1957). This relationship between speech perception and auditory psychophysics piqued the interest of experimental psychologists in both the phenomenon itself and the study of speech itself as a worthy subject for examination within the framework of general cognitive psychology.

A second development was the interest generated in the articulatory events underlying the acoustic events. Collaboration with the Institute of Logopedics and Phoniatics of the University of Tokyo allowed Haskins Laboratories to examine events at the larynx directly with fiberoptic instrumentation, and show that the dynamic differences seen in the acoustic signal mirrored the physiological timing of events at the larynx and upper articulators (Sawashima, ABRAMSON, COOPER and LISKER, 1970). Subsequent research has shown that the study of voice onset time is an important tool in tracing the development of speech from babbling to adulthood, in characterizing the difference between pathological and normal speech, as well as in documenting cross-language differences.

SPEECH PRODUCTION

Katherine Harris and PETER MACNEILAGE began to study speech production, initially to test the motor theory's prediction that EMG signals from muscles used in production of phonetic properties would be found to be less context-sensitive than the corresponding movement signals. The tests failed to support the theory, leading to modifications of it. However, Katherine Harris and, later, her students, Fredericka Bell-Berti, Lawrence Raphael, and Gloria Borden recognized the important puzzles requiring solution for our understanding of speech production, and work in that domain began to develop along lines somewhat independent of research on perception.

The initial interest in the muscles of articulation as a potential source of invariant signals led, eventually, to the development of a novel set of methods for studying them. The researchers from the University of Tokyo brought with them techniques for using fine hooked wires inserted in the articulatory and laryngeal muscles to examine the organization of muscles involved in the articulation of various sounds. Bell-Berti (1976) examined the muscles of velopharyngeal closure. The Tokyo researchers, with Tom Baer, made contributions to laryngeal articulation (Hirose, Lee and Ushijima, 1974; see the review by Harris, 1981). Raphael and Bell-Berti (1975) examined the muscular correlates of the distinction between tense and lax in vowels.

COARTICULATION

One area in which researchers at the Laboratories have made important theoretical and methodological contributions to an understanding of speech production is in the area of coarticulation. Based on their research findings, Bell-Berti and Harris (1979) challenged a popular theory of coarticulation, the look-ahead model, based on feature descriptions of phones. According to that theory, talkers will begin producing a phonetic feature (such as lip rounding or nasalization), as early as they can in a word and therefore during any segments that do not require an opposite-sign feature value (lack of rounding or nasalization). Bell-Berti and Harris found that anticipations are much shorter than previous research had suggested and tend to begin an invariant interval before other phonetic properties of, for

example, a rounded or nasal segment. Demonstrating this involved a methodological improvement over earlier research designs. In the study of rounding, for example, lip movement or lip muscle activity in the phonetic environment of a rounded vowel is evaluated relative to lip movement or lip muscle activity in the same phonetic environment, but of an unrounded vowel. In this way, lip movement that may accompany production of unrounded segments can be factored from coarticulatory lip rounding.

ARTICULATORY PHONOLOGY

Beginning in the late seventies, work on production and perception moved closer together, and related work on a theory of articulatory phonology was initiated. One idea motivating the joint attention to phonology, production, and perception was that independent development of these three domains may have exaggerated apparent incompatibilities among their component units. Phonological theory offered units that could not be implemented nondestructively as vocal tract activity; vocal tract activity, therefore, could not be supposed to cause an acoustic signal that conveyed the phonological units directly; accordingly, perception of speech necessarily was construed as indirect and reconstructive.

One line of theoretical development and experimental work, therefore, was to discover the consequences of assuming that phonological units are, as it were, designed for the vocal tract. Catherine Browman and Louis Goldstein proposed and developed an articulatory phonology (1986) in which primitives of the phonology are articulatory gestures, rather than abstract features or phonemes. The theory has excited considerable discussion and debate in the literature. They have implemented their theory as a Linguistic Gestural Model on the computer that serves as a component of an integrated model of production.

ACTION THEORY AND TASK DYNAMICS

As for production itself, the search began for physical evidence of gestures. Stimulated by theoretical advances in our understanding of intentional action made by Michael Turvey, it was proposed by FOWLER, Rubin, REMEZ and Turvey (1980) proposed that articulatory "units" of action in speech are coordinative structures (that is, synergies). For example, in production of /b/, the two lips and the jaw temporarily form a "special purpose device" the goal of which is to produce a constriction at the lips. The synergies produce the articulatory gestures described by Browman and Goldstein's articulatory phonology. Research by Vincent Gracco (1988) and by Scott Kelso, Betty Tuller and colleagues (Kelso, Saltzman and Tuller, 1986) tested and confirmed proposals that transient coordinations form during speech. Subsequently, these theoretical ideas were made more explicit and were related to dynamical systems theory by Elliot Saltzman (Saltzman and Kelso, 1987), who developed a "task dynamic" model of speech production. Browman and Goldstein's Linguistic Gestural Model provides "gestural scores" for words to Saltzman's task dynamic model. In turn, the task dynamics model controls Haskins' articulatory synthesizer. The synthesizer first developed by PAUL MERMELSTEIN (1973) [at Bell Labs] and further developed by Mermelstein, Pat Nye, Tom Baer and Philip Rubin (Rubin, Baer and Mermelstein, 1981), produces acoustic speech signals from vocal tract shapes and

motions. Accordingly, the integrated model produces theory- and model-driven acoustic speech signals.

THE LINK BETWEEN PRODUCTION AND PERCEPTION

An essential characteristic of any communication system is that it must consistently achieve "parity" — here, a relation of equivalence between messages sent and received. A proposal that gestures are units of words as language users know them and are units in actions of the vocal tract producing speech is a proposal that the units of the spoken message are preserved in vocal-tract activity — a parity-fostering characteristic of speech if the proposal is accurate. If listeners perceive gestures, then units of the original message (at the phonological level of description) are preserved throughout a communicative exchange, further fostering achievement of parity. Two theories of perception developed at Haskins Laboratories suggest that listeners perceive gestures, and a recognition model has tested the feasibility of gesture extraction in machine recognition of speech.

One theory is the revised motor theory (LIBERMAN and MATTINGLY, 1985), which proposes that gesture extraction is an important function of a specialized phonetic module of the brain. In that theory, gesture extraction is achieved by recruitment of the speech motor system in perception. The other is direct realist theory (FOWLER, 1986), which claims that listeners perceive gestures because they are what is conveyed by the structure in the acoustic speech signal. As for the recognition model, Richard McGowan (1994) has used genetic algorithms to find a best-fitting gestural solution to acoustic input representing VCVs.

Together, the theories of articulatory phonology, of task dynamics in production and of gesture perception constitute the most integrated account of these components of language use in the field of speech to date.

FIRST LANGUAGE DEVELOPMENT

Finally, researchers at Haskins have made significant contributions to the field of phonetics in their work on development of speech production and perception in infants and young children. The work on production carried out by MICHAEL STUDDERT-KENNEDY and his students (Nittrouer, Studdert-Kennedy and McGowan, 1989; Goodell and Studdert-Kennedy, 1993) has shown that phonological (and therefore gestural) structure in words emerges gradually from larger, syllable like structures. The work on perception carried out by Catherine Best and colleagues (Best, 1994) has led to a theory (the Perceptual Assimilation Model) that explains how the infant's perception of native and nonnative phones undergoes change beginning at about 10 months of age. Nonnative phones that are very similar to native phones assimilate to native categories. Two nonnative phones that assimilate to the same native category become difficult to discriminate by 10 months of age even though they may have been readily discriminated at younger ages. Pairs of nonnative phones that assimilate to different native categories remain discriminable.

CLINICAL RESEARCH

Finally, we should point out that the Laboratories have consistently carried out work on problems of clinical populations in parallel with investigations of normal production and perception. We have performed studies of stuttering (e.g., Story,

Alfonso and Harris, 1996) and the speech of the deaf (e.g., McGarr and Löfqvist, 1982). Most notably, researchers at the Laboratories have developed a theory of phonological awareness as a way of accounting for the difference between good and poor readers (e.g., LIBERMAN and Shankweiler, 1989).

ACKNOWLEDGMENTS

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THE UNIVERSITY OF IOWA LABORATORIES

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In trying to portray the history of the University of Iowa laboratories in this brief paper, I have had to be highly selective in citing areas of research (e.g., research on hearing has been omitted) and the individual scientists who have made contributions. In addition, only a few sample bibliographical references have been included for each major area.

THE BEGINNINGS AND THE LABORATORIES

Research related to the phonetic sciences has been conducted at the University of Iowa for over 75 years. The founding father of this work was Carl E. Seashore who came to Iowa as a professor of psychology in 1897, became dean of the Graduate College in 1908, and had a major impact on the program into the 1940's. Due to his influence, Iowa became a national leader in the development of psychology as an experimental science. His interests in the laboratory study of music, voice, hearing, and speech disorders had been stimulated by his contact with E. W. SCRIPTURE at Yale. Although his own research in these areas was significant (e.g., development of musical aptitude tests and one of the first audiometers), Seashore's greatest contributions were to stimulate interest in phonetic science research among faculty members and students across the University and to provide the laboratories and equipment for that research. It should be noted that the Iowa laboratories have never been a cohesive, easily identifiable entity. The first laboratory was in the Department of Psychology and included a sound-treated room and the best equipment then available for analysis of acoustic signals (e.g., a high-speed oscillograph and a Henrici Harmonic Analyzer). Later, the primary laboratories were located in the Department of Speech and then in the Department of Speech Pathology and Audiology. As noted later, however, research in the phonetic sciences has always involved laboratories located in various University units: e.g., Otolaryngology, Child Welfare Research Station, Dentistry, Neurology, Pediatrics, and Psychiatry. The following sections include work carried out in all of these sites.

MAJOR RESEARCH AREAS

Although research on speech production and disorders at Iowa has covered a broad range, some of the areas in which sustained, major contributions have been made are the following:

Stuttering

In 1924, Lee Edward Travis became one of the first persons in the country to receive a doctorate degree based on a program of study in speech and speech disorders. As a faculty member at Iowa, he instituted a research program focused on the problem of stuttering, a program that has continued to this day. Travis used newly developed electromyography and, later, brainwave observations, in an attempt to identify physiological factors related to this disorder. His work was stimulated by the hypothesis that stuttering was related to a lack of cerebral dominance. Although the hypothesis could not be adequately

affirmed, this research provided an important base of information about the physiological characteristics of stuttering. From the late 1930s until the mid-1960s, leadership in stuttering research was assumed by one of Travis's former students, Wendell Johnson. Unlike Travis, Johnson focused on the psychosocial aspects of stuttering. He was interested particularly in studying children and their interactions with parents in order to look at stuttering onset. In addition, he and his colleagues (e.g., John Knott) described in detail the "moment" of stuttering behavior and how it varied with linguistic context, the social situation, and other factors. The discovery of such phenomena as "adaptation" contributed greatly to future work on this disorder, both here and abroad. From the mid-1960's through the 1980's, stuttering research at Iowa was led by Johnson's student, Dean Williams. His work focused on studying this disorder as a learned behavior and investigating what clinical approaches were effective in modifying it. During this same period, another Iowa scientist (Gerald Zimmermann) went back to Travis's approach of studying the physiological characteristics of stuttering, particularly motor control of the speech articulators. In the 1990s, stuttering research is being conducted by Patricia Zebrowski, who has combined previous themes by studying the physical capabilities of stutterers (visual-motor tracking and articulator movements), detailed characteristics of stuttering and non-stuttering behavior (acoustic studies of temporal factors), and parent-child relationships. The focus has continued to be on children and on the onset and development of this disorder.

Voice Production and Disorders

From the time of Seashore, there has been an interest at Iowa in the laboratory study of voice production and disorders. During the 1930s, GRANT FAIRBANKS and his students obtained basic data on the fundamental frequency characteristics of speech as a function of age and other factors. From 1940-80, James Curtis and a number of his students (e.g., Harry Hollien) carried out studies of the physiological aspects of voice production. Since 1979, the primary leadership in this area has come from Ingo Titze. His comprehensive research program has focused on quantifying the details of laryngeal function, including how muscles and aerodynamic factors interact to control pitch, intensity, registers, etc. in both speaking and singing. This research has included basic neurophysiological studies (Erich Luschei), detailed study of anatomy and histology, assessment of voice differences among individuals, and the development of computerized models of laryngeal function (Fari Alipour). In addition, in collaboration with faculty in otolaryngology, studies on voice disorders have been carried out. Currently, research in this area is supported by the NIDCD (National Institute of Deafness and other Communication Disorders) -funded National Center for Voice and Speech, which is directed by Ingo Titze and involves scientists from various Iowa departments and from other

institutions (Univ. Wisconsin, Univ. Utah, and the Denver Center for the Performing Arts).

Speech Articulation

Iowa research in this area has had four distinct phases. Initial studies (1930-60) attempted to describe the static articulatory positions for speech sounds through palatography (Brady, 1932) and still x-ray procedures (Kelly and Higley, 1934) or to relate the vocal tract configurations to acoustic properties (e.g., Wendahl, 1957). The second phase, beginning in 1960, involved the use of cineradiography, in conjunction with EMG and/or aerodynamic measures, to specify the nature, timing, and overlap (coarticulation) of movements of the tongue, lips, jaw, and velum as phonetic context, stress, rate and other factors were varied. The research was directed by this author with the help of numerous students and colleagues: e.g., Ray Daniloff, Jim Lubker, Jerry Carney, RAY KENT, and Dave Kuehn. These studies yielded a large amount of physiologic phonetic data that served as a base for the development of theories of speech programming and control. The third phase began in 1977 when John Folkins became director of this NIH-(National Institute of Health) funded project. Over the next 15 years, he and his colleagues (e.g., Gerry Zimmermann, Don Cooper, Anne Smith, Raymond Linville) used cineradiography, EMG, and strain-gauge techniques to study the motor control of speech production, particularly movements of the lips, jaw and velum. The emphasis was on describing how structural movements were modified under changes in mechanical loading or other experimental conditions and how the movements related to each other rather than to phonetic or linguistic variables. These approaches also were applied to such disorders as deafness (Nancy Tye-Murray) and cleft palate speech, and stuttering (Zimmermann). The fourth and current phase of articulatory research, directed by Jerry Moon as part of the National Center for Voice and Speech, involves the study of normal and disordered functioning of the velopharyngeal mechanism. The focus is on obtaining the detailed data on velar anatomy and physiology, functional characteristics (muscle patterns, closure forces, etc.), and coordination with other articulators that are required to develop a finite-element model of how this mechanism functions during speech production.

Cleft Palate Project

A major interdisciplinary research program on problems associated with cleft lip and palate has been conducted at Iowa since 1955, with long-term support from NIDR (National Institute of Dental Research) grants. This program, initially directed by D. C. Spriestersbach (1955-65) and then by Hugh Morris (1966-94), has involved scientists from the departments of speech pathology and audiology, otolaryngology, orthodontics, pediatrics, biology, anatomy, and psychology. Research has focused on the speech, physical, and psychosocial characteristics of persons with cleft palate and the surgical, dental, and speech management of their problems. Relative to the phonetic sciences, these studies have made major contributions to (1) our understanding of the basic functioning of the velopharyngeal mechanism in both normal and disordered speech (David Kuehn, KEN MOLL, John Folkins, Raymond Linville, David Jones), (2) detailed knowledge of the speech characteristics of persons with cleft palate and their relationship to physical and other factors

(D.C. Spriestersbach, Hugh Morris, Duane VanDemark, Mike Karnell), and (3) the development of procedures and standards to be used for diagnostic evaluations and for assessing the efficacy of surgical, dental, and other management procedures in establishing the necessary physical pre-requisites for normal speech (Spriestersbach, Morris, VanDemark). These contributions made Iowa an international leader in this area.

Language Development and Disorders

During the 1940s, the research program on infant vocalizations carried out by O. C. Irwin of the Iowa Child Welfare Research Station provided some of the first available data on the sequential development of individual speech sound production. Work in this area was continued during the 1950s by Frederic Darley, who also focused on the study of language disorders and the development of clinical techniques for assessing various dimensions of language. Beginning in the early 1980s, Bruce Tomblin and his colleagues began a series of projects on developmental language impairments. The initial epidemiological studies (with Herman Hein and James Hardy) followed over 2000 children from 0-5 years and demonstrated that the most prominent risk factors for developmental language impairment were the speech, language, and learning characteristics of the parents. Subsequent studies showed that the familial nature of such language impairment is due to both genetic and environmental sources, established prevalence statistics for such disorders, and obtained cross-sectional data on the speech and language status of a large cohort (2000) of kindergarten children. This cohort is currently the focus of longitudinal research being conducted under the Child Language Research Center, funded by NIDCD, which involves investigators at Iowa (Tomblin, Jeff Murray, and Amy Weiss) and at Purdue, Wisconsin, and Kansas.

Neuropathologies

Early studies of speech and language disorders related to neuropathologies were carried out at Iowa by Spencer Brown (1940s) and Frederic Darley (1950s). In the 1960s James Hardy focused on respiratory and other mechanisms of speech production in dysarthric patients, the physiological deficits they exhibited, and how their speech problems could be managed. Since 1984, Donald Robin and his colleagues have studied (1) the motor control abilities of persons with aphasia, apraxia of speech and dysarthria, (2) the role of auditory processing and attentional deficits in communication disorders associated with stroke, and (3) the language, speech and attentional abilities of children and adolescents with traumatic brain injury.

Other Areas

Unfortunately, there is not space here to describe the contributions made by Iowa researchers in many other areas of the phonetic sciences. Worthy of specific mention are (1) the pioneering work of Glenn Merry, Joseph Tiffin, and Milton Metfessel in applying basic instrumental techniques to the study of speech (1920s and 1930s), (2) the application of psychological scaling techniques to the measurement of speech dimensions by Donald Lewis and Dorothy Sherman (1950s), (3) research on speech perception (Richard Hurtig); and (4) investigations by Richard Tyler, Nancy Tye-Murray, and others, of receptive and

expressive language skills in deaf children and adults with cochlear implants (1990s).

SOME BASIC TRADITIONS

Throughout its history, work in the phonetic sciences at Iowa has been characterized by three basic traditions that have uniquely shaped the scope and nature of the program.

Interdisciplinary Efforts

There is a university-wide tradition, going back to Carl Seashore, for interdisciplinary efforts across departmental and collegiate lines. As Graduate Dean, Seashore instituted the "individual plan" whereby graduate students could design interdepartmental programs, encouraged and facilitated multidisciplinary research efforts, and fostered the development of the new interdisciplinary field of speech pathology and audiology. This tradition has manifested itself in two ways. First, the Department of Speech Pathology and Audiology has always maintained a faculty prepared in a variety of basic disciplines. Current faculty represent the areas of experimental psychology, neurophysiology, physics, psycholinguistics, and communication engineering, as well as communication sciences and disorders. This diversity has had a distinct effect on the nature of the research carried out and the orientation of the new scientists being prepared. Second, the tradition is reflected in the interdepartmental and interinstitutional research that has been conducted, major examples of which are the three comprehensive research programs discussed above: (1) the Cleft Palate Project, (2) the National Center for Voice and Speech, and (3) the Child Language Research Center. The contributions of these programs could not have been achieved without the collaborative efforts of scientists from a variety of departments and institutions.

Basic and Clinical Sciences

The second tradition of the Iowa programs has been an emphasis on integrating basic science research with the study of communication disorders and their clinical management by providing an environment where persons interested in basic communication processes and those with more clinical research interests could closely interact. This emphasis grew out of the philosophies that research knowledge must precede clinical treatment and that research into normal and disordered processes cannot be meaningfully differentiated. This tradition led to the application of basic laboratory procedures to the systematic study of communication disorders and provided a unique perspective that has undoubtedly affected those scientists trained at Iowa.

Research and Education

The third tradition is that the Iowa research activities have always been closely integrated with the educational preparation of new scientists, teachers, and clinical professionals. Perhaps some of the most important contributions of Iowa are not the research results generated, but those graduates who went on to make significant contributions to the field. Many of those who spent most of their careers at Iowa are mentioned in preceding sections: e.g., Johnson (1931)¹, Curtis (1942), Spriestersbach (1948),

Williams (1952), MOLL (1960), Morris (1960) VanDemark (1962), Zimmermann (1973), and Karnell (1983). Some of those early graduates who established pioneering programs at other universities were GILES GRAY (1926, LSU, Louisiana State University), Clarence Simon (1925, Northwestern), Bryng Bryngelson (1931, Minnesota), Charles Van Riper (1934, W. Michigan), JOHN BLACK (1935, Ohio State), and Max Steer (1938, Purdue). Among the many Iowa graduates who achieved wide recognition for their work in phonetic sciences at other institutions are GRANT FAIRBANKS (1936, Illinois, Stanford), Frederic Darley (1950, Mayo Clinic), Harry Hollien (1955, Florida), FRED MINIFIE (1963, Wisconsin, Washington), Tom Hixon (1965, Wisconsin, Arizona), Ray Daniloff (1967, Illinois, Purdue, LSU), Jim Lubker (1967, Univ. Stockholm; University of Vermont), RAY KENT (1970, Wisconsin), Ed Conture (1972, Syracuse), Dave Kuehn (1973, Illinois), and Anne Smith (1978, Purdue).

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¹ Information in parentheses is the date the person received the doctoral degree at Iowa and the primary institutions, other than Iowa, at which they spent their career.

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HISTORY OF PHONETIC SCIENCES AT THE UNIVERSITY OF MICHIGAN

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So far as we have determined, the first Professor of Phonetics at the University of Michigan was John H. Muyskens (1887-1957). Muyskens received his ScD from Michigan in 1925 with a dissertation on "The Hypha", a term he used to refer to a minimal physiological unit of speech. Appointed as Assistant Professor of French and Phonetics in 1924, Muyskens was Associate Professor of Phonetics and General Linguistics as well as Director of the Speech Clinic at the time of his death in 1957. Muyskens collaborated with Clarence L. Meader (Professor of Latin, Sanskrit, and General Linguistics) on the study of the physiology of normal and pathological speech. Their ambitious program for the study of speech is documented in Meader and Muyskens (1950) *Handbook of Biolinguistics*.

1940 - 1950

During the 1940s, the most important contributions to the study of phonetic sciences at Michigan were made by KENNETH L. PIKE. Pike's interest in phonetics stemmed from his evangelical commitments, especially that of providing the Scriptures to linguistic communities throughout the world. His early association with the Summer Institute of Linguistics (SIL) taught him the value of phonetics as preparation for Bible translation. Through his work with SIL, fieldwork in languages of Mexico, and graduate studies under SAPIR, BLOOMFIELD, and FRIES at the Linguistics Society of America Summer Institutes, Pike earned his PhD at Michigan in 1942. On the Linguistics faculty at the University of Michigan from 1942-1977, President of SIL from 1942-1979, former President of the Linguistics Society of America (1961), permanent council member of the International Phonetic Association, and named Charles C. Fries Professor in 1974, Pike became Emeritus Professor after his retirement in 1977.

Pike's dissertation, published in 1943 (Pike, 1943), was the most thorough survey up to that time of the phonetic possibilities of the human vocal tract, and possibly the most influential of his many phonetic publications. This work was quickly followed in the subsequent five years by a series of publications on tone, intonation, and phonemic theory. Inspired by extensive field experience, Pike's contributions, while firmly grounded in theory, were also highly practical and pedagogically oriented. He was among several faculty members who inspired a group of Michigan graduate students to found the journal *Language Learning* in 1948, with Pike as an Editorial Advisor.

As a teacher of phonetics and linguistics, PIKE is legendary for his demonstrations of the monolingual field technique in which he shows, through a 40-minute exchange with a native speaker of a language unknown to Pike, that language can be learned without an interpreter. As Eunice Pike observed,

"Watching [a demonstration] is something like watching a high diver in Acapulco, Mexico, as he dives from the cliffs there into the ocean below. It's beautiful, and you know he's an expert, so you don't expect trouble, but there is always the chance that he might end up on the rocks instead of in the ocean. That possibility makes you watch all the more intently" (Pike, E., 1981, p. 130). (A videotaped demonstration is available through the University of Michigan Television Center's *Pike on Language* series.) Through his long-standing affiliation with Michigan and SIL (including field seminars on several continents), Pike's influence on our knowledge of linguistic phonetics — either directly or through his students — extends to hundreds of indigenous languages.

1950 - MID 1960s

By 1950, PIKE's interests were being re-directed from phonetics and phonemics towards grammatical theory. Although some of Pike's students continued to work on phonetic issues, the primary driving force behind the study of phonetics at Michigan in the 1950s through the mid 1960s was GORDON E. PETERSON. Peterson left Bell Laboratories in 1953 to join the Departments of Speech and Electrical Engineering at Michigan. His interests in the phonetic sciences were broad, including acoustic analysis, speech synthesis, automatic speech recognition, and phonemic theory. A member of the Permanent Council for ICPhS, during his years at Michigan Peterson was also editor of the *Journal of Speech and Hearing Disorders* (1955-57) and Vice President of the Acoustical Society of America (1966).

PETERSON brought with him from Bell Laboratories a Model D spectrograph (one of only a few spectrographs then in existence) and in doing so introduced the study of experimental phonetics for research purposes to the University of Michigan. Peterson's former students have graciously offered us glimpses of the earlier years. ILSE LEHISTE describes "the special excitement that the availability of the spectrograph created — we knew that whatever we were looking at, nobody had seen before. I imagine a biologist might have felt the same way when handed the first microscope" (personal communication). (That spectrograph now resides in the Smithsonian Institute, donated by June Shoup). The new Communication Sciences Laboratory required major changes to the basement of the Frieze Building, including installation of a sound-attenuated room and an anechoic chamber. In describing Peterson's perfectionism ("in the best sense"), WILLIAM WANG recalls that the evening the chamber was installed, he and Peterson crawled with flashlights and crowbars around the base of the chamber to sever any solid contacts between the chamber and the surrounding building left by the poured concrete.

PETERSON's own work bridged experimental phonetics and linguistic theory, hence it is not surprising that research in both phonetics and phonology was conducted by members of the laboratory he directed. Examples of the work undertaken by this interdisciplinary group of linguists, engineers, speech scientists, and psychologists give a sense of the laboratory's varied activities. ILSE LEHISTE (Linguistics PhD, 1959; now Emeritus Professor at the Ohio State University) focused on the acoustic structure of English; her discoveries included the intrinsic pitch, intensity, and duration of vowels. Lehiste continued as a Research Associate in the laboratory until 1963. Language automation was a major research effort of the laboratory, funded by numerous governmental grants (Air Force, Navy, National Institute of Health (NIH), National Science Foundation (NSF)). WILLIAM S.-Y. WANG (Linguistics PhD, 1960; now Emeritus Professor at the University of California, Berkeley) and June Shoup (Linguistics PhD 1964; now Emeritus Professor at the University of Southern California) worked on phonetic issues with practical applications to automatic speech recognition and speech synthesis. Wang and Charles Fillmore (Linguistics PhD, 1962; now Emeritus Professor at the University of California, Berkeley) collaboratively investigated acoustic cues for speech perception; Fillmore also worked in phonological theory. DENNIS KLATT (Computers and Communication Sciences PhD, 1964; Professor at MIT at the time of his death in 1988) investigated information processing in the peripheral auditory system; Norris McKinney (Computers and Communication Sciences PhD, 1965; now with the International Linguistics Center) worked on techniques for analyzing fundamental frequency.

In 1966, due to failing health, PETERSON left the University of Michigan for California. He founded the Speech Communications Research Laboratory (subsequently directed by June Shoup) in Santa Barbara, and was joined there by some of his former students. Peterson died of leukemia in 1967.

MID 1960s - MID 1980s

For the 20 years following PETERSON's departure, the most prominent phonetician in Speech and Hearing at Michigan was Donald Sharf. A specialist in speech perception, Sharf was on the Michigan faculty from 1964 until his retirement in 1987; he remained Emeritus Professor until his death in 1995.

Harlan Lane was on the Psychology faculty from 1960-1971; he studied the role of acoustic cues in speech and non-speech perception, and also investigated prosodic properties (pitch, speaking rate) using psychophysical scaling techniques. In 1965, Lane founded (and directed until 1969) the Center for Research on Language and Language Behavior which, similar to PETERSON's Communication Sciences program, drew together faculty and students working on language phenomena from a range of academic disciplines.

In 1964, J. C. CATFORD came to the University of Michigan from the School of Applied Linguistics, which he had founded at the University of Edinburgh, to be Director of Michigan's English Language Institute. A phonetician who had studied under Jones, Fouché, and Durand (among others), Catford not only directed the Institute, but also took over the direction of the Communication Sciences Laboratory, as well as much of the teaching of phonetics in the Department of Linguistics.

During this period, the laboratory — now known as the Phonetics Laboratory — was maintained as an ongoing and

generally available resource for faculty or students investigating spoken language, whether in phonetics, applied linguistics, or psycholinguistics. Instrumentation included a Kay Sonograph, a mingograph, and airflow recording equipment. Between 1966 and 1985, 38 dissertations were written on topics in phonetics and phonology, about half of them incorporating research carried out in the laboratory. CATFORD's *Fundamental Problems in Phonetics* (1977), and his work on the phonetics of Caucasian languages, likewise owed much to research in the laboratory.

The theory of componential-parametric phonetics expounded in CATFORD's *Fundamentals* was taught to Linguistics, and Speech and Hearing, students through intensive introspective observation of the motor sensations of speech production and intensive ear-training. This approach induced students to acquire a personally experienced understanding of the basic components of speech production — initiation, articulation, and phonation — and of the parametric ranges of characteristic features of these components.

Upon retirement as Emeritus Professor in 1985, CATFORD presented a series of informal talks on his phonetics career; videotapes are available through the university's English Language Institute Library (for an autobiographical account of Catford's work, see also Catford, in press).

LATE 1980s - PRESENT

In the late 1980s, study of the phonetic sciences outside of Linguistics at the university subsided, with a major factor being the dissolution of the Department of Speech and Hearing in 1987. In that year, Patrice Speeter Beddor joined the Linguistics faculty from Yale/Haskins Laboratories. André M. Cooper, also from Yale/Haskins Labs, was appointed to the Linguistics faculty in 1989. Cooper left Michigan in 1996 (he is now at the College of William and Mary). The resulting gap in the phonetics program was filled in 1997 by José Benkí from the University of Massachusetts.

Beginning in 1987, the university provided Linguistics with substantial funding, augmented by NSF support in later years, to bring the Phonetics Laboratory into the computer age. The laboratory's initial computer systems were a Kay Digital Sonograph and a VAX network running acoustic analysis and speech synthesis software; the VAX system has since been replaced with a Macintosh system. To accommodate COOPER's expertise in speech articulation, especially laryngeal timing, transillumination and strain gauge systems were added shortly after. More recently, the sound room and anechoic chamber built for PETERSON's lab have been renovated and equipped for on-line presentation of auditory stimuli. The newest portion of the laboratory includes Sun SPARC and PC workstations, and a PC-based speech airflow measurement system.

The current study of phonetics continues the 50-year tradition at Michigan of closely integrating research in phonetics and phonology. BEDDOR's research areas include coarticulatory organization, acoustics, speech perception, and the phonetics-phonology relation. Of particular interest are the ways in which the human auditory system constrains phonological systems, as well as the ways in which experience with a particular coarticulatory structure influences perceptual abilities. Also, under Beddor's editorship, the University of Michigan was "home" to the *Journal of Phonetics* from 1995-97. Benkí works on problems in speech perception, including models of phonetic

cue interaction, whole word perception, and lexical access. His interests extend to second language speech perception and how articulatory and perceptual realities affect phonological systems. Other faculty at Michigan working on sound structure also investigate issues in phonetics-phonology, and interact closely with the phonetics faculty and students. San Duanmu's work in theoretical phonology involves study of the phonetic realizations of phonological constructs (e.g., phonological syllable weight). Lesley Milroy's sociophonetic investigations include work on stop glottalization in British English and the vowel shift in northern U.S. cities; she is more generally interested in sociohistorical accounts of language change.

In 1989, an International Conference on Linguistic Approaches to Phonetics was held at Michigan in honor of J. C. CATFORD. In hindsight, we are struck by the fact that the common thread of that conference — the fundamental interaction of research in phonetics with areas not traditionally viewed as part of the phonetic sciences — is the common thread of the past decade of phonetics research at Michigan. Recent and on-going

dissertations in phonetics all reflect this interest in the integration of the linguistic sub-disciplines concerned with sound structure.

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HISTORY OF PHONETICS AT MIT

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THE BEGINNINGS

Phonetics research at MIT began around 1950 at the Acoustics Laboratory. Leo Beranek, who was one of the directors of the laboratory, had developed an interest in speech as a consequence of his work on aircraft communication systems during the war. Beranek invited Gunnar Fant from Stockholm to spend some time as a visiting scientist at MIT. At the Acoustics Laboratory, Fant developed an expanded interest in the source-filter theory of speech production — an interest that began earlier in Sweden. This theory models speech sound production as the generation of sources, and the filtering of these sources by the vocal tract based on one-dimensional wave propagation in non-uniform tubes. During his stay at MIT, Fant also began a collaboration with ROMAN JAKOBSON and MORRIS HALLE (1952), with whom he helped to propose acoustic bases for the distinctive features. Although some details concerning the inventory of distinctive features have undergone changes over the years, the concept of features is one of the underpinnings of phonological theory (Chomsky and Halle, 1968). During his stay at MIT, Fant also proposed the design of a formant synthesizer that later evolved into speech synthesizers of similar design at a number of laboratories and commercial organizations around the world (KLATT, 1987).

In 1952 the first of several conferences on speech communication was held at MIT, where communications engineers, phoneticians, linguists, and psychologists discussed theoretical issues relating to the underlying speech code and its acoustical manifestation, as well as potential applications such as automatic speech recognition, speech coding, and aids for the handicapped. Researchers from MIT and Harvard University at this conference included ROMAN JAKOBSON, J. C. R. Licklider, and William Locke.

DISTINCTIVE FEATURES AND TRACT-SOUND RELATIONS

During the late 1950s and early 1960s the distinctive feature theory motivated several experimental studies of the properties of speech sounds, beginning with the work of MORRIS HALLE and his students and colleagues. These early studies were followed by experimental work of KENNETH STEVENS and Arthur House, showing the effects of consonantal context on the properties of vowels (Stevens and House, 1963). Interpretation of these acoustic data was spurred by continuing development of the acoustic theory of speech production, which provided a basis for interpreting the acoustic data in terms of the articulatory shapes and movements that produced the sound. The acoustic theory was bolstered by experimental studies of turbulence noise sources in speech, carried out by Christine Shadle (Shadle, 1985) and Leah Pastel.

SPEECH PRODUCTION

Several years later an interest in the kinematics of speech production developed, spurred by the publication of the book *Physiology of Speech Production* by Joseph Perkell (1969). That book gave the results of a frame-by-frame analysis of a cineradiographic film of a number of utterances. Data from the film, which was made in Sweden by Sven Öhman and KENNETH STEVENS, showed the movements of the tongue blade, tongue body, lips, and pharynx for different vowels and for consonants with different places of articulation and contrasting voicing characteristics. One goal of the research on speech movements was to develop a theory of how these continuous movements could be controlled from a linguistic description that is essentially categorical or quantal. The need for data on speech movements led later to Joseph Perkell's creation of a magnetometer system (called EMMA, Electromagnetic Midsagittal Articulometer) for measuring movements of points on the surface of the tongue and other articulators (Perkell et al., 1992). The EMMA system was used to examine strategies used by speakers to produce certain vowels and consonants occurring in different contexts and with different speaking styles and rates.

THE KLATT YEARS

Phonetics research at MIT was strongly influenced over a 25-year period by DENNIS KLATT. Klatt brought the science and technology of speech synthesis to a new level. He developed rules for speech timing (Klatt, 1976), he devised a new formant synthesizer, and he was a key member of the teams that developed the text-to-speech synthesizers MITALK and DECTALK (Klatt, 1987). Design of the MITALK synthesizer was overseen by Jonathan Allen, whose basic work on the relation between the two orthographic and phonetic representations of words provided an important component of this synthesizer (Allen, Hunnicutt and Klatt, 1987). The work of Dennis Klatt (with his daughter Laura) on the synthesis of female voices represented a significant advance in understanding the parameters that define the individuality of both male and female voices (Klatt and Klatt, 1990). He left a legacy of his broad knowledge of the speech process and of the "Klatttools" for speech analysis, synthesis and processing that have been the mainstay of the experimental work on speech acoustics and perception in the Speech Communication Group at MIT.

SPEECH ERRORS

While much of the early phonetics research at MIT concentrated on phenomena at the level of the segment, the research of Stefanie Shattuck-Hufnagel examined the role of larger units in the planning and processing of speech. Her studies of speech errors (1979) provided insight into the structure of the concatenated lexical units that are precursors to the actual

production of an utterance. And her work on prosody has led to quantitative descriptions of the acoustic correlates of the boundaries of phrasal units and of prominences within these units (Shattuck-Hufnagel and Turk, 1996).

COMPUTATION IN PHONETICS

The use of computation facilities in the study of phonetics was begun in the early 1960s at MIT, with the development of interactive systems for the analysis and synthesis of speech. Among those who developed and used these facilities for studies in acoustic phonetics were Gordon Bell, Hiroya Fujisaki, OSAMU FUJIMURA, John Heinz, and William Henke. As computers became more powerful, Victor Zue was instrumental in adapting these tools to the analysis and use of large databases of speech, particularly the TIMIT database (Zue, Seneff and Glass, 1990). This research led to detailed descriptions of variability in the acoustic manifestations of speech across contexts, across speakers, and across speaking styles, and the utilization of this knowledge in the development of systems for dialog between people and computers.

INTERDISCIPLINARY WORK

The early collaboration between Fant, whose training was in electrical engineering, and the linguists JAKOBSON and HALLE began a collaboration between researchers in linguistics, engineering, computer science, and other disciplines that spanned the 50-year interval of phonetics research at MIT. The theme of this collaboration has been the interaction between the physical worlds of acoustics and phonetics on the one hand and the more categorial worlds of linguistics and cognitive science, particularly phonology (Halle and STEVENS, 1991). Results of this collaboration have included studies of the details of particular phonetic contrasts (Stevens, 1999), quantal aspects of speech production and acoustics (Stevens, 1972, 1989), relation of prosody to linguistic structure (Shattuck-Hufnagel and Turk, 1996), articulatory and perceptual bases for a hierarchical structure of distinctive features (Keyser and Stevens, 1994; Stevens, 1993), strategies for planning and control of speech production (Perkell et al., 1995), and factors contributing to the enhancement of phonetic contrasts (Stevens and Keyser, 1989).

Over a 50-year period, 100-odd graduate students carried out thesis research on various aspects of phonetics, receiving degrees in engineering, linguistics, and cognitive sciences. The Massachusetts Institute of Technology was host to numerous postdocs and international visitors from all continents.

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PRELIMINARIES TO SPEECH ANALYSIS (1952)

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In 1949-51 Cambridge, MA, was the scene of one of the most fundamental innovations in phonetic history: the development of the phonetically-defined Jakobsonian distinctive features. To put this in perspective, a brief review of the history of features is necessary.

A BRIEF HISTORY OF PHONETIC FEATURES

The use of features to describe speech sounds is as old as the science of phonetics itself. Panini some two and a half millennia ago in his description of Sanskrit used features indicating place and manner of articulation. His features were almost exclusively anatomical-physiological (Allen, 1953). The Greeks in their phonetic analysis used features, too, but a significant number of them were of the impressionistic auditory sort, e.g., $\psi\lambda\acute{o}\nu$ ("smooth", i.e., un aspirated) and $\delta\alpha\sigma\acute{\upsilon}$ ("rough", i.e., aspirated) (Allen, 1968: 12). These features were used to describe individual sounds as well as to name classes of sounds that showed similar behavior.

These two fundamentally different types of features, articulatory and auditory-impressionistic, have survived up to modern times (Lloyd, 1890) although the dominant approach, fostered by the International Phonetic Association, uses articulatory features. Nevertheless, impressionistic terms like 'sibilant', 'liquid', 'emphatic', 'tense', 'fortis', and so on are very common in the discourse of modern phonetics and phonology.

To some extent by the later 19th c. the two approaches to features were popular in different geographical regions. Phoneticians in the UK and France, for example, favored articulatory features whereas in Eastern Europe auditory features were more common. Many in Germany and elsewhere who were enthusiastic about the discoveries of Willis and Helmholtz in characterizing the acoustic properties of vowels, held out the hope that ultimately the auditory-impressionistic features could be grounded in empirically-determined acoustic features. Eventually, since the IPA was started largely with Western European backing, articulatory features become dominant.

Of course, it must be said that given technological limitations of the age — which, to some extent, are still present — it wasn't possible to give precise, observer-independent, auditory labels to sounds. However this could be done using articulatory features. On the other hand everyone agreed that for the language user, especially the language learner, the only aspect of speech that was universally accessible was the sound, not the articulation.

The problem was succinctly characterized by R. J. Lloyd in 1890:

Both lines of investigation [articulatory and acoustic-auditory], ... are of precisely equal importance to the scientific study of language and of its history. The two views are in fact complementary to each other. ... The trouble hitherto has been that

there has been no means of reconciling the classification according to ear with the classification according to articulatory shape and position. ...

Let us only succeed in shewing, from the ascertained laws of acoustics, *why* certain dissimilar articulations are found to produce very similar sounds, and *why*, on the contrary, certain small changes in articulation have a great effect upon the quality of sound, and the rivalry and repugnance of system which otherwise subsists will be smoothed entirely away.

[Lloyd himself made a creditable attempt to rectify this problem in a series of articles published in *Phonetische Studien* (Lloyd 1890-92, 1899/1900).]

In the 1930s, JAKOBSON, one of the principal members of the Prague School, not only developed a system of features based on acoustic-auditory properties but he also insisted that some of the same features could apply both to consonants and vowels. In lieu of acoustic definitions of his features he noted how certain sounds had common resonator shapes. (See Jakobson, 1939, 1942, 1939[1949].)

JAKOBSON emigrated to the United States in 1941, eventually moving to Harvard in 1949. This was the same year that Gunnar Fant came to Cambridge at the invitation of acoustician Leo Beranek for two years of study.

PRELIMINARIES TO PRELIMINARIES TO SPEECH ANALYSIS (1952)

The first few months of his stay in Cambridge (before moving to the M.I.T. Acoustics Lab) Fant spent in the Psychoacoustics Lab at Harvard. In December 1949 he gave a seminar there which was attended by ROMAN JAKOBSON. Up to then a great deal of acoustic analysis had been done on vowels but much less on consonants. Fant presented some new results he had obtained on the acoustic analysis of stops, especially on the spectra of stop bursts. As Fant reports:

Roman was intrigued. Here was the missing link in his theory of perceptual equivalence of vowel and consonant features. ... the single peak concentration of energy for the velar stop [k] ... conforms with the Jakobsonian feature of compactness. In the labial and alveolar stops ... the spectral energy is spread, conforming to the feature diffuse. ... There is a low frequency dominance for the labial [p] and high frequency dominance for the alveolar [t]. These two are contrasted as being grave versus acute.

Subsequently Fant, with JAKOBSON's help, started (at the Massachusetts General Hospital) his x-ray study of the vowel and consonant articulations of Russian, the subject being an emigré

Russian actor. In addition, Jakobson proposed a collaboration with Fant to give an acoustic base to the features that he, Jakobson, had been using in his previous work. HALLE, who was "fluent" in both the languages of physical acoustics and of linguistics, acted as "translator" and secretary (Fant, 1996; p.c.). Most of these working sessions took place in Jakobson's home. Fant reports (personal communication, June 1998)

I was given the role of a kind of 'medium'. For example, Roman would ask "What is the nature of 'flatness,' due to lip rounding, retroflexion, or pharyngealization?" If I was silent for too long, the question would be repeated. "Be quiet, Roman, I'm thinking!" I would have to say. I did my best to give some common denomination to the features he proposed.

In the end, 12 binary features were proposed (JAKOBSON, Fant, and HALLE, 1952). Fant acknowledges that the acoustic basis for some of the features may be "obscure" (p.c.) and he has himself published critiques of them (Fant, 1973). Nevertheless, he regards one of the important characteristics of the features is that they are defined relativistically, i.e., tilting toward what is called today 'relative invariance' of the distinctive elements of speech.

THE HISTORICAL SIGNIFICANCE OF PRELIMINARIES

JAKOBSON, Fant, and HALLE's *Preliminaries* was the first systematic attempt to develop a system of features that could be used to describe the (contrastive) structure and behavior of speech sounds in, potentially, any human language in a way that united the articulatory and acoustic-auditory aspects of sounds and laying particular weight on the acoustic side. Although tentative (the word 'preliminaries' in the title of their work was deliberate), it did prove itself useful in a number of ways (see OHALA, 1979, 1985; Ohala and Lorentz, 1977). Much subsequent work, refining our knowledge of the articulatory-acoustic mapping in speech, and showing how linguistic form and patterning of speech sounds can be understood by reference to physical principles, owes a debt to this initial pioneering effort (Fant, 1960; STEVENS, 1998).

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HISTORY OF PHONETICS AT OHIO STATE

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INTRODUCTION

The history of phonetics at OSU extends through four academic generations: from RUSSELL to BLACK to LEHISTE to Fox, Beckman and Johnson — or, in other words, from the study of primarily English articulation to the practical application of speech science to speech correction, elocution, and even rhetoric, to linguistics-oriented experimental study of the phonetic structure of various languages, to experimental phonology. These four stages will be described below in some detail.

EPOCH 1

G. OSCAR RUSSELL joined the faculty of OSU as an Assistant Professor of Spanish in 1925. In 1928, he completed his doctorate at Columbia University and published his famous book *The Vowel*. This early X-ray study of speech articulation sought to highlight individual differences in speech production by studying vowel articulations under changes in head and neck posture. Also in 1928, Raymond Herbert STETSON at Oberlin College published his *Motor Phonetics*, based on experimental work which he carried out in his self-made (and appropriately named) "Oscillograph Laboratory". These two enterprising pioneers of American phonetics set the tone at the university for over a decade, and OSU phonetics starting from this time was characterized by a focus on instrumental-experimental studies of the physiology of speaking. When the Department of Speech was established in 1936 Russell became the director of its phonetics laboratory, which he headed until 1941.

A more traditional approach to phonetics was likewise well represented in Ohio and at Ohio State. For example, J. S. KENYON (Hiram College), described by BRONSTEIN et al. (1977, p. 113) as the 'dean' of American phonetics in the 1920s, had published his *American Pronunciation* in 1924. Ohio State was home at this time (1921-27) to LEONARD BLOOMFIELD, who published his *Menomini Texts* in 1928. Hans Kurath was professor at Ohio State 1927-32; his *Linguistic Atlas of the United States and Canada* appeared in 1931. Several students trained at OSU during this period went on to influential careers. For example, Orvis C. Irwin, who received his PhD degree in 1929, went on to serve on the faculty of the University of Iowa for thirty years. Bert Emsley, likewise receiving his PhD in 1929, taught at OSU until 1959, also thirty years.

A strong emphasis on instrumental phonetics has continued at OSU to the present day, both at the Department of Speech and Hearing Science, and since 1965 in a parallel stream at the Department of Linguistics.

EPOCH 2

The second epoch in OSU phonetics began in 1947, when Henry Michael Moser joined the OSU faculty. Perhaps not as well known as the earlier Ohio phoneticians, Moser was a program

builder who served as the director of the OSU Speech and Hearing Clinic starting in 1948. He was also evidently partly responsible for bringing JOHN W. BLACK to OSU from nearby Kenyon College (1949). Black has been described as one of the eminent phoneticians of the modern century (BRONSTEIN et al., 1977, p. 15). He was instrumental in establishing speech science as an academic discipline at Ohio State and in the nation. Among Black's important publications are the books *Speech: Code, Meaning, and Communication* (1955) (with Wilbur E. Moore); *Phonation and Phonology* (1969) (with Ruth B. Irwin); and *Lectures in Speech Sciences* (1976).

This period in the history of phonetics at OSU saw the development of speech science and clinical speech pathology as disciplines of study. As with the earlier instrumental phonetics tradition, this clinical speech science strand of history has continued to the present at OSU in the Department of Speech and Hearing Science.

EPOCH 3

This epoch in the history of phonetics at OSU began in 1963, when ILSE LEHISTE started her long and productive tenure at Ohio State. Lehiste came to OSU from the University of Michigan, where she received her PhD in Linguistics in 1959 and was a Research Associate at the Communication Sciences Laboratory 1959-63. At Ohio State, she divided her time between phonetics, historical linguistics, and administration, serving as Chairman 1965-71, Acting Chairman 1984-85, Chairman 1985-87, and Professor Emeritus since 1987. She established the phonetics laboratory associated with the Department of Linguistics, then equipped primarily for research in acoustic phonetics.

Her research areas included the study of boundary signals, the phonetic realization of syntactic structure, and the description of units of speech production and perception. Much of her research dealt with the prosodic structure of numerous languages: an early summary appeared as the book *Suprasegmentals* (1970) (cf. also, for example, LEHISTE, 1997a). Her more recent projects deal with the phonetic realization of metrical structure in orally produced poetry. The languages to which she has devoted considerable attention are Estonian (Lehiste, 1997b; I. Lehiste and J. Ross (Eds.), *Estonian Prosody: Papers from a Symposium*, 1997; and Serbocroatian (I. Lehiste and P. Ivic, *Word and Sentence Prosody in Serbocroatian*, 1986). Lehiste has also worked in the areas of historical linguistics (*Principles and Methods for Historical Linguistics* (with Robert Jeffers), 1979) and language contact (*Lectures on Language Contact*, 1988).

Research by graduate students during that time culminated in eight dissertations directed by LEHISTE:

1970-71: Zinny Bond, *Units of Speech Perception*; 1973-74: Linda R. Shockey, *Phonetic and Phonological Properties of Connected Speech*; Sara S. Games, *Quantity in Icelandic*:

Production and Perception; **1976-77**: John Perkins, *An Acoustic Phonetic Study of Cross-Dialect Borrowing*; Holly Semiloff, *An Acoustic Correlate of Syllabicity in English*; Robert K. Herbert, *Language Universals, Markedness Theory, and Natural Phonetic Processes: The Interaction of Nasal and Oral Consonants*; **1981-82**: Christopher Farrar, *A Prototype Model of Speech Perception*; Rachel Schaffer, *Vocal Cues for Irony in English*; **1982-83**: Deborah Schaffer, *Intonation Cues to Management in Natural Conversation*.

The dissertations of Bond and Shockey were published in the *Working Papers in Linguistics* series established by the department (of which fifty issues have appeared 1967-97). The dissertation of Garnes was published in *Hamburger Phonetische Beiträge Bd. 18*, Hamburg: Buske (1976), and the dissertation of Herbert in *Trends in Linguistics: Studies and Monographs 25*, Berlin: Mouton de Gruyter (1986).

EPOCH 4

All of the approaches to phonetics found in the history of the institution extend to the present day at OSU, and in many ways are more vibrant than ever. The fourth and latest epoch started with the appointments of Robert A. Fox in Speech and Hearing Science in 1984 and Mary E. Beckman in Linguistics in 1985, followed in 1993 by the appointments of Keith Johnson in Linguistics and Marios Fourakis and Jan Edwards in Speech and Hearing Science.

Robert A. Fox received his MA and PhD degrees in Linguistics in 1978 from the University of Chicago, and was a member of the OSU linguistics faculty before moving to the Department of Speech and Hearing Science. He is presently Chairman of the Speech and Hearing Science Department. His current research is concerned with the perceptual magnet effect, particularly for the "corner" vowels [u] and [a] (all of the work so far has been using the [i]-[ɪ] continuum) (Fox, R.A. and Carahaly, L. (1998), "Perceptual magnet effects in the corner vowels /u/ and /a/"). Recent work includes also investigation of scaling (Fox, R.A., Flege, J. E. and M. J. Munro (1995), "The perception of English and Spanish vowels by native English and Spanish listeners"). Fox also has a long-standing interest in the effects of aging on perception (Fox, R. A., Wall, L. G. and J. Gokcen, (1992), "Age-related changes in the perception of dynamic phonetic information").

Fox is also Principal Investigator of an NIH Training Grant, entitled "Multidisciplinary Program in Speech and Hearing Science". Co-investigators include Professors Feth (Speech and Hearing Science), Weisenberger (SHS), Krishnamurty (Electrical Engineering), Beckman (Linguistics), Mari Jones (Psychology), Johnson (Linguistics), and Fourakis (SHS). This project represents an interdisciplinary program to train predoctoral graduate students and postdoctoral scholars to pursue research in the area of speech and hearing science.

Linguistically-oriented courses taught by Fox include Principles of Phonetics, Language Development, Speech Science, Articulation, Acoustic Phonetics, Experimental Phonetics, and Computer Use in Speech and Hearing. Of phonetics-oriented dissertations directed by Fox, the following may be mentioned:

1989: Ying-Yong Qi, *Acoustic Features of Nasal Consonants*. Ying-Yong Qi was the recipient of the first joint ASA-ASHA KLATT award; **1994**: Ho-Hsien Pan, *The*

Acquisition of Taiwanese (Amoy) Initial Stops; **1997**: Julia McGory, *Acquisition of Intonational Prominence in English by Seoul Korean and Mandarin Chinese Speakers*.

Mary E. Beckman has an MA degree in Oriental Languages from the University of California at Berkeley (1976), and MA and PhD degrees in linguistics from Cornell (1982 and 1984). Beckman has expanded and diversified the phonetics offerings and has brought the laboratory up to date. She is co-founder (with John Kingston) of the *Laboratory Phonology* conference series and associated biannual collections of *Papers in Laboratory Phonology*. During the five years from 1990 through 1994, she also promoted laboratory approaches to fundamental issues in phonology as the editor of *Journal of Phonetics* (see, for example, the 1990 special issue on the theme of "Phonetic Representation"). Much of her own research focuses on prosody in all its aspects, from modeling the details of various phonetic correlates to developing computationally tractable phonological representations of stress and phrasing. She has published two monographs on aspects of prosody in English and Japanese: *Stress and Non-Stress Accent* (1986) and (with Janet Pierrehumbert) *Japanese Tone Structure* (1988), and has developed several experimental paradigms for investigating articulatory and physiological representations of prosodic structure and timing. She has also done experimental work in first and second language phonological acquisition. (Some examples of recent research topics: "Speech Models and Speech Synthesis" (1997), and "A typology of spontaneous speech" (1997)).

Up to now, Beckman has directed six dissertations:

1988: Keith A. Johnson, *Processes of Speaker Normalization in Vowel Perception*. **1991**: Kenneth J. de Jong, *The Oral Articulation of English Stress Accent*. **1993**: Sun-Ah Jun, *The Phonetics and Phonology of Korean Prosody*. **1994**: Sook-hyang Lee, *The Role of the Jaw in Consonant Articulation*. **1996**: Shu-hui Peng, *Phonetic Implementation and Perception of Segmental Coarticulation and Tone Sandhi*. **1996**: Gayle Ayers, *Nuclear Accent Types and Prominence: Some Psycholinguistic Experiments*.

Keith A. Johnson earned his MA and PhD in Linguistics at OSU (1985 and 1988), returned to the department in 1993, after post-doctoral research fellowships at Indiana University with David Pisoni and UCLA with PAT KEATING and PETER LADEFOGED. Johnson also taught at UCLA and at the University of Alabama, Birmingham, prior to returning to OSU.

Johnson's research is focussed on processes of speaker normalization in speech perception. His 1988 OSU dissertation *Processes of Speaker Normalization in Vowel Perception* was directed by Mary Beckman, Robert Fox, ILSE LEHISTE, and Neal Johnson. His research has resulted in several published articles (Johnson, 1989; 1990a; 1990b; 1991; 1997), an edited volume (Johnson and Mullennix, 1997), as well as articles on speech perception in general (Johnson and Ralston, 1994; Johnson, Flemming and Wright, 1993) and on individual differences in speech production (Johnson, LADEFOGED and Lindau, 1993). Johnson has also published a textbook, *Acoustic and Auditory Phonetics* (1997), which has been adopted at several universities in the U.S.

His recent research with Elizabeth Strand (Strand and

Johnson, 1996; Johnson and Strand, 1998) takes a sociophonetic approach to the role of talker differences in speech perception. (The sociophonetic approach is being developed in collaboration with Professor Norma Mendoza-Denton from the Department of Spanish and Portuguese).

Jan Edwards received her M.S. degree from Massachusetts Institute of Technology in Linguistics in 1981, and her PhD degree from the CUNY Graduate Center in 1985 in Speech Science. Her current research deals with phonological development and disorder, and specific language impairment. Linguistically oriented courses taught by Edwards include Language Acquisition and Phonological Disorders.

Marios Fourakis received his PhD degree in Linguistics from Indiana University in 1983. His research areas include speech production by deaf children and by persons with motor speech disorders, speech perception by persons with cochlear implants, and speech production. Fourakis teaches courses in Undergraduate Speech Science, Advanced Speech Science, Acoustic Phonetics, and Neurology of the Speech and Hearing Mechanism.

PHONETICS IN OTHER DEPARTMENTS AT OHIO STATE

Lively and friendly exchanges of ideas characterize the frequent interactions of phoneticians on the faculty of OSU. Several other faculty members (some of whom have already been listed in connection with the NIH training grant) deserve special mention: in Speech and Hearing Science there are Professors Larry Feth (a specialist in auditory signal processing) and OSAMU FUJIMURA (the developer of the original x-ray microbeam and of many ideas such as "demissyllable synthesis"); in Psychology there are Professors Neal Johnson and Mark Pitt (both psycholinguists); and in Electrical Engineering there is Professor Ashok Krishnamurty (a specialist in speech signal processing). Each of these faculty members has a well-equipped laboratory that complements the facilities in the Linguistics Laboratory. Strong interactions among the faculty also allow pooling of resources, such as site licenses for some software and shared purchasing of some expensive equipment.

The Department of Speech and Hearing Science also offers several phonetics courses every year, which complement the offerings in the Department of Linguistics.

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THE SPEECH COMMUNICATIONS RESEARCH LABORATORY (SCRL)

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In the latter part of 1966 GORDON E. PETERSON and June E. Shoup founded the Speech Communications Research Laboratory, Inc., (SCRL) as a non-profit corporation in Santa Barbara, California. They brought with them a small group of graduate students and support staff from the Communication Sciences Laboratory (CSL) of the University of Michigan. Funding consisted of a tiny amount of personal capital together with grants and contracts mostly transferred from the CSL.

Before his death at the age of only 53 in July of 1967, PETERSON had encapsulated his vision for the Laboratory in a statement which we later had framed in our entryway:

Speech Communication is concerned with the scientific study of the basic linguistic structures of spoken languages and with the application of this information to problems in electronic communication and speech automation.

This Laboratory has been established in recognition of the fact that the experimental and theoretical study of spoken language is not an adjunct to some other discipline but is a distinct and major field of investigation. It is the purpose of this Laboratory to provide a place where scientists and scholars from various disciplines, both technical and humanistic, can work together in mutual respect and enthusiasm on the endless and fascinating problems of speech communication.

The statement for speech communication in relation to other disciplines might also apply to the phonetic sciences: Both need their own space in which to flourish.

PETERSON's death posed the dilemma of whether to keep SCRL open. Except for Peterson himself, none of us had any particular stature in the field and we, our funding agencies, and colleagues all had doubts that our inexperienced group could run a viable lab. On the other hand, we were inspired by Peterson's vision and felt we had to carry it forward. Somehow Shoup convinced our funding agencies to give us the chance to try.

Subsequent work from SCRL was as diverse as the interests of the individual researchers. This is reflected in the titles of the Laboratory's monograph series. Many of these were PhD dissertations, some done mostly at the Michigan CSL, others from various universities done with direct funding at SCRL. One monograph was later revised as a popular book (Markel and Gray, 1976) on linear predictive coding (LPC). Also noteworthy was Shoup's participation in the ARPA SUR (Speech Understanding Research) project with an ambitious study of the phonetic sequences of conversational speech (Oshika, Zue, WEEKS, Neu and Aurbach, 1975).

In its early years SCRL had a PDP-8 computer with only 4,000 words of 12-bit memory. We used it interactively to

measure TV images of sound spectrograms (Broad and Fertig, 1970) and frames of cineradiographic films (Hayden and Koike, 1972). The PDP-8 had to scan tapes to analyze a database of any size and it took about 24 hours to perform one series of analyses of variance (Broad and Fertig, 1970).

Spectrograms were made on one of the prototypes (Koenig, Dunn, and Lacy, 1946) brought by PETERSON from Bell Labs to Michigan and later to SCRL. SCRL finally donated this spectrograph to the Smithsonian Institution.

Getting on-line with larger computers and using digital signal processing was a welcome luxury. One of the first user-oriented integrated systems for digitizing, labeling and analyzing audio data, the Interactive Laboratory System (ILS) was initially developed at SCRL.

In 1979 SCRL moved to Los Angeles and began an association with the University of Southern California, where Shoup started a multi-disciplinary graduate degree program in speech science and technology. SCRL closed a few years later, but not before spinning off some notable successors, including Signal Technology, Inc., (STI) founded in 1977 by John Markel and his signal-processing group and the Speech Technology Laboratory (STL) founded in 1981 by HISASHI WAKITA as an entity within Matsushita Electric.

SCRL was an exciting environment for research and the idea of such a multi-disciplinary laboratory for the study of speech can still inspire.

REPRESENTATIVE SCRL MONOGRAPHS

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UCLA CONTRIBUTIONS TO THE PHONETIC SCIENCES

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BEGINNINGS

In 1961 Robert Stockwell, then a professor in the English Department at UCLA, acquired a sound spectrograph and taught a seminar in acoustic phonetics. The following year PETER LADEFOGED was appointed as an Assistant Professor of Phonetics, and less than a year later received an NIH grant to build a working model of the vocal organs. This was the start of the UCLA Phonetics Lab. Ladefoged and Jim Anthony, visiting from the University of Edinburgh, immersed themselves in rubber molds and plaster casts, and failed to achieve anything noteworthy. They were saved from ignominy by the contributions of their colleagues who were using electromyography and aerodynamic techniques to describe the muscular activity and associated gestures that they had hoped to build into the model.

PHYSIOLOGICAL PHONETICS

The first project in this area was that of VICKI FROMKIN, whose lips became well known through her description of the muscular actions and the resulting lip positions in American English vowels (Fromkin, 1964). This work was followed by Minoru Hirano's studies of the laryngeal muscles. Others, notably at Haskins Laboratories, had been studying these muscles using needle electrodes implanted in the muscles as seen in a mirror looking down into the pharynx. Hirano pioneered a technique using hooked wire electrodes which he inserted through the neck, thus avoiding rigid needles in the muscles and also avoiding wires coming out of the mouth in a way that impeded pronunciation (Hirano and Ohala, 1969). Using these techniques, JOHN OHALA, Hirano's principal speaker, trailed hook wired electrodes from various articulators, and collaborated further with him to tell the world how laryngeal activity was coordinated (Hirano, Ohala and Vennard, 1969).

START OF THE COMPUTER AGE

In 1967 the UCLA Phonetics Lab acquired a LINC-8 computer, described in the lab report as "a large general purpose computer with 8K of memory". Richard Harshman, who did all the early programming, performed wonders with this minuscule memory (including teaching PETER LADEFOGED how to program). Shortly the computer was upgraded to a machine thought of then as having a massive 32K memory, enabling Lloyd Rice to salvage the failure to build a physical vocal tract by programming a computer model (Rice, 1971).

One of the problems of articulatory modeling is how to specify the vocal tract shapes that the model uses. If we assume that the shape of the body of the tongue can be specified in terms of two factors, then we can extract the underlying factors of tongue shape. Richard Harshman invented PARAFAC, a form of factor analysis that provided a unique set of factors underlying the variation in such data (fully described in Harshman and

Lundy, 1984). It was found that two factors, front raising and back raising could generate most of the possible gestures of the tongue body (Harshman, LADEFOGED and Goldstein, 1977). A number of computer models now use these two factors (or variants of them) to specify tongue body shapes. It is also possible to use these techniques for deriving vocal tract shapes from formant frequencies (Ladefoged, Harshman, Goldstein and Rice, 1978).

Studies of tongue shape and jaw position have continued at UCLA. The data from the 1970s has been combined with later x-ray microbeam data to show how individuals vary. Our current conclusion is that, alongside the possibility of a motor theory of speech perception, there is support for an auditory theory of speech production in which at least part of the speech output is controlled in acoustic terms (Johnson, LADEFOGED and Lindau, 1993).

During the 1970s there were a number of other projects in the UCLA Phonetics Lab. VICKI FROMKIN had started her ongoing research on speech errors (Fromkin, 1971), which led to her work on speech performance (Fromkin, 1980). At the same time Cathe Browman was also working on errors of speech perception and production (Browman, 1980).

TONE, PHONETIC UNIVERSALS, AND FIELD WORK

A group of UCLA researchers, VICKI FROMKIN, Jack Gandour, Jean-Marie Hombert, Ian Maddieson, and Eric Zee, were working on tone languages. Part of the tone project was concerned with studies of individual languages, such as Thai (Gandour, 1974), Yoruba (Hombert, 1977) and Shanghai Chinese (Zee and Maddieson, 1980). Another aspect was the study of general problems such as universals of tone (Gandour and Harshman, 1978; Maddieson, 1978a; see also Maddieson 1991) and the relationship between tone and consonant type (Hombert, 1978; Maddieson, 1978b). Many results of this work appeared in Fromkin (1978).

PETER LADEFOGED spent much of his time wandering around the world trying to hear and analyze for himself all the sounds that could distinguish words in some language or other. The first UCLA portable phonetics lab weighed more than 100 pounds, and included a Nagra tape recorder, a battery powered oscilloscope, and an ultra violet recorder. These devices are now replaced by a small DAT recorder, and a solar powered laptop computer. Air pressure and flow measurements are made with battery operated equipment designed at UCLA. There is multichannel software that provides spectrograms, LPC, and FFT spectra and pitch and intensity displays enabling complex analyses to be done in the field. Video recording of static palatography and articulatory movements has been developed so that standardized pictures can be taken in remote regions. Voiceless implosives, bilabial trills and velar laterals were among the sounds first instrumentally documented at that time

(Ladefoged, Williamson, Elugbe and Uwalaka, 1976; Ladefoged, Cochran and Disner, 1977). Current instrumental phonetic fieldwork techniques are described in Ladefoged (1997).

Phonetic fieldwork and the study of the sounds of a wide variety of languages led to the construction of linguistic phonetic feature systems. The Jakobsonian and later SPE feature systems were shown to be inadequate. LADEFOGED (1971) proposed a new feature system that accounted for a wide range of phonation types and several articulations previously unknown in the phonetic literature. He also noted the importance of recognizing an auditory basis for some features. (A later feature system of this type is given in Ladefoged and Maddieson, 1996.) Fieldwork studies were also part of the impetus for urging revision of the IPA (Maddieson, 1987). Extensive work within the International Phonetic Association eventually led to major revisions of the IPA (Ladefoged, 1990).

Studies of the phonetic characteristics of phonological features have always been an important aspect of the work at UCLA. One of the features that has been investigated extensively is Advanced Tongue Root (ATR). Mona Lindau discussed it when looking at the features required for vowels (Lindau, 1978), and later used x-ray data to study the gestures for ATR vowels (Lindau, 1979). Michel Jackson undertook further work along this line (Jackson, 1988) and more recently Susan Hess investigated acoustic properties of ATR vowels (Hess, 1992). Work on the acoustics of this feature is still continuing (Falup, Kari and LADEFOGED, 1998). As a result of all this work it is clear that ATR is not the same as 'tenseness' in Germanic languages, and must not be confused with it.

Another area of phonetic research has been the linguistic use of different phonation types. Techniques were developed for investigating phonation types in different languages (LADEFOGED, Maddieson and Jackson, 1988). These techniques were used by Marie Huffman to measure the phonation types in Hmong (Huffman, 1987), and Sarah Dart to investigate Korean stops (Dart, 1987).

Sarah Dart also developed new techniques for static palatography, and used them to describe differences between English and French laminal and apical coronal consonants (Dart, 1998). New methods of using electropalatography were also developed (Byrd, Flemming, Mueller and Tan, 1995). Dani Byrd described influences on articulatory timing in consonant sequences (Byrd 1996a). Further work along these lines is being conducted using electromagnetic articulography.

In the early 1980s Maddieson compiled the first UCLA Phonological Segment Inventory Database (UPSID). This database has now been extended so that it includes over 400 languages, carefully chosen to reflect the language families of the world. Aspects of the distribution of the phonological distinctions used by languages were documented by Maddieson in his book *Patterns of Sounds* (1984). More recently, LADEFOGED and Maddieson (and their students) have been describing the phonetic structures of endangered languages. So far descriptions of 12 languages have been published, and work on a further 22 languages is in the process of being analyzed or is in press. Ladefoged and Maddieson (1996) pooled their knowledge of both endangered languages and more familiar languages to produce a book in 1996, *The Sounds of the World's Languages*.

PHONOLOGICAL THEORY AND PHONETICS

PATRICIA KEATING, who joined the UCLA Phonetics Lab group in 1981, became the Director of the Phonetics Lab in 1991. She has developed a view of phonetics as part of a grammar (Keating, 1985). Her emphasis on the linking of phonetic observations and phonological theory is exemplified in her study of the phonetic and phonological representation of stop consonant voicing (Keating, 1984). Subsequent work led to notions concerning underspecification in phonetics (Keating, 1988), and the formulation of a window model of coarticulation (Keating, 1990). This model suggests that instead of specific targets, features may be characterized by requiring articulations to have values within a certain window. John Choi investigated phonetic underspecification and target interpolation with reference to Marshallese vowel allophony (Choi, 1995). Abby Cohn investigated nasalization in English phonology and phonetics (Cohn, 1993). Dani Byrd described a phase window framework for articulatory timing (Byrd, 1996b). Cécile Fougeron collaborated with Keating in a study of higher level linguistic units and the strengthening of segmental components in different prosodic positions (Fougeron and Keating, 1997). Sun-Ah Jun joined the lab in 1993 and gave increased impetus to the study of prosodic features, especially intonation (Jun and Oh, 1996; Fougeron and Jun 1998).

Through the years the UCLA Phonetics group has been host to too many distinguished visiting scholars to be listed here. There has also been a notable post-doc program which has been an important influence, as can be exemplified by the collaborative work instigated by Keith Johnson that led to studies of the perception of vowels (Johnson, Flemming and Wright, 1993).

In the current UCLA Phonetics Lab a new model of linguistic phonetic research has emerged. There are no boundaries between those working in phonology and those working in phonetics. Theoretical phonology has long been one of the strengths of UCLA linguistics. Now both the phonologists on the faculty, Bruce Hayes and Donca Steriade, support their theoretical advances by experiments in the lab. Their students, such as Dan Silverman and Jongho Jun do the same (Silverman and Jun, 1994), and phonetics and phonology students move freely between the two areas.

OTHER LABS AT UCLA

Significant contributions to the phonetic sciences have also been made by other labs at UCLA, notably the self-styled Bureau of Glottal Affairs where the "glottal bureaucrats" Bruce Gerratt and Jody Kreiman are well known for their work on normal and pathological phonation types. In a number of studies they have argued that traditional methods of perceptual voice evaluation will never be sufficiently valid or reliable for clinical application, because listeners differ substantially in how they judge disordered voices (Gerratt, Kreiman, Antonanzas-Barroso and Berke, 1993; Kreiman, Gerratt and Berke 1994; Kreiman and Gerratt, 1996). Current work attempts to explain and model these individual differences, and applies analysis-by-synthesis approaches to modeling voice perception.

Recently UCLA has been strengthened by the establishment of the Speech Processing and Auditory Perception Laboratory in the School of Engineering, under the direction of Abeer Alwan. They have developed a model that accounts for adaptation in the

auditory system. When used as a front-end for a word-recognition system, it increases word recognition scores by 10-20% (Strope and Alwan, 1997). On the production side, this group has collected and analyzed a large MRI database of speakers producing different sounds. In addition to obtaining valuable estimates of areas and volumes, the 3D reconstructions have illustrated, for the first time, inter-speaker similarities and differences in tongue shapes that have important acoustic consequences (Narayanan, Alwan and Haker, 1997; Alwan, Narayanan and Haker, 1997).

All three of these groups, the UCLA Phonetics Lab, the Bureau of Glottal Affairs and the Speech Processing and Auditory Perception Lab, work closely together, with joint publications by members of the different labs, and students from different groups mingling in classes and acting as subjects in one another's experiments.

PHONETICS PEDAGOGY

From the earliest days until the present the UCLA Phonetics group has had a major role in the teaching of phonetics. LADEFOGED'S *A Course in Phonetics* (1975, 1982, 1993) introduced a style of teaching phonetics not previously used in the United States. Now, thanks to PAT KEATING'S leadership, not only phoneticians but also phonologists and engineers pay attention to phonetic detail, do experiments in the lab, and learn to hear and produce all the sound patterns they describe.

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PART III. BIOGRAPHICAL SKETCHES

ABRAMSON, ARTHUR S. (b. Jersey City, NJ, 26 Jan 1925). *Educator, linguist, phonetician.*

MA, 1950, PhD, 1960, Columbia Univ.; U.S. Army, 1943-46; teacher, public high schools, Jersey City, NJ, 1950-53; teacher, secondary schools, Songkhla, Thailand, 1953-54; teacher, College of Education, Bangkok, Thailand, 1954-55; Research staff, Haskins Labs, New York, NY, 1959-63, 1964-65; assoc. prof., 1963-64, prof., 1965-67, Queens College and Grad. Center, City Univ. of NY; prof. 1967-92, prof. emeritus, 1992-present, Univ. of Connecticut; research assoc. Haskins Labs, New York, NY and New Haven, CT, 1963-64, 1965-present. Temporary positions at New York U. and Columbia U. Member, Perm. Coun. ICPhS, 1971-present; Ling. Soc. Am., Sec.-Tres., 1974-78, Pres., 1978; Vice Pres., Intl. Soc. Phon. Sci., 1985-89; Editor, *Language and Speech*, 1975-87; Fellow, Acoust. Soc. Am., Intl. Soc. Phon. Sci. Abramson's research interests include links between the production and perception of speech, cross-language experiments in perception, and experimental phonetic studies of Southeast Asian languages, especially Thai.

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ARTHUR S. ABRAMSON

BÉKÉSY, GEORG VON (né Békésy, György). (b. Budapest, Hungary, 3 Jun 1899, d. Honolulu, HI, 13 Jun 1972). *Auditory scientist.*

Békésy ([^hbe:keʃi] in Hungarian) came from a comfortable and cultured background. His father was a diplomat, and the family moved between various cities in Europe during his childhood. A talented musician, he considered making a career as a concert pianist, but opted instead for physics, with a PhD in

fluid dynamics. From 1923 to 1946, apart from a year's break in Berlin, he worked for the telephone research laboratory of the Royal Hungarian Post Office. In 1939 he was appointed professor of experimental physics at the University of Budapest, whilst continuing his work for the Post Office. However, first-hand experience of the effects of war and of the Russian presence in Hungary drove him to emigrate. He went firstly, in 1946, to the Karolinska Institute in Sweden, then, a year later, to a research post in the Department of Experimental Psychology at Harvard. One of his colleagues there was Stanley S. Stevens, a major researcher in the field of hearing. In 1966, Békésy was appointed professor of sensory sciences at the University of Hawaii.



Fig. 2. Georg von Békésy.

His work in Budapest for the telephone research laboratory is the key to his research into the dynamics of the cochlea. Part of his remit was to investigate the mechanical factors causing sound-distortion, especially on long-distance lines, in the telephones that were in use in Hungary in the 1920s. This led him to question the current state of knowledge about the process of hearing, and so he began his own investigations into the vibratory characteristics of the basilar membrane in his Budapest laboratory. One of his starting-points was von Helmholtz's

assumption — which in the 19th century could not be tested empirically — that particular fibres along the basilar membrane respond to particular frequencies. Békésy's work was to provide the scientific evidence for von Helmholtz's assumption, as well as to refine it.

His research necessitated the use of cochleas of human cadavers, as well as those of animals — from mice to elephants. Special microscopes and microsurgical tools had to be designed as part the research procedures, to cope with the exceedingly small measurements he was undertaking. Particularly at Harvard, he was able to make greater use of carefully enlarged models of the cochlea.

His interest in phonetics *per se* was relatively limited. He made some measurements of the transmission of vocal-fold vibrations to the upper part of the body, of transmission losses in intensity between the lips and the external auditory meatus, and of vibration patterns of the skull during vowel production (Békésy, 1960: 185-86).

By the late 1950s, his research, almost all of it undertaken by himself alone, had established much of the detailed biomechanics of the cochlea, and in 1961 he was awarded the Nobel Prize for Physiology or Medicine, specifically for this work. He had determined the characteristics of the travelling wave along the basilar membrane, the types of frequency analysis performed by the organ of Corti, and some of the neurophysiology (especially the electrical potentials) of hair-cell stimulation. His *Experiments in Hearing* (1960) is a compilation in English of his most significant papers on various aspects of the hearing process. At a practical level, his research contributed to improvements in the surgery for hearing disorders, as well as to the design of an audiometer that bears his name.

His wider scientific interests included architectural acoustics, and the physiology of sight, touch, smell and taste. Throughout his life he maintained a keen interest in artistic matters, and he bequeathed his fine collection of works of art to the University of Hawaii. (See: <<http://www.pbrc.hawaii.edu/bekesy/gallery/>>.)

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MIKE MACMAHON

BELL, ALEXANDER GRAHAM (b. Edinburgh, Scotland, 3 Mar 1847, d. Baddeck, Nova Scotia, Canada, 2 Aug 1922). *Teacher of the deaf, inventor, philanthropist*.

On the world stage, Bell is remembered as the inventor of the telephone; in phonetics, as an applied phonetician who strongly advocated the use of 'Visible Speech', an iconic general phonetic alphabet devised by his father, Alexander Melville Bell (1819-1905), in the audio-lingual education of deaf and hearing-impaired speakers.

His early years, up until 1870, were spent in Britain, where his ideas about phonetics were influenced by his father's work in articulatory phonetics, the elocutionist activities of his

grandfather, Alexander Bell (1790-1865), and the acoustic principles that Hermann von Helmholtz (1821-1894) had elaborated, especially that of 'fixed-pitches' (i.e. formants) for vowels. As a teenager, Bell was given a demonstration by Sir Charles Wheatstone (1802-1875) of an improved version of Wolfgang von Kempelen's (1734-1804) 'sprechende Maschine' of 1791. Fired with enthusiasm, Aleck devised his own synthesizer, which attempted to model phonatory and articulatory actions, though to no great effect. Later, he learned how to discover formant frequencies of vowels: first by holding tuning-forks in front of his mouth as he uttered the vowels, then by whispering the vowels or tapping his throat as he said them. Acquaintance with Alexander John Ellis (1814-1890) taught him something about the electrical and acoustic principles behind Helmholtz's electrically-driven tuning-fork vowel synthesizer. Such examples of the convergence of acoustic phonetics, electricity, and the mechanical properties of speech synthesizers were the seed-corn for the later development of the telephone.

His work on the telephone, begun shortly after arriving in Boston in 1870, led in due course to his successful acquisition, in March 1876, of a patent which covered 'the method of, and apparatus for, transmitting vocal or other sounds telegraphically ... by causing electrical undulations, similar in form to the vibrations of the air accompanying the said vocal or other sounds'. Trials, as well as errors, involving the use of experimental phonetic techniques such as the Scott-Morey phonautograph, and Koenig's manometric flame capsule — equipment borrowed from MIT — and even a phonautograph fitted with a cadaver's hearing mechanism, then steered Bell towards the idea of constructing a 'harmonic telegraph', which would convert several simultaneous messages into telegraphic 'chords' of sound. Speech, as well as telegraphic clicks, he reasoned, could be transmitted by the same means.

His original version of the telephone, involving an electromagnetic transmitter connected by an armature to a diaphragm, was soon modified: the electromagnetic transmitter was replaced by a liquid transmitter of acidulated water. Other improvements quickly followed, based on the work of, for example, Emile Berliner, THOMAS EDISON (1847-1931), and David E. Hughes; as a result, carbon transmitters were used in the early telephones. In 1880, the French government awarded Bell the prestigious Prix Volta for his invention. The Bell Telephone Company was set up in 1878, a year later becoming the Bell Telephone Corporation. By 1880, there were 50,000 subscribers to the Bell system in the USA. In 1900 the American Telephone and Telegraph Company (AT&T) was established as the Bell parent company.

In 1879, Bell set to work with Charles S. Tainter and, later, his cousin Chichester A. Bell, to build an 'electric photophone' (sometimes referred to as the 'photophone' or the 'radiophone'). This was a device for transmitting speech by means of a light beam — an early example of the application of the fibre-optic principle. By the spring of 1880, a prototype was ready. A mirror acted as the diaphragm in the transmitter; the degree of light reflected from it then varied according to the acoustic patterns. The receiver was a piece of selenium, a non-metallic element with an electrical resistance sensitive to light. Variations in the speech waveforms led to changes in the resistance of the selenium, and hence variations in the current passed through it.

The establishment of the Volta Laboratory, financed by the Volta Prize, and manned by Tainter and the two Bells, quickly spawned a development of the photophone, namely the 'spectrophone'. This was an instrument for analysing the infrared spectrum of light by means of sound. Neither the photophone, nor the spectrophone, achieved much success in the scientific world. Yet Bell maintained to the very end that the photophone (despite its limitations), and not the telephone, had been his greatest invention.

In 1881, the Volta Laboratory began work on improving certain features of EDISON's phonograph. In place of tinfoil cylinders, wax-coated ones were used, and much effort went into re-designing the stylus. The recording apparatus was called a phonograph, the reproducing apparatus a graphophone, and the record that resulted a phonogram. The Volta-Laboratory work compelled Edison to return to the design and, thereafter, the improvement of his own phonograph.

Through the Volta Graphophone Company which had been set up, the Volta Laboratory benefited financially from the acquisition of several patents. In 1887, a section of the Volta Laboratory, which was being used to house files about deafness in the USA, was designated the Volta Bureau; the name continues to this day. A further beneficiary from the patents was the American Association to Promote the Teaching of Speech to the Deaf (now the Alexander Graham Bell Association for the Deaf), established in 1890.

Bell's mother was deaf, as was his wife, Mabel Gardiner Hubbard Bell (1857-1923). Bell taught Mabel to achieve a high degree of intelligible speech by using Bell senior's 'Visible Speech' system of 1867. This was the key to his method of helping deaf people. Bell argued that it was preferable for deaf people to attempt to speak, rather than to resort to sign language, finger-spelling, or, simply, writing as their mode of communication. Deaf children should, he said, be educated in public day schools which, if possible, should be integrated into schools for normal-hearing children.

Bell first taught Visible Speech to deaf children at a school in London in 1868; then, in 1871 at the Boston School for Deaf Mutes (see also Bell 1872). In 1878, he established a day school for the deaf in Greenock (Scotland), where the system was also taught. His greatest challenge was to teach Helen Keller (1880-1968) to speak; she had been deaf-blind since before the age of two. He succeeded, with the help of Helen's teacher, Annie Sullivan. The Visible Speech system was used in many schools for the deaf in the USA, an indicator of its popularity being that one of his father's textbooks was reprinted as late as 1932. Professional interest in the consequences of deafness led Bell to play an important role in arguing publicly for specific government strategies for the welfare and education of deaf speakers; he also took a particular personal interest in genetic factors associated with deafness. His *Mechanism of Speech* (1906) contains a series of lectures which discusses phonetics and the audio-lingual education of deaf speakers.

Bell's income from his patents and his shares in AT&T allowed him to disperse often large sums of money to scientific, educational, and charitable organizations, as well as to individuals. (He provided most of the start-up finance for the journal *Science*, for example).

Throughout his life, he never stopped inventing — or thinking about inventing. He was fascinated by aeronautics and

designed large man-carrying kites and biplanes. He designed hydrofoils. He suggested a particular form of radium treatment for cancer. He thought about how to condense drinking water from sea-water; how to build an air-conditioning system; how to conserve heat in stoves. The list was extensive. Yet, when asked what his occupation was, he would always reply: 'teacher of the deaf.'

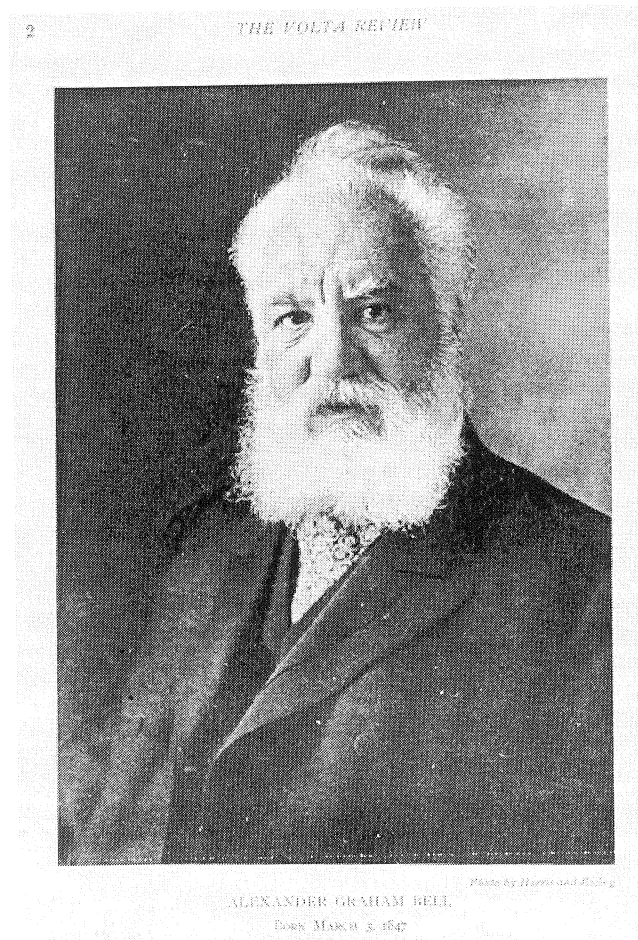


Fig. 3. Alexander Graham Bell.

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MIKE MACMAHON

BLACK, JOHN W(ILSON) (b. Veedersburg, IN, 9 Feb 1906). *Educator, phonetician.*

John Black was, in Sadanand Singh's words "one of the eminent phoneticians of the modern century ... he has influenced the direction of phonetic and psycholinguistic research and application on a pan-international scale" (BDPS: 15-16). Black was the author of numerous articles on such subjects as vowel quality, the effects of consonants on adjacent vowels, interconsonantal differences, the nature of spoken vowels, and consonant production in such journals as *Speech Monographs*, the *Journal of Speech and Hearing Disorders*, the *Journal of the Acoustical Society of America*, the *Quarterly Journal of Speech*.

Black's interests led to the development of electronic devices that were instrumental in enhancing intelligibility, the teaching of linguistic rules to aphasics, critical acoustic and psychological correlates of speech sounds, listeners' reactions to the measurable properties of speech, voice, and language, and interphonemic differences.

Black was the Senior Advisor to the *Biographical Dictionary of the Phonetic Sciences* at whose suggestion (in 1966) that effort was undertaken and completed in 1977. His numerous students at Kenyon College (where he taught from 1935 - 1949) and at Ohio State University (from 1949 until his retirement) and their oft-published contributions to the field of phonetic research have continued Black's influence to the present day.

John Black's honors included a Fulbright Research Fellowship in Italy in 1954 and an Ohio Regents Professorship in 1966. He was the president of the Speech Association of America in 1966; the editor of *Speech Monographs* in 1958-59, and Vice-President of the American Speech and Hearing Association in 1964. A few of his numerous publications are listed below.

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ARTHUR J. BRONSTEIN

BLOCH, BERNARD (b. New York, 18 Jun 1907; d. New Haven, CT, 26 Nov 1965). *Linguist, dialectologist, phonetician.*

While serving as a post-MA fellow at Northwestern University from 1929 - 1931, Bloch was a student of Werner Leopold's, in the latter's course in linguistic theory. Leopold, highly impressed with Bloch's grasp of phonetic details and the then developing theories of linguistic analysis, referred him to Miles Hanley who was then seeking fieldworkers for the development of the Linguistic Atlas project, under the direction of Hans Kurath. That experience led to Bloch's study for the PhD under Kurath at Brown University and a subsequent career in the field of linguistics at Yale University. Bloch became a full professor there in 1950 and the Director of Graduate Linguistic Studies in 1952. Bloch's amazing capacity for "work" enabled him to become the editor of *Language*, remaining in that position for a 26 year period, until 1965, as well as one of the participating professors at ten Summer Institutes in Linguistics between the years 1937 and 1962.

LEONARD BLOOMFIELD was another major influence on Bloch's thinking about linguistic analysis, considered by many to be his successor in the developing field of structural linguistics. Bloch became the Assistant Editor of the *Linguistic Atlas of New England*, and one of Hans Kurath's three "collaborators" (the other two were Marcus Hansen and Julia Bloch) of the *Handbook of Linguistic Geography of New England*, a project sponsored by the American Council of Learned Societies and published in 1939.

Bloch's published paper, co-authored with George Trager, "The Syllabic Phonemes of English" which appeared in *Language* in 1941, his article in *American Speech* (1941) on "Phonemic Overlapping", his "Set of Postulates for Phonemic Analysis" that appeared in *Language* (1948), and his numerous published studies on spoken Japanese established him as a major researcher in the field, known as an extraordinary teacher of phonetics and linguistics who attracted numerous students to his classes at Yale.

Bloch's name belongs in the historical list of the then developing field of linguistics in the 1930's — a list that would include such names as BLOOMFIELD, Hanley, Kurath, PIKE, Trager, KENYON, Malone and others — a compliment not easily placed upon too many shoulders!

FURTHER READINGS

For further details the reader is referred to the entry on Bernard Bloch by John Ritter in the *Biographical Dictionary of the Phonetic Sciences*, pp. 16-18.

ARTHUR J. BRONSTEIN

BLOOMFIELD, LEONARD (b. Chicago, IL, 1 Apr 1887, d. New Haven, CT, 18 Apr 1949). *Linguist, educator.*

Leonard Bloomfield, often called the "father" of American Structuralism, had a strong influence on the linguistic sciences, including phonetics for several decades in the mid-20th c. His writings continue to be read, referenced, and critiqued, nearly half a century after his death. His true academic life in linguistics began in 1906 with his graduate study at the University of Wisconsin, where he took advantage of his undergraduate education from Harvard and his language background to serve as

Assistant in German. His affinity for Germanic languages would later be reflected in his research into Indo-European. And although he published classic texts and articles within general linguistics, some of his best-known works are also those in very specific areas of linguistics, such as Indo-European, Native American, and Tagalog studies. It is in both these areas, but especially in the latter, where his contributions to phonetics and phonology can best be seen.

His doctoral dissertation, completed in 1909-1910 at the University of Chicago and entitled *A Semasiologic Differentiation in Germanic Secondary Ablaut*, discussed meaning and sound change, in conjunction with "phonosemantics", better known perhaps as "sound symbolism". Another early work on sound change was his *The Indo-European Palatals in Sanskrit* (1911), comparing various sound changes, including spirantization, in Iranian, Sanskrit, and Germanic.

Much of Bloomfield's research united his Indo-European/Germanic or Amerindian interests with historical analysis. *Initial [k-] in German* (1938) intertwines discussion of German sound change, modern German usage (for 1938), and dialectology. Thus the initial affricate-to-fricative change of [kx-] to [x-] is compared to the behavior of other Germanic fricatives. Much of his work on Fox, Ojibwa, Plains Cree and Menomini included historical reconstructions of those languages. In his *A Note on Sound Change*, Bloomfield reveals his admiration for the Neogrammarians: "this postulate [i.e. that of sound change without exception] yields ... predictions which otherwise would be impossible".

Bloomfield was also very interested in solidifying the study of language into a genuine science of linguistics. One very important result of this was the founding of the Linguistic Society of America (cf. "Why a Linguistic Society?" and "Call for the Organization Meeting"). Equally as important for the phonetic sciences were Bloomfield's highly organized descriptive publications such as *On the Sound System of Central Algonquian* and *Menomini Morphophonemics*, a detailed description of this Algonquian language's morphophonemic inventory and distributional constraints. A synchronic study in a similar descriptive vein is *The Stressed Vowels of American English*. This description of "Standard" English as Bloomfield heard it while in Chicago is an excellent example not only of the so-called stressed vowels and their patterning, but also of a very detailed and readable account of a dialect of American English.

Less well known, unfortunately, are Bloomfield's forays into language teaching and education. He attempted to apply concepts of theoretical linguistics to "practical" uses. *Let's Read, a Linguistic Approach*, was the method he used to teach his son to read. It does not concentrate on word meaning, but rather associates word form and sound. Published posthumously, its premises have sadly not been much explored in the classroom. In addition, Bloomfield wrote a number of foreign language manuals, for German, Dutch, and Russian (cf. the bibliography in Hall 1987).

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KENNETH R. SETZER; EDS.

BLUMSTEIN, SHEILA E. (b. New York, NY, 10 Mar 1944). *Educator, phonetician, neurolinguist*.

BA, 1965, University of Rochester, PhD, 1970, Harvard University; Asst. to Full Professor, Brown University, 1970-1991; Albert D. Mead Professor, 1991-present, Brown University. Research Assistant to Research Associate, Harold Goodglass Aphasia Research Center, 1968-present. Visiting positions MIT Speech Group, Wellesley College. Phi Beta Kappa, 1964; Phi Sigma Iota, 1965; Guggenheim Fellow, 1977-78; Radcliffe Institute Fellow, 1977-78; Fellow, Acoustical Society of America, 1982-; Claude Pepper (Javits Neuroscience) Investigator Award, 1985-1992; Fellow, American Academy of Arts and Sciences, 1993-. Served on Board of Governors, Academy of Aphasia, 1978-81, 1995-99, Committee on Hearing, Bioacoustics, Biomechanics, National Research Council, 1980-82; NIH, Communicative Sciences Study Section, 1976-80; NSF Linguistics Panel, 1983-1986; Advisory Council, National Institute of Deafness and other Communication Disorders, 1989-93. Blumstein's research has focused on the acoustic properties characterizing the phonetic categories of speech, the mapping of sound structure onto the lexicon, and the neural basis of such processing through the study of aphasic patients. She has authored over 100 journal articles and has authored, co-authored, or edited 4 books.

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SHEILA E. BLUMSTEIN

BOAS, FRANZ (b. Minden, Westphalia, Germany, 9 Jul 1858, d. New York, NY, 21 Dec 1942). *Anthropologist, ethnologist, linguist, professor, theoretical physicist, geographer*.

Franz Boas is widely considered to be the developer of American descriptive linguistics. One of his major accomplishments in linguistics was to show that American Indian languages, heretofore considered primitive and irregular, were as complex and as systematic as European languages. In the late 1800's, for example, frequent discrepancies between phonetic transcriptions of the same words by different analysts had resulted in the popularly held notion that the American Indian languages did not have systematic sound systems. In an early paper, 'On Alternating Sounds,' Boas suggested that these discrepancies were most probably due to the different perceptions of sounds unfamiliar to the European ear. These sounds were then interpreted by linguists as one European sound or another, rather than on their own merit as sounds of non-European linguistic systems. He emphasized, here and in succeeding works, the need for linguistic relativism: rather than imposing classical European interpretations of grammar on non-European languages, as was the accepted method of linguistic description of so-called primitive languages in Boas' day, the analyst must instead attempt to understand and describe a language according to its own classification system. This point is particularly well expounded in his seminal 'Introduction' to the *Handbook of American Indian Languages* (1911). He saw the need to classify experiences as a characteristic inherent in the human condition; and as sounds are experienced and are potentially infinitely varied in nature, they are subject to human attempts at classification. How sounds are classified in a language therefore depends on how speakers perceive them, and the results are different cross-linguistically. In effect (without the modern terminology), the results of identifying groups of similar phonetic sounds which are distinct from and contrast with other such groups are phonemes. Most importantly, these are language particular: what seems arbitrary to speakers of one language seems systematic to speakers of another.

A consequence of his firm belief in linguistic relativism and the systematicity of the phonetic inventories of all languages was his insistence on exact phonetic transcriptions of linguistic data. Even while acknowledging the contributions of linguists such as SAPIR and BLOOMFIELD to the study of phonology and the phoneme, he felt that too much information was lost by relying on phonological transcriptions. At the same time, he also remained traditionally in favor of the use of standard alphabetic representations and was little inclined to the adoption of too many special orthographic symbols for the phonetic transcription of American Indian languages.

Boas left the field of linguistics with a scientific methodology for describing languages, a much richer understanding of the American Indian languages, and an awareness of the need to study languages according to their own grammatical systems.

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ANNA BERGE

BOLINGER, DWIGHT LEMERTON (b. Topeka, KS, 18 Aug 1907, d. Palo Alto, CA, 23 Feb 1992). *Linguist, language teacher, phonetician*.

Bolinger's contributions extend to many areas of linguistics, theoretical as well as applied, including Spanish language pedagogy and educating the general public about linguistic processes. Among the phoneticians, however, he is probably best known for his pitch accent theory, first published in 1958. It was a result of an attempt to account for experimental data presented in Fry's (1955) classic study (Ladd, 1996). Bolinger's claim may be characterized as follows: prominence of a particular word in a sentence results from pitch movement on the lexically stressed syllable of the word. He considers lexical stress a phonological abstraction. Janet Pierrehumbert's PhD thesis (1980), which became a standard in the current formal studies of intonation, in effect revived some of the basic tenets of Bolinger's theory of intonation.

Bolinger's research on intonation began with a 1943-1944 fellowship to Yale on a Sterling Fellowship and continued throughout his entire life. It reflected his pioneering ideas about the role of context and speaker's intentions in linguistic theory. His work on the nature of intonation has been grounded in part on experimental research. In 1956-1957, Bolinger spent a year at Haskins Laboratories conducting experiments on stress and intonation, much of it in collaboration with PIERRE DELATTRE.

In his further work, Bolinger proposed a notion of intonational morphemes (1965). His life-long research on intonation has been presented in his two volume-study: *Intonation and its parts* (1986) and *Intonation and its uses* (1989). While some linguists describe this study as a further account of intonational nuances and the paralinguistic features of intonation suggesting thereby that some of the features of intonation are outside of the realm of linguistics, it is important to emphasize that for Bolinger changes in intonation within a sentence are as important as the changes in syntax or the lexical component.

Intonation is defined by Bolinger (1986), "as a non-arbitrary, sound symbolic system with intimate ties to facial expression and bodily gestures, conveying, emotions and attitudes". Although he did not ignore the role of convention in his views of intonational structures, Bolinger embraced the

growing support for the sort of universal frequency code as presented in OHALA (1983).



Fig. 4. Dwight L. Bolinger.

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KRYSTYNA WACHOWICZ

BRONSTEIN, ARTHUR J. See Editors' Page.

CASSIDY, FREDERIC G. (b. Kingston, Jamaica, 10 Oct 1907). Professor, lexicographer, dialect geographer, creolist, etymologist.

MA Oberlin College 1932; PhD Univ. of Michigan 1938; Memorial Univ. of Newfoundland 1982; Litt.D. (Hon), Indiana State Univ-Terre Haute 1983; Litt.D. (Hon), Oberlin College 1983; Hum.D. (Hon), Univ. of the West Indies, Jamaica 1984 Litt.D. (Hon), Univ. of Michigan 1986 Litt.D. (Hon); asst. to full prof. 1939-78, prof. emeritus 1978-pres., chief editor, *Dictionary of American Regional English*, 1965-pres, Univ. of Wisconsin-Madison. Temporary and visiting positions at Oberlin College, Univ. of Michigan, Univ. de Strasbourg, France, Columbia Univ., Univ. College of the West Indies, Stanford Univ. Fulbright, Jamaica 1951-52, 1958-59; Pres., Am. Dialect Soc. 1959-61; Pres., Soc. for Caribbean Ling., 1972-74; Pres., Am. Name Soc. 1980; Musgrave Silver Medal, Inst. of Jamaica 1962, Centenary Medal 1980, Gold Medal 1983; SNACS Distinguished Service Award, 1986. Cassidy's chief research interest has been in the English language, from Old English to present forms, with emphasis on lexicography: the historical gamut and stylistic variations from literary to folk speech, the latter especially as in Jamaica, West Indies. The *Dictionary of American Regional English*, covering lexical differences throughout the fifty states, has published 3 volumes, down through O. Two more volumes of text and one of fieldwork data will complete the project.

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FREDERIC CASSIDY

CATFORD, JOHN C. (b. Edinburgh, Scotland, 26 Mar 1917). *Phonetician, phonologist, general and applied linguist*.

At age 14 Shaw's Pygmalion aroused Catford's enthusiasm for phonetics. He thereafter intensively studied Sweet's *Primer of Phonetics* and received encouragement and some tuition from Daniel Jones. He had further education at Universities of Edinburgh (French and Romance), Paris (Institut de Phonétique), London (Russian and Slavonic, General Linguistics). His subsequent career included in 1939-46, British Council Overseas Service (teaching English and phonetics Greece, Egypt,

Palestine); 1946-52, BBC radio actor (doing applied phonetics in exotic dialects etc.), part-time phonetics instructor, Royal Academy of Dramatic Art; 1952-64, University of Edinburgh; 1952-57, Research lecturer, Linguistic Survey of Scotland; 1957-64, Senior Lecturer, Director, School of Applied Linguistics; 1964-85, Univ. of Michigan Professor of Linguistics (Chairman, 1968-71, 1984-5); 1964-68, Director English Language Institute; 1967-8, Acting Director, Center for Research on Language and Language Behavior; 1968-85, Director, Phonetics Lab. 1985-present, Professor Emeritus. 1986-9, Visiting Professor Univ. of the Bosphorus, Istanbul, Hebrew Univ. Jerusalem, UCLA. 1934, joined IPA; 1985-present, member of Council. 1990-present, member of Conseil scientifique of Revue des études georgiennes et caucasiennes. 1985, UofM Warner Rice Humanities Award for "a distinguished career in his field"; 1989, UofM International Conference on Linguistic Approaches to Phonetics in honor of JCC. 1988-94, Executive Editor (translation) and contributor on articulatory phonetics, Caucasian languages, translation, Pergamon Press *Encyclopedia of Language and Linguistics*. Research and teaching interests include phonation types, aerodynamic phonetics, componential-parametric phonetics, diachronic phonetics, phonetic pedagogy, dialectology, Caucasian languages, ergativity, translation theory. He has authored scores of articles and three books.

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JOHN C. CATFORD

CHAO, YUEN REN (*b.* Tienstin, China, 3 Nov 1892, *d.* Cambridge, MA, 24 Feb 1982).

Raised in a multi-lingual and multi-dialectal environment, he very early developed a fascination for and facility with languages. He entered Cornell University in 1910 on a Tsing Hua scholarship, studying science and mathematics as well as languages and linguistics, receiving his A.B. in 1914. "The most important course I took in linguistics at Cornell", Chao (1976) reported, "was one in phonetics. For the first time I learned to use the International Phonetic Alphabet...". He received his doctorate (in philosophy) from Harvard in 1918. In the seven years following his graduation he taught physics at Cornell, served as interpreter for BERTRAND RUSSELL and Dora Black during their visit to Peking University, married Buwei Yang (the first woman in China to become a licensed physician), taught philosophy and Chinese at Harvard, and went on a phonetics-linguistics study tour of Europe. Among those he met and studied with during this period, both at Harvard and in Europe, were CHARLES HALL GRANDGENT, Daniel Jones, Stephen Jones, Joseph Vendryes, Antoine Meillet, and Henri Maspero.

From 1925 to 1938 he was, at first, professor of Chinese at the National Tsing Hua University, teaching Chinese phonology and music, and the Research Fellow and Chief of the Linguistics Section of the Academia Sinica, which he helped to found. It was at this time that he conducted the first extensive dialect surveys of Chinese based on modern linguistic methods and that he published the still theoretically fresh paper "The non-uniqueness of phonemic solutions of phonetic systems" (1934). He emigrated to the United States with his family in 1937 and took up teaching positions at University of Hawaii, Yale University, and Harvard University, finally settling at the University of California, Berkeley, in 1947 where he was appointed Professor of Oriental Languages and, in 1952, Agassiz Professor. He retired from teaching in 1960. Among the numerous awards he received were honorary degrees from Princeton, Ohio State University, and University of California, Berkeley, as well as two Guggenheim fellowships and a Fulbright fellowship.



Fig. 5. The Chaos: Yuen Ren and Buwei Yang.

In China, Chao is also well known for his lively Chinese translation of Lewis Carroll's *Alice's Adventures in Wonderland*, as composer of many popular songs, and for his lifelong service to the National Language Unification movement. His efforts in this last area included helping to define and promote *p'u t'ung hua* (the Standard Dialect) and the invention of *Gwoyen Romatzyh*, one of the official National Phonetic Alphabets. When Chao and his wife visited their homeland in 1973 they were welcomed in person by the Chinese premier, Chou En Lai.

Members of the IPA will also remember Chao for his frequent contributions to *Le Maître Phonétique*, in particular his proposal for the system of tone letters which bears his name and which has been widely adopted (1945.24-27, 1930). Within phonetics and phonology, Chao's contributions range from acoustic phonetics ("Experimental study of Chinese word tones," 1924), to word games (and their value for validation phonological

analyses), child phonology, the audio-lingual method of second language teaching, automatic speech recognition, and historical phonology.

His published works include numerous articles and over a score of books and monographs including *Cantonese primer* (1947), *Mandarin primer* (1948), *A grammar of spoken Chinese* (1968), *Language and symbolic systems* (1968), and *Aspects of Chinese sociolinguistics* (1976). In his published works as well as his conversations, Y. R. Chao displayed an incredible breadth of knowledge and an ingenious and cultivated sense of humor.

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JOHN J. OHALA
(reprinted from *J. Int. Phonetic Assoc.*)

COOPER, FRANKLIN S(EANEY) (b. Robinson, IL, 29 Apr 1908, d. Palo Alto, CA, 20 Feb 1999). *Physicist, engineer, phonetician, speech scientist, administrator.*

BS, Univ of Ill, 1931; PhD, Mass Inst of Tech, 1936. Res engineer, General Electric Res Labs, 1936-39; assoc res dir, Haskins Labs, 1939-55, president and res dir, 1955-75, assoc res dir, 1975-86. Cooper and Caryl P. Haskins were co-founders of Haskins Laboratories in 1935. It was a nonprofit research laboratory devoted to research on color photography, marine ecology, and biochemistry (genetics). During the war, at the request of Vannevar Bush, Director of the Office of Scientific Research and Development under Presidents F. Roosevelt and Truman, the labs started research on aids for the blind, sponsored by the Veterans Administration.

Cooper's initial work in speech synthesis grew out of a project aimed at the development of a speech reading machine for the blind. The output of such a machine, a speech synthesizer, was engineered and constructed by Cooper in the late 1940s. This synthesizer, generally known as the Pattern Playback, converted hand drawn, schematized, versions of sound spectrograms into intelligible speech. The Playback was probably the first modern synthesizer to be developed which permitted close control of dynamic input parameters, and was certainly the most useful experimental device of its type for years. Using it (and several second-generation devices of a related nature), Cooper and his colleagues at Haskins Laboratories (esp. ALVIN. M. LIBERMAN and PIERRE DELATTRE) pioneered the search for the acoustic cues to speech perception.

The search for acoustic cues led Cooper and his colleagues to conclude that many speech sounds are encoded, rather than enciphered, in the acoustic signal, and that a model of speech perception which reflects the perceptual processes of listeners must include a motor (i.e., articulatory-physiological) component as well as a strictly sensory component. This was the well-known "motor theory of speech perception".

Postulating that listeners make reference to articulation when decoding the acoustic speech signal led to a series of experiments in speech production and physiology. Cooper instigated and participated in many of these, as well as in the development and importation of the technical facilities needed to carry out studies employing such techniques as electromyography indirect and direct viewing of the laryngeal mechanism and cineradiography.

Under Cooper's directorship Haskins Laboratories became a major center for the study of speech and attracted, in addition to its permanent staff of research associates, many eminent visiting scholars and scores of students who have undertaken graduate research projects using the facilities of the Laboratories.



Fig. 6. Franklin S. Cooper (Kyoto, 1968).

He took a leave of absence only once, during World War II and shortly thereafter. From 1941-46 he came to Washington, D.C., at the request of Vannevar Bush, science adviser to President Franklin Roosevelt, to take a position in the Office of Scientific Research and Development. During the war he also consulted for several public entities, including the Department of Defense and the United Nations. A second invitation to Washington came in 1973, when he was selected to form a panel of six experts charged with investigating the famous 18-minute gap in President Richard Nixon's Oval Office tapes discussing the Watergate conspiracy.

Among Cooper's many honors were: Honors of the Association, American Speech and Hearing Association; Fellow, Acoustical Society of America; Fellow, Institute of Electrical and Electronic Engineers; President's Certificate of Merit, 1948; Pioneer Award in Speech Communication, Institute of Electrical and Electronic Engineers, 1972; Silver Medal in Speech Communication, Acoustical Society of America, 1975; Member, National Academy of Engineering, 1976; Honorary Doctor of Science Degree, Yale University, 1976.

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LAWRENCE J. RAPHAEL; *PALO ALTO WEEKLY*; EDS.

DELATTRE, PIERRE C. (b. Roanne, France, 21 Oct 1903, d. Santa Barbara, CA, 11 Jul 1969). *Experimental, comparative and applied phonetician, linguist, French language teacher.*

Pierre Delattre emigrated from France as a young man with a background in music, French linguistics, and classical phonetics, and his career continued in the tradition of Paul Passy with a focus on speech articulation and the application of phonetics to language teaching. Once in the United States, he taught French at Wayne State University and enrolled at the University of Michigan. His 1937 thesis, a study of factors affecting syllable duration in French, initiated what would be a life-long interest in prosodic features of language. After completing his doctorate, he went on to the University of Oklahoma and began a 16-year tenure as director of the Summer Remedial Phonetics Program at Middlebury College, where the curriculum emphasized training in the articulatory set of the

target language. Over the course of his career, Delattre developed an array of French teaching materials, including several audio recordings, and actively sought to convey the results of experimental research to applied linguists and language teachers.

In 1947, Delattre joined the faculty of the University of Pennsylvania. He took considerable interest in the emerging technology for speech analysis, and established contact with researchers at Bell Laboratories, MIT, and Haskins Laboratories. At Haskins, the Pattern Playback was being employed as a synthesis tool by FRANKLIN COOPER, a physicist and engineer, and ALVIN LIBERMAN, a psychologist. Delattre, enthusiastic about the possibilities the device offered, soon became a collaborator in the search for the acoustic cues of speech, work that fueled extensive theoretical development in the field of speech perception. Delattre brought to the research program his phonetic knowledge, a well-trained ear, and a talent for painting the simplified spectrographic representations that were the input to the Pattern Playback. His compendium of acoustic cues (1958) served as a sourcebook for much subsequent speech synthesis.



Fig. 7. Pierre C. Delattre (Haskins Labs, NYC, 1967).

Although he left Pennsylvania for Colorado in 1953, Delattre made occasional visits to Haskins for several years until he eventually established his own laboratory, which included a replica of the Pattern Playback. His later experimental work included comparative acoustic studies of English, French, German and Spanish, and cross-linguistic comparisons of

cineradiographic data. In 1964, Delattre moved to the University of California at Santa Barbara, and at the time of his death was actively involved in the development of a new graduate program there in linguistics and literary studies.

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Laura L. KOENIG

DENES, PETER B. (b. Budapest, Hungary, 9 Nov 1920, d. Gilette, NJ, 30 Jan 1996). *Engineer, educator, administrator*.

BSc, MSc in Elect Eng, Manchester Univ, 1941, 1943; cert, Univ Col, London; PhD (Eng), Univ of London, 1960. Lect, Univ Col, 1947-61; memb tech staff, Bell labs, NJ, 1961-67, head, speech & commun res dept, 1968-1983; memb tech staff, AT&T 1983-86. visit. fel, Columbia Univ, 1956. Denes emigrated from Hungary to England in the 1930s where he obtained degrees from Universities of Manchester and London. From 1946 to 1961 he researched and taught phonetics at the University College where he was also head of the Phonetics Laboratory. In 1961 he went to work in the speech research department at Bell Laboratories, at Murray Hill, NJ, and eventually became head of the speech and communication research department. A.M. Noll notes "[h]e was a pioneer in the use of digital computers in speech research and championed dedicated laboratory computers at a time when central main-frame computers were much in vogue." His research covered many areas in speech from automatic speech recognition to speech compression.

Among his scores of publications, his popular book (and accompanying film) *The Speech Chain* (with Elliot N. Pinson, Baltimore, MD, 1953) was perhaps the most influential, serving to introduce speech science to tens of thousands of students around the world.



Fig. 8. Peter B. Denes (Kyoto, 1968).

He served the Acoustical Society of America as chair of the Speech Communication Technical Committee and as associate editor of the *Journal of the Acoustical Society of America*. He was a fellow of the society.

Denes acknowledged that those who had the greatest influence on his work were Dennis Fry, FRANKLIN S. COOPER, ALVIN M. LIBERMAN, and Daniel Jones.

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EDS., BASED ON PBD'S ENTRY IN THE *BDPS* AND THE OBITUARY BY NOLL

DUPONCEAU, PIERRE, É. (Duponceau, Du Ponceau, Peter, S.) (b. St-Martin-de-Ré, France, 3 Jun 1760, d. Philadelphia, PA, 1 Apr 1844). *Linguist, lawyer, historian*.

DuPonceau had a natural flair for languages. As a child in France, he quickly acquired a good command of English, Danish, German, Italian and Latin. His first employment — after abortive attempts to train for the army and then the priesthood — was as the secretarial assistant to the philologist Antoine Court de Gébelin (1725-1784), the author of *Monde Primitif* (1773-1782), a multi-volume study of language origins, universal languages, and classical languages. The job lasted only a few months before his linguistic abilities came to the attention of Baron Friedrich Wilhelm von Steuben (1730-1794), currently planning to travel to North America to assist in the War, and seeking someone to act as his interpreter. DuPonceau arrived in New Hampshire at the age of 17 in 1777 with von Steuben. Within a year he was to be the youngest serving officer in the Continental army at Valley Forge — an experience which also brought him into contact for the first time with a speaker of a native Amerindian language. Later, between 1781 and 1783, he was appointed Undersecretary

for Foreign Affairs, whilst at the same time training as a lawyer in Philadelphia. His legal and commercial activities, as well as his publications on international law, history and the commercial and industrial world (see Knott 1930, Gawalt 1999), were to earn him national respect.

His reputation as a linguist — he held no teaching post in the subject, and his published linguistic work began in earnest only in his mid-50s — rests on his studies of the linguistic structures of several languages, especially those of the Americas (cf. Belyj 1975, Smith 1983). He took great pains to discover as much as possible about the languages he was studying: this involved a meticulous examination of all printed sources and, wherever possible, discussions with native speakers.

English Phonology (1817) is an important analysis of the phonemic system of American English. DuPonceau avoids the trap of describing speech in terms of letters of the alphabet, instead setting up the near-equivalents of phonemic units using the principle of 'elementary sounds.' To avoid any association with letters of the alphabet, he gives these elementary sounds exotic names such as 'vel' for /v/, 'oreb' for /o:/ (the predecessor of modern /ou/), and 'zhim' for /ʒ/. Having more or less categorized them into vowels and consonants — and commented on such factors as length differences, and even allophonic differences (e.g., the different varieties of /k/ and /g/ in *king*, *call*, *gain* and *god*) — he then moves on to the question of how they should be symbolized. He recognizes the need for a special phonetic alphabet — a 'phonological alphabet' — which should have 'the Greek alphabet as the basis, with the addition of characters borrowed from other languages, particularly the Russian'. He does not attempt to devise such an alphabet, however, since his purpose is primarily to exemplify a methodology for the analysis of the phonemes. One might note in passing, though, his somewhat prescriptivist views on 'vicious' pronunciations such as Virginian *there* with /a:/, and the 'vulgarized' version of *can't you* so that it is homophonous with *can't chew*, and *raven*, *maiden*, etc. pronounced with /ə/-deletions. For DuPonceau, the 'true and genuine' pronunciation was only to be heard in 'solemn recitation'. *English Phonology* is his most original foray into 'a curious and interesting science'.

The 'Dissertation' on Chinese (1838b) takes issue with the dominant view — at least in the early 19th century — that the writing system of Chinese was ideographic. DuPonceau puts forward, admittedly tentatively, various arguments in favor of a 'lexigraphic' base: 'the Chinese system of writing is essentially phonetic, because the characters represent words, and words are sounds; and because, if not connected with those sounds, they would present to the mind no idea whatever'. The bulk of the 'Dissertation', however, consists of two dictionaries of Vietnamese, written by J. Morrone and M. de la Palun.

DuPonceau's studies of the indigenous American languages derive mainly from his work as the Corresponding Secretary and, later, President of the American Philosophical Society — a focal point in his scientific-cultural life. In 1815, the Society had set up a special committee (the 'Historical and Literary Committee'), one of whose aims was to collect data on Amerindian languages. DuPonceau, together with his contemporaries JOHN PICKERING (1777-1846) (also a lawyer) and the Moravian missionary and linguist, Rev. John Heckewelder (1743-1823) of Ohio (cf. DuPonceau 1819b), were to be its mainstays. As well as reporting on current researches, DuPonceau published and/or

republished earlier studies of North American languages, including those by JOHN ELIOT (1604-1690) and David Zeisberger (1721-1808). For one of his own reports (1819a), he accumulated as much information as he could find on eight different languages of the three Americas: namely Eskimo, Delaware, Iroquois (North America), Pocanchi, Nahuatl, Tarascan (Central America), Carib and Arawakanian (South America).

His *Mémoire sur le système grammatical de quelques nations indiennes de l'Amérique du Nord* (1838a), for which he was awarded the Prix Volney, is an elegant typology of the Algonquian language-family. The chapter on 'Phonologie des langues algonquines' draws attention to the variety of sounds to be heard in these and various other American languages. For example, he comments that, to the ear of a European, the sound of 'la lettre K' in Quicha and Othomi 'ressemble ... au bruit que fait un singe qui casse des noix!' (Even so, he does attempt a rather more phonetic description of it as 'doublement articulée du fond du gosier'.) He notes too the relative absence of labiodental fricatives in many Amerindian languages. For notational purposes, he uses roman orthography — in other words, there is no sign of the 'phonological alphabet' he had hinted at some 20 or so years earlier.

His philological notebooks, covering his studies of the languages of North America, Asia, Africa and the Pacific, as well as his correspondence with linguists, reveal a much wider range of interests than is evident from his published work: see Smith 1983 and American Philosophical Society 1999.

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MIKE MACMAHON

EDISON, THOMAS (b. Milan, OH, 11 Feb 1847, d. Glenmont, NJ, 18 Oct 1931). *Inventor, scientist (chemist, electricity), industrialist, promoter.*

Thomas Edison is considered history's most prolific inventor (holding 1,093 patents) and is the only person in the U.S. to ever be granted a patent for sixty-five straight years (1868-1933). Some of his more famous inventions included the incandescent electric lamp, the electrical vote recorder, the electric pen, the carbon telephone transmitter, the motion-picture projector, and the phonograph. Edison's inventions helped to create and contribute to modern night-lights, movies, telephones, records, and even CDs.

Noted for his famous quotation, "genius is one percent inspiration and 99 percent perspiration", Edison was a self-educated and home-schooled man. He began to lose his hearing as a young child after a bout with scarlet fever. Then at age fifteen, Edison was involved in an accident in which he fell off a moving train. This further contributed to his hearing loss, which continued to grow until later in life he was totally deaf in his left ear and had only 10 % hearing in his right ear.

At age 30, the phonograph was Edison's most original and favorite invention, and it was considered by many as the most revolutionary. Edison invented the phonograph (or "sound writer") accidentally while he was working on improving both the telegraph and the telephone. Edison had been working on a way to record telegraph messages. It was not until 10 years after Edison began his work on the phonograph that it began to be sold to the public. The phonograph was made from tinfoil and was called the "talking machine". The phonograph was described by Edison as "an apparatus for recording automatically the human voice and reproducing the same at any future period", (Conot: 104). The first recorded words were "Mary had a little lamb." Edison continued to work on perfecting the phonograph for another 20 years. For example, he used wax records to help improve the phonograph and later used rain-forest nuts for making phonograph needles. Upon hearing that teenagers were turning up the speed of his cylinder phonograph to increase the speed of the music, Edison replied "I don't want it and won't have it", and then he ordered workers to add a record speed control.

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Links to Thomas Alva Edison Site on the Web:

Thomas Alva Edison: <http://www.edisonfestival.org/Link.htm>

Thomas Edison Papers: <http://edison.rutgers.edu/>

The Edison - Ford Winter Estates, <http://edison-ford-estate.com/index.htm#MENU>

STEPHEN LAMBACHER

EIMAS, P(ETER) D. (b. Bridgeport, CT, 5 Nov 1934). *Educator, psycholinguist, cognitive scientist.*

BA, Yale University, 1956; MA, 1959, PhD, 1962, University of Connecticut. NIMH Pre- and Postdoctoral Fellow, University of Connecticut; Assistant Professor, Williams College, 1964-67; Rutgers University, 1967-68; Associate Professor, 1968-71; Professor, 1971-91; Fred M. Seed Professor of Cognitive and Linguistic Sciences, 1991-96, Emeritus Professor, 1996, Brown University. Guggenheim Fellow and Visiting Scientist, Haskins Laboratories, 1874-75, James McKeen Cattell Fellow and Visiting Scientists, MIT, 1982-83. Fellow, American Psychological Society and American Association for the Advancement of Science. Eimas's research since 1970 has primarily centered on the development of speech perception and the manner in which the development of competence in speech perception and phonetics make language acquisition possible. He has also done work on the perception of speech and lexical access in adult listeners. More recent research has investigated the development of concepts for natural kinds and artifacts and how this achievement underlies the development of meaning and more general cognitive competence. He has published over 100 papers and chapters and co-edited three books.

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PETER D. EIMAS

ELIOT, JOHN (b. County Essex, England, 1604, d. Roxbury, Massachusetts Bay Colony, 21 May 1690). *Missionary and translator.*

John Eliot emigrated to New England in 1631, probably shortly after he had become a Puritan. In 1632 he became pastor at Roxbury, Massachusetts Bay Colony, a position he held until his death. He is mainly remembered as the 'Apostle to the Indians.' His missionary work with the Massachusett (an Eastern Algonquian people) resulted in some 4000 converts and the founding of 14 towns of 'praying Indians'. He produced a Massachusett translation of the Bible (New Testament completed in 1661, Old Testament in 1663, published in 1663), which became the first Bible published and actually printed in the New World. (His now lost Massachusett Catechism of 1654 had been the first book to be printed in New England in an Indian language.) His Massachusett orthography continued to be used in one form or another for a variety of purposes (including public records in the Indian towns) until the language became extinct in the early nineteenth century. He also translated other religious texts into Massachusett, drafted a grammatical sketch of the language, and wrote several works in English on religious and political topics.

Eliot's work is significant for linguistics almost solely because of the light it can shed on the extinct Massachusett language and thus on the Algonquian family generally, especially its Eastern branch. Since most of the other Eastern Algonquian languages are also extinct, the best (and sometimes the only) evidence about them is often early textual material such as Eliot's Bible. (Paralleling Eliot's legacy is the work done by his contemporary ROGER WILLIAMS on the closely-related Narragansett language.)

The Massachusett inventory (in the orthography of Goddard and Bragdon 1988, an 'idealization' of Eliot's) is as follows:

p	t	t ^e	ch	k
	s	sh		h
m	n			
w		y		
a, á		u, 8		
e#		ô		

[t^e/ was some sort of palatalized t; /a/ and /u/ were short, while the other four vowels were long; /e#/ is roughly the English 'long e' ([i:] without diphthongization; the symbol /8/ was tilted 90° in the original texts and was intended by Eliot to resemble the 'oo' sequence in 'book'; the circumflex (˘) represented nasalization.] This orthography was generally successful in representing all the phonemic contrasts in the language, but was often used inconsistently, as Eliot himself acknowledged. His representation of the (apparently) sole Massachusett nasal vowel /ô/ is worthy of comment. He expressly adopted the circumflex (˘) as a mark of nasalization, but seems often to have omitted it, especially before continuants. When the nasal vowel was followed by a stop or affricate, he nearly always used the sequence of vowel plus either 'n' or 'm' instead. Native writers were less consistent in marking this feature at all. There has been good bit of controversy about the nature and origin of nasalization in Eastern Algonquian, which has been accompanied by speculation about why Eliot and the native writers represented these segments as they did.

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WILLIAM F. WEIGEL

FAIRBANKS, GRANT (b. 26 Jul 1910, d. 14 Jun 1964). A specialist in general, experimental, and clinical phonetics, and in the teaching of English.

Fairbanks received his Bachelor's degree from University of Redlands, and a Doctorate in psychology from the State University of Iowa. He began his career teaching at the latter university, and at the University of Southern California, where he was in charge of the Speech and Hearing Clinic laboratories, then moved to the University of Illinois, where he was director of the Speech Research Laboratory. He was also in charge of the speech research group at the Stanford Research Institute, and held a professorship at the university there until the time of his death. He also worked for the Army and Navy on a number of speech communication projects, and acted as consultant and associate editor for the *Quarterly Journal of Speech*, *Folia Phoniatica*, and the *Journal of Speech and Hearing Disorders*. His principal research interests lay (i) in examining the acoustic characteristics of vowels (intrinsic cues: intensity, fundamental frequency and duration), the influence of consonantal environment on characteristics of vowels; (ii) intelligibility of speech. Fairbanks developed the Rhyme Test, which is systematically used in evaluating intelligibility; he was also the co-inventor of the Speech Compressor (a device for temporal compression of speech) which was used in perceptual tests before the advent of numerical sampling techniques. Interested in the teaching of English, he was a highly meticulous specialist in experimentation and instrumentation, and supervised fifty graduate theses before his career was interrupted by his untimely death.

LOUIS-JEAN BOË

FLANAGAN, JAMES L(OTON) (b. Greenwood, MS, 26 Aug 1925). *Scientist, educator, administrator.*

BS, Miss St Univ, 1948; MS and ScD, Mass. Inst. Tech., 1950, 1955; Rockefeller Foundation fel, 1952-53, 1955. Res

engineer, acoust lab, Mass Inst Tech, 1948-50, 1953-54; asst prof, Miss St Univ, 1950-52; electronic scientist, US Air Force Cambridge Res Center, 1955-57; memb tech staff, Bell Tel labs, 1957-61, head, speech & auditory res dept, 1961-67; head, Acoustics Research Dept, 1967-85, Dir., Information Principles Research Laboratory, 1985-; Dir., Rutgers Univ Ctr for Computer Aids for Industrial Productivity, vice-pres., reseach. Awards and honors: Fellow, ASA; ASA Gold Medal; Marconi International Fellowship Award; L. M. Ericsson International Prize in Telecommunications; IEEE Edison Medal; National Medal of Sci., 1996.; member: National Academy of Engineering, National Acad. Sci. Service: associate editor, *J. Acoust. Soc. Am.*, 1959-1962; ASA exec coun. 1970-73, memb., finan. comm. 1974-76; vice-pres., 1976-77, pres., ASA 1978-79.

The scope of Flanagan's research is well-characterized by the title of his book, *Speech Analysis Synthesis and Perception* (second expanded edition, New York, 1972). His research ranges from speech compression, automatic speech recognition, speech synthesis, modeling basilar membrane motion, a physiologically-based model of vocal excitation in speech.

EDS., BASED ON ENTRY IN *BDPS* and CITATIONS FOR ASA GOLD MEDAL, WRITTEN BY M. V. MATHEWS and L. R. RABINER

FOWLER, CAROL A. (b. Providence, RI, 11 Nov 1949). *Speech researcher.*

MA, 1973, PhD, 1977, University of Connecticut; instructor to full professor, Dartmouth College, 1976-1992; full prof., University of Connecticut, 1992- present. President, Haskins Laboratories, 1992-present. Guggenheim Fellowship, 1987; Fellow of the Acoustical Society of America. Associate Editor, *Journal of Experimental Psychology: Human Perception and Performance*, 1983-1988; 1993-1998; Associate Editor, *Psychological Review*, 1998-present. Fowler's research focuses on links between speech production and speech perception as mediated by a common gestural phonology.

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CAROL FOWLER

FRANKLIN, BENJAMIN (b. Boston, MA, 17 Jan 1706, d. Philadelphia, PA, 17 Apr 1790). *Author, printer, scientist (electricity, physics, oceanography, meteorology), diplomat.*

Benjamin Franklin, in addition to his other pursuits, was interested in promoting spelling reform. In 1768, while living in London, he wrote *A Scheme for a new Alphabet and a Reformed Mode of Spelling*, a reasonably accurate phonetic system for spelling English which, published in 1779, greatly influence Noah Webster. His new phonetic alphabet consisted of 26 symbols: the conventional letters *c, j, q, w, x*, and *y* were eliminated as redundant and six new characters, were devised for sounds for which he thought there was no unambiguous orthographic representation; see Fig. 9. The remaining letters of the traditional Roman alphabet were retained but their sound value was strictly defined according to the principle 'one symbol (or unique digraph), one sound'. Thus *g* could only represent the voiced velar stop, as in 'give', never the voiced palatal affricate, as in 'gentle'. This affricate and its voiceless counterpart (as in *chew*) he represented by clusters of stop plus palato-alveolar fricative (the fricative portion being the voiceless one in both cases). Other notable features of his system are: 1) the use of double vs. single vowel letters to stand for long vs. short vowels, e.g., *mend* for 'mend' but *remeend* for 'remained', 2) the transcription of the diphthong in words such as 'I' and 'buy' with two letters, the first equal to the initial vowel in 'unto' and the second equal to the vowel in 'did', or as we would transcribe it today using the International Phonetic Alphabet, [aɪ]. This latter feature undoubtedly reflects a regional pronunciation which may still be found in some British English and New England dialects.

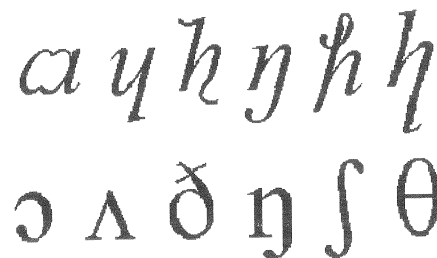


Fig. 9. Franklin's six new letters and, below, their modern IPA equivalents.

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JOHN J. OHALA

FROMKIN, VICTORIA A. (b. Passaic, NJ, 16 May 1923). *Educator, phonetician, neurolinguist.*

Victoria A. Fromkin received her MA in Linguistics in 1963 and her PhD in 1965 at the University of California, Los Angeles, where she then continued as a faculty member, becoming a Professor of Linguistics in 1972. She served as the Chair of the Department of Linguistics from 1972 to 1976, and the UCLA Graduate Dean and Vice Chancellor of Graduate Programs from 1979 to 1989. Dr. Fromkin has been a visiting professor at the Universities of Cambridge and Oxford, English, and the University of Stockholm, Sweden. Dr. Fromkin served as president of the Linguistic Society of America in 1985, as President of the Association of Graduate Schools (of the AAU), and as Chair of the Board of Governors of the Academy of Aphasia. She is currently the Chair-Elect of Section Z - Linguistics and the Language Sciences of the AAAS. She received the UCLA Distinguished Teaching Award and the Professional Achievement Award, and serves as the US Delegate and a member of the Executive Committee of the International Permanent Committee of Linguists (CIPL). In 1996 she was elected to membership in the National Academy of Sciences, and is also an elected Fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, the New York Academy of Science, the American Psychological Society, and the Acoustical Society of America. The textbook, *An Introduction to Language*, co-authored with Robert Rodman is in its fifth edition and has been translated into Chinese, Japanese, Korean, Portuguese, and Dutch. She has published over one hundred books, monographs, and papers on topics concerned with phonetics, phonology, tone languages, African languages, speech errors, processing models, aphasia, and the brain/mind/language interface. Fromkin's research spans diverse areas: the phonetics and phonology of African languages, speech production (especially of the lips), speech errors, neurolinguistics.

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VICTORIA A. FROMKIN

FUJIMURA, OSAMU (b. Tokyo, Japan, 28 Aug 1927). *Speech scientist, linguist, educator, administrator.*

Education: B.Sc. and D.Sc., University of Tokyo, physics. Upon obtaining his B.Sc. in 1952, Fujimura started speech research at Kobayashi Institute of Physical Research in Tokyo. Subsequently he spent two and half years at the Research Laboratories of Electronics, MIT, where he conducted speech synthesis experiments and speech production research. After returning to Japan to teach at the University of Electro-Communications, Tokyo, he went to work at the Royal Institute of Technology (KTH), Stockholm, for one and a half years. There, with Jan Lindqvist (Gauffin), he recorded the vocal tract transfer functions for vowels and other articulations using a sweep-tone method, giving direct experimental proof to Fant's acoustical theory of speech production. He was appointed professor in 1965 at the University of Tokyo, and head of the Research Institute of Logopedics and Phoniatrics, Faculty of Medicine. During his tenure there he pioneered several novel

techniques for the study of speech production: the x-ray microbeam method for automatically tracking metal pellets on articulatory organs, dynamic palatography, and fiberoptic examination of the larynx, among others. During this time he taught Chomskyan syntactic theory and wrote several review and tutorial articles in this area and edited a monograph on syntactic, phonological, and semantic theories. Collaborating with Sumiko Sasanuma he studied psycholinguistic impairment of aphasia with speech apraxia in Japanese patients. He left the University of Tokyo in 1973 to head a new Department of Linguistic Research at Bell Labs. There he assembled a linguistic research team consisting of several young leaders in phonetics, phonology, computational linguistics, semantics, experimental psychology, and artificial intelligence. He assisted NIH in implementing a more powerful version of the microbeam system at the University of Wisconsin, Madison, as a nationally shared experimental facility of speech production research. Within speech technology he has promoted a demisyllables as useful concatenative units. Within speech production he has studied asynchronous movements of articulators and, more recently, has promoted the Converter-Distributor (C/D) theory of speech organization. His contribution to speech science over a number of years is reflected in his *Festschrift* (Kiritani, et al. (1997)).

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OSAMU FUJIMURA; EDS.

GODDARD, PLINY E. (b. Lewiston, ME, 24 Nov 1869, d. 12 Jul 1928). *Teacher, school principal, professor, and museum curator.*

Goddard received an A.B. in 1892 and an A.M. in 1896 from Earlham College in Indiana, as well as a PhD in Linguistics from the University of California in 1904. He was appointed Assistant Professor at the University of California in 1906,

Assistant Curator of the American Museum of Natural History in 1909, Associate Curator in 1910, and Curator of Ethnology in 1914, while he was also founder and co-editor of the *International Journal of American Linguistics*, starting in 1917.

It was only in the last few years of the 19th century that Goddard, at the time aged 30 years and living in Hupa, California, became aware of his ambitions towards ethnology. He was ostensibly performing missionary work for the Women's Indian Aid Association, but he actually spent more time on what would prove to be extremely detailed field work on the language and culture of the Hupa. He enrolled at the University of California in 1900, where he was influenced by his teacher (and at the time newly appointed University President) Benjamin Ide Wheeler and soon thereafter by ALFRED KROEBER. However, his first, and arguably his best, work, *Life and Culture of the Hupa*, was essentially completed in 1901, before he had had extended contact with ethnologists or linguists.

As a general principle, he looked at both articulatory and acoustic aspects of speech sounds, using instrumental means such as an adapted Rousselot machine, palatography, which he borrowed from SCRIPTURE, and the innovative generation of vowel tracings using microphotography. It was his belief that the documentation of language using human transcription did not suffice due to the simple inaccuracy of the human listener, and that rather, whenever possible, instrumental documentation should be made. His *Phonology of the Hupa* not only makes use of, but creates a central role for, this documentation. Consonants are not simply described, but are accompanied by tables of palatograms and photographs, representing their production.

Goddard also used instrumental methods to determine the validity of certain phonological claims (1904). He tested Henry Sweet's contention that so-called English "long" and "short" vowels were in fact not distinguished by length. Using kymographic recordings, he showed that there was a consistent, yet statistically insignificant advantage in length to the "long" vowels. In the course of his investigation, however, he came across a novel generalization; any vowel followed by voiced stop is longer than its counterpart which precedes a voiceless stop, both of which are shorter than syllable-final vowels.

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BENJAMIN K. BERGEN

GRANDGENT, CHARLES HALL (b. Dorchester, MA, 14 Nov 1862, d. Cambridge, MA, 11 Sep 1939). *Phonetician, romance philologist, educator, author.*

Charles Hall Grandgent was a Romance philologist, Dante scholar, expert on language pedagogy, phonetician, author, and sometime poet. He began his education at Roxbury Latin School, then proceeded to college at Harvard, where he graduated head of his class in 1883. After a three-year fellowship for study in western Europe (University of Leipzig, Collège de France, École des Chartes), he began his Harvard career in 1886 as a Tutor in Modern Languages. In 1889, he left Harvard to become the Director of Modern Language Instruction for the Boston Public Schools, but returned in 1896 to become a Professor of Romance Languages until his retirement in 1932. Grandgent chaired the department from 1899 to 1911, and was Acting Dean of the Graduate School of Arts and Sciences in 1929. He twice served as an Exchange Professor at the Collège de France in Paris (1915, 1931).

His most influential linguistic works were his triumvirate of Romance philology: *An Outline of the Phonology and Morphology of Old Provençal*, *An Introduction to Vulgar Latin* (translated into Italian and Spanish), and *From Latin to Italian*. Of particular interest to phoneticians are five of his works: "Warmph" (1896), which was concerned with emergent stops and consonant clusters and for which he conducted a survey by post of over a 100 American linguists; "Vowel Measurements" (1890) in which he reported his results of determining the tongue shapes for vowels by using wire probes; "From Franklin to Lowell" (1915), a history of phonetic transcriptions of New England pronunciation between the 18th to early 19th centuries; *German and English Sounds* (1892), a descriptive account of phonetic differences in these two languages; and *The N.E.A. Phonetic Alphabet* (1912) (with RAYMOND WEEKS and James Bright) a critique of the system used to represent English pronunciation in dictionaries.

Grandgent received many honors during his life: honorary degrees from University of Chicago, University of Michigan, and Oberlin College and he was also awarded the *Chevalier de la Légion d'Honneur* (France), and the *Commendator dell'Ordine della Corona d'Italia* (Italy). He was an active member of many professional societies, notably the Modern Language Association, in which he served as Secretary and PMLA editor (1902-1911) and as president in 1912. He was also president of the American Simplified Spelling Board and vice president of the English Simplified Spelling Society.

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the Phonology and Morphology of the Italian Language. Cambridge: Harvard University Press.

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SUZANNE WERTHEIM; EDS.

GRAY, GILES W. (b. Shelbyville, IN, 11 Dec 1889, d. Baton Rouge, LA, 29 Aug 1972). *Phonetician, educator*.

BA, 1914, DePauw University; MA, 1923, University of Wisconsin; PhD, 1926, University of Iowa. Gray taught at the University of Iowa and at Louisiana State University. He served as Visiting Professor at the University of Wisconsin, the University of Georgia, St. Louis University and the University of California at Berkeley. Gray's book, *The Bases of Speech*, coauthored with CLAUDE M. WISE (1934), was "a landmark contribution to the speech discipline," remarked his colleague Claude Shaver of Louisiana State University. (See Shaver's entry on Gray for *The Biographical Dictionary of the Phonetic Sciences*, noted at the end of this entry.) Gray's chapter on 'Speech Sound Formation' for the *Handbook of Speech Pathology*, edited by Lee Edward Travis (1957 and 1971), added to his growing reputation as a major contributor to the developing field of experimental phonetics. He authored numerous articles for *The Quarterly Journal of Speech* (for which he served as Editor from 1929 - 1941), *Speech Monographs*, and for *The Southern Speech Journal*.

It was due to Gray's suggestion, in the late 1950s, that an effort be made to record the contributions of major scholars in the field of phonetics to provide a needed historical perspective to other scholars in the developing field of speech science that the *Biographical Dictionary of the Phonetic Sciences*, by A. J. BRONSTEIN, L. J. Raphael, and Cj Stevens (Lehman College Press, 1977) was written. This note is based on the entry on Gray, authored by Claude Shaver of LSU, for that volume.

ARTHUR J. BRONSTEIN

HALDEMAN, SAMUEL STE(H)MAN~STEDMAN (b. Locust Grove, PA, 12 Aug 1812, d. Chickies, PA, 10 Sep 1880). *Zoologist, phonetician, linguist, geologist*.

Haldeman was bilingual in English and German (Pennsylvanian Dutch). He was also blessed with very fine hearing, being able as an entomologist to classify insects on the basis of the sounds they emitted. These two facts may have predisposed him to turn to the study of linguistic topics.

A boyhood enthusiasm for natural history was to lead to an appointment, in 1836, as a field geologist in New Jersey and Pennsylvania. This was followed by academic posts at various times and in various American colleges over the next 30 years in zoology (cf. Sorensen, 1984), geology, chemistry, and natural sciences. In 1868, he was appointed the first Professor of Comparative Philology at the University of Pennsylvania.

His contributions to language study fall into four broad categories: (i) phonetics (e.g. 1856, 1860, 1868, 1874); (ii) morphology (e.g. 1865); (iii) German dialects (e.g. 1872); (iv) dictionaries (e.g. 1869).

Since the 1840s, his interests in linguistics and natural history had run in parallel. For example, when American Indian delegations arrived in Washington on government business, Haldeman would try to meet them in order to obtain first-hand information about their language(s). By the mid to late 1840s, he had published on general phonetics, diphthongs, syllables, and the 'phonology' of Wyandot.

His attention was not restricted, however, to North America. He travelled on several occasions to Europe, specifically to undertake field-work on various languages and dialects. (A paper he read to the American Philosophical Society in 1862 on the phonetics of Basque was one such result.) He maintained contacts, in person or by correspondence, with various European phoneticians and linguists, including Bleek, Ellis, Lundell, Pitman, and de Saussure.

His major contribution to phonetics was his *Analytic Orthography* (1860). In 1857, prizes of £100 and £40 had been offered by the Phonetic Society of Great Britain — a spelling reform organization — for the two best essays on 'a reform in the spelling of the English language, by the introduction of a phonetic instead of the present unphonetic system'. The prizes were underwritten by Sir Walter C. Trevelyan (1797-1879), a friend of Pitman's, and, like Haldeman, a scientist who specialized in zoology and geology. Haldeman, who had already shown his interest in theories of notation (cf. Haldeman 1856), entered the competition. Neither he nor anyone else won the prizes, but he was awarded £50 for his submission, plus a further £50 on condition that he revise and publish it.

Analytic Orthography is both a critique of the notational practices of some of his predecessors and contemporaries—particularly in connection with attempts to establish initial or reformed orthographies for various languages (cf. Lepsius/Kemp 1981)—as well as an exposition of the range and characteristics of the categories that any general phonetic notation must be capable of dealing with. The consonant and vowel systems of more than 70 languages are discussed *en passant*, and Haldeman provides examples of his own phonetic dictation of speakers of 61 of the world's languages and dialects, primarily from North America, Europe and Asia. His favored notation is one which uses Latin and Greek characters, with appropriate modifications, as its symbol base. It clearly anticipates in principle, if not in detail, the IPA alphabets of the 1880s and later (see Fig. 10).

Ellis commended it highly, and published extracts from it (cf. Ellis 1874). Nevertheless, its impact on the world-wide linguistics community appears to have been limited.

Wyandot	Chickasaw	Choctaw	Shaw	Lenape
¹ scut	¹ sánmús	¹ v'ástsi	¹ tré'bs	¹ evé'ti
² tendí	² áhā	² bith (t'h)	² vité	² nífā
³ zé'hc	³ páhāz't	³ éhā'v	³ taré'	³ nu'z'v
⁴ náōze	⁴ vó'xístz't	⁴ dšé'v	⁴ tševitr	⁴ axvā
⁵ uví'r	⁵ mántchit' (é'h)	⁵ dšé'scār	⁵ isevéto	⁵ palénu'c
⁶ avay	⁶ ná'vāz't	⁶ dá'fci	⁶ cī'āhāo	⁶ evs'tar
⁷ tsutóé'p'	⁷ tātšz't	⁷ b'šich	⁷ cšā'vitr	⁷ nira r
⁸ tré' >	⁸ ná'bévo'xístz't	⁸ dá'vsic	⁸ cū'tí'vā	⁸ z'ar
⁹ tró' >	⁹ sé'vóné'vūhā'v'	⁹ í'vō'sse'	⁹ tsiescū'ntē	⁹ pērou'fē
¹⁰ āšé'h, sš'h	¹⁰ sš'vā'ghp't	¹⁰ bū'ā'vā	¹⁰ cū'vō'vō'hāo	¹⁰ tšān

Fig. 10. The numbers 1-10 in 5 North American languages (Haldeman 1860:145). (The handwritten annotations are Haldeman's.)

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MIKE MACMAHON

HALLE, MORRIS (b. Liepaja, Latvia, 23 Jul 1923). *Linguist, educator*.

MA, Univ. of Chicago, 1948; PhD, Harvard, 1955. DSc (hon), Brandeis University, 1988; DHL, Univ. of Chicago, 1992. Pres. LSA 1974. Assist. Professor to Institute Professor, MIT, 1951-1996; Institute Professor Emeritus, MIT, 1996-. Guggenheim Fellow 1960-61. J. R. Killian, Jr. Faculty Achievement Award Lecturer, MIT, 1978-9. Science Prize, Union d'Assurance de Paris, 1991. Fellow, American Academy of Arts and Sciences 1963-; Member, National Academy of Sciences 1988-. The main focus of Halle's research concerns phonology, broadly conceived, from the acoustic and articulatory properties of speech to the theoretical bases of the field. A significant portion of this work is devoted to the study of phonetic universals (the features), the nature of rules, and the prosodic structures underlying stress and accentuation. The results of these theoretical studies have been illustrated and defended in detailed accounts of the phonologies of various languages, in particular, of English and of Russian, and in a reconstruction of the accentual system of the IE proto-language. Halle has also contributed to the development of the theory of

distributed morphology, and to the elucidation of the nature of metrical verse.

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MORRIS HALLE

HAN, MIEKO, S. (b. Tokyo, Japan, 28 Mar 1929). *Phonetician, educator*.

Born and raised in Japan, Mieko S. Han received most of her linguistic and phonetic training in the United States in the 1950s, culminating in a PhD in linguistics from the University of Texas, Austin (1961). Her dissertation was an acoustic phonetic study of Japanese under the supervision of Professor Ernest F. Haden. This was the first detailed study of Japanese using the sound spectrograph.

In 1961 she was appointed Assistant Professor in the Department of Oriental Languages at the University of California, Los Angeles and in 1964 accepted a position at the University of Southern California, where she is currently a professor in the Department of East Asian Languages and Cultures.

Mieko S. Han was one of the earliest scholars to turn attention to the acoustic features of Asian languages. Her extensive studies of Japanese, Korean, and Vietnamese have yielded a wealth of data on the acoustic properties of vowels and consonants, syllable structure, duration, and tonal phenomena in these languages.

The following is a selected bibliography of just the acoustic phonetic works of Han. In addition, she has developed curricular materials in Japanese language and bilingual-bicultural education.

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RAYMOND WEITZMAN

HEFFNER, R(OE)-M(ERRILL) S(ECRIST) (b. Bellefontaine, OH, 25 Aug 1892, d. Madison, WI, 17 Feb 1981). *Educator, phonetician, philologist*.

AB, Wittenberg Coll., 1913; AM, 1915; Litt D, 1954; AM, Harvard, 1916; PhD, 1925. Instr, Wittenberg Coll., 1913-15; instr, Worcester Polytech Inst, 1916-18; instr, Harvard, 1922-27; Harvard fel in Germany, 1927-28; instr, 1928-36, asst prof, 1936-38; assoc prof, Univ of Wis, 1938, prof, 1939-63, emeritus prof, 1963-81. During WWI Heffner served in the Army Signal Corps, rising to the rank of second lieutenant, teaching radio engineering. Heffner's research outside phonetics was German philology. He produced important editions of works by Schiller and Goethe and published various articles and word indexes to MHG texts. In the field of general phonetics he published a major text, *General Phonetics* and a series of six ground-breaking articles in vowel duration in *American Speech* between 1937-43; one coauthored with W. N. Locke and two coauthored with W. P. Lehmann. He was strongly influenced by his teachers CHARLES HALL GRANDGENT, W. F. Twaddell, George Lyman Kittredge and Hans Karl Guenther von Jagemann.

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EDS., BASED ON THE ENTRY IN THE *BDPS*

HOLBROOK, RICHARD THAYER (b. Windsor Lakes, CT, 13 Dec 1870, d. San Francisco, CA, 31 Jul 1934).

Education: BA, Yale, 1893; Sorbonne, College de France, École des Hautes Études, Paris, 1893-96; PhD, Columbia Univ., 1902. Honors: Chevalier de Légion d'Honneur (France), 1920. Holbrook was a professor in the French department at the University of California, Berkeley, from 1919 to 1934, the year of his death. His published works in this field include a study of the 15th century anonymous work: *Maistre Pierre Pathelin*, a critical study of the iconicity in *Portraits of Dante from Giotto to Raffael*, and a textbook for learning French as a second language. His interest and skill in what we would now call phonetics stemmed perhaps from his talent for language learning, and his pedagogical interests. In Dec. 1927, Dr. R. G. Van Nuys, a röntgenologist of Berkeley, offered Holbrook an opportunity to study speech articulations systematically with the technology of X-rays.

Holbrook was by no means a pioneer in this field; scholars such as G. O. RUSSELL, PARMENTER, Treviño, and Bevans had used radiography to document the speech organs during the production of vowels almost since the invention of X-rays in the late 19th century. Holbrook's systematicity and accuracy as well as his improvements to the techniques used in radiography of speech organs set him apart from the scholars who preceded him in this field. He improved upon the rudimentary use of foil

sheets or small gold chains placed along the articulators during speech so that they would show up on the X-rays. Unsatisfied with their impediments of the speech itself, inaccuracy of portraying dips in the tongue, and inability to mark such articulators as the epiglottis or pharyngeal wall, as well as any three-dimensional aspects to the production of a particular speech sound, he sprayed iodized sesame oil (lipiodol) into the mouth, nose, and throat: "A spray has the virtue of revealing clearly obtained incurved outlines (for example, between the epiglottis and the base of the tongue) which a chain cannot follow accurately, if at all."

Unlike his predecessors, who seemed content to collect either a few isolated specimens or many with no metrically homogeneous series for their studies, Holbrook spent the first six months at his newly designed lab developing a system of leather helmets and straps that held the speaker in a firm, known position with reasonable comfort, so that any photographs and X-rays made could be used for precise measurements of the speech organs. Once firmly in place, the speaker was instructed to utter a continuant for two or three seconds (the quality of the vowel was determined by Holbrook's ear), and the two strings of the X-ray tube and the camera shutter were pulled simultaneously. The consistency of his measurements (across radiographs of different subjects at different times, the position of the speech organs for a given vowel varied little) speaks to the accuracy of his technique, as well as his ear.

In his first publication of his technique, the usefulness of radiography in documenting speech sounds seemed limited to aiding in the comparison of vowels across European languages. His notes, later arranged and published by Francis J. Carmody, however, proved that the extensive X-rays not only mapped out the production of vowel systems in Russian, Polish, English, French, Italian, Portuguese, Spanish, and German, but showed the secondary effects of various speech events on these articulators. He studied the influence of pitch, head tilt, size of jaw opening, and amplitude on the major articulators. He also used his measurements to suggest a vowel parallelogram instead of the vowel triangle used in language-learning. His student and co-author, Francis J. Carmody would further these studies to account for the role of the pharyngeal wall as an articulator.

Richard T. Holbrook's desire for accuracy and the sheer quantity of measurements taken brought us important knowledge about the position of articulators during the production of vowels and the effects of manners of production on these articulators in a new, though somewhat dangerous way. For this, he is one of the most important contributors to the field of phonetics at Berkeley.

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MADELAINE C. PLAUCHÉ

HOUSEHOLDER, FRED WALTER, JR. (b. Wichita Falls, TX, 1 Feb 1913, d. Bloomington, IN, 4 Jan 1994). *Educator, linguist.*

Householder's 119 publications covered diverse topics in classical languages, Greek, Azerbaijani, English, and linguistics. While studying at Columbia University, he used oscillograms to study the speech of New Yorkers, which aided him in supervising the collection of Indiana dialect atlas records. Soon after the spectrograph was invented, Householder, who could be viewed today as laboratory phonologist, promoted technical and experimental methods in the study of linguistics. He said: "phonetic and phonemic analysis can proceed directly from these records, and statistical method can replace subjective judgments almost entirely. Like it or not, phonologists will now be forced to become statisticians or rely blindly on the statistics of others" [Householder 1948:53]. On the importance of acoustic features, he said "we can now formulate accurate descriptions of vowels either disregarding our pseudo-articulatory 'imitation label' terminology, or at any rate redefine the terms on the basis of acoustic analysis" (p. 53- 54). Since 1948, Householder taught phonetics at Indiana University in which he used the sound spectrograph. Householder is remembered most for his exquisite reviews, such as his review of Jones' *The Phoneme*. For that review he conducted a number of small experiments, one of which was the first study on the acoustics of schwa.

In his paper "Unreleased ptk in American English," he reports the results of perception study on the confusability of place of articulation in word-final unreleased /p t k/. The stimuli were presented live to students in a classroom and in order to deprive them of visual cues to place of articulation, he spoke the text with his back turned to them. In spite of the informality of the test, the results are quite congruent with those from other more controlled studies.

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BUSHRA ADNAN ZAWAYDEH; EDS.

JAKOBSON, ROMAN OSIPOVICH (b. Moscow, Russia, 22 Oct (10 Oct Old Style) 1896, d. Boston, MA, 18 Jul 1982). *Linguist, poet.*

Education: Lazarev Institute for Oriental Languages (Moscow), 1914; diploma, Moscow University, 1918; PhD, Charles University (German), Prague, Czechoslovakia, 1930. Numerous honorary degrees. Appointments: docent in Medieval Czech literature and language, Masaryk University, Brno, Czechoslovakia, 1933-37; professor, Russian philology and Old Czech literature, Masaryk University, 1937-39; professor, Slavic Studies, École Libre des Hautes Études, New York, 1942-46; professor, Slavic Studies, Columbia University, New York, 1943-

49; Samuel Hazzard Cross Professor of Slavic Studies, Harvard University, Cambridge, Massachusetts, 1959-67; Institute Professor, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1957-82. Jakobson's early career includes the formation of the Moscow Linguistics Circle while an undergraduate at Moscow University (where he first met N.S. Trubetzkoy) and his assuming a leading role in that precursor to structuralism known as Russian Formalism. Closely aligned with the Russian avant-garde (especially the poets Majakovskij and Kruchěnykh), Jakobson also wrote futurist, "transrational" (*zauumnaja*) poetry under the pseudonym Aljagrov.

In 1920 Jakobson went to Prague to work as an interpreter for the Red Cross in repatriating Russian prisoners-of-war. He enrolled in the doctoral program in Slavic studies in the German Division of Charles University, to which he ultimately submitted his *Habilitationsschrift* in 1930 (on the metrics of South Slavic epic poetry). Earliest major works are concerned with Russian and Czech poetics. In 1926 Jakobson joined the Prague Linguistics Circle and served as its vice-president until 1938. Other members included the Czechs V. Mathesius, B. Trnka, B. Havránek, and Jan Mukarovský, as well as the Russians N. S. Trubetzkoy, S. Karcevskij, and P. Bogatyrëv. In a statement, co-signed with Trubetzkoy and Karcevskij and delivered at the First International Congress of Linguists in the Hague in 1928, "Quelles sont les méthodes les mieux appropriées à un exposé complet et pratique de la phonologie d'une langue quelconque?" 1928, SW I, 2, 3-6), Jakobson held that languages are systems, and that the sound system of a given language can be investigated by studying the correlations and "significant differences" within it. The most important work done by Jakobson in phonetics and phonology during this period was on the phoneme and its structure (insights into the phoneme as a bundle of features, the archiphonème, and sound change as system maintenance); important works include "The Concept of the Sound Law and the Teleological Criterion" (1928, SW I, 1, 1-2); "Remarques sur l'évolution phonologique de russe comparée à celle des autres langues slaves" (1929, SW I, 3, 7-116); "Über die phonologischen Sprachbünde" (1931, SW I, 5, 137-143); "Phoneme and Phonology" (1932, SW I, 10, 231-233). In 1939, Jakobson was forced to flee occupied Czechoslovakia (where his younger brother eventually perished in a concentration camp); he moved from Copenhagen to Oslo to Stockholm to avoid the Nazis, while continually working on his study *Kindersprache, Aphasie und allgemeine Lautgesetze* (1941, SW I, 19, 328-401). Jakobson came to the United States in 1941, teaching at the Franco-Belgian École Libre des Hautes Études and Columbia University, before taking a position at Harvard University in 1949. Phonetic work during this period is marked by Jakobson's refinement of distinctive feature theory, the conviction that the feature bundles that make up phonemes can be reduced to (acoustically-based) binary oppositions: [±grave], [±diffuse], [±tense], etc.

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ADAM COHEN-SIEGEL



Fig. 11. Roman Jakobson (UCLA, 1966).

JEFFERSON, THOMAS (b. Goochland [now Albemarle] County, VA, 13 Apr 1743, d. Albemarle County, 4 Jul 1826). *Statesman, diplomat, surveyor, scientist, third President of the United States*.

Jefferson is best remembered as a seminal figure in American politics: author of the Declaration of Independence, governor of Virginia, ambassador to France (succeeding BENJAMIN FRANKLIN), secretary of state under George Washington, Vice President and later President of the United States, negotiator of the Louisiana Purchase, and founder of the University of Virginia. However, he was also accomplished in the sciences, working in agriculture, botany, cartography, ethnology, meteorology, paleontology, surveying, and technology.

Jefferson was also learned in languages; he had studied Old English and had written essays such as, "Essay on the Anglo-Saxon Language," "An Essay Towards Facilitating Instruction in the Anglo-Saxon and Modern Dialects of the English Language for the Use of the University of Virginia," and "Thoughts on English Prosody." His interest in languages and Indians naturally led him to investigate the languages of North America. He was interested in using comparative linguistic methods to determine the origin of Native Americans, and he concluded that

Were vocabularies formed of all the languages spoken in North and South America, preserving their appellations of the most common objects in nature, of those which must be present to every nation,...with the inflections of their names and verbs, their principles of regimen and concord, and these deposited in all the public libraries, it would furnish opportunities to those skilled in the languages of the old world to compare them...and hence to construct the best evidence of the derivation of this part of the human race. (quoted in Wissler, 191)

He became an avid collector of Native American vocabularies, commissioning people such as Lewis and Clark (whose expedition he launched) to bring him back word lists. Sadly, this collection as well as Jefferson's own work on native languages were lost in later years when robbers waylaid a shipment of his manuscripts in transit from Washington DC to his home in Virginia. Upon discovering that the shipment consisted just of "worthless" paper, they threw everything in the river. A few pages of the collection subsequently washed ashore. These were given to the American Philosophical Society, where scholars such as PETER S. DUPONCEAU and Albert Gallatin used them. One of the manuscripts that survived was Jefferson's Unquachog word list, the only vocabulary he personally elicited from Indians. See Fig. 12 (in Jefferson's own hand).

His work with speakers of Unquachog came about while on a scientific expedition with James Madison. They heard that there were a few Algonquian Indians living in the small settlement of Pusspátuck. On June 14, 1791, he made an impromptu stop there and elicited about two hundred words in the Unquachog dialect of Wampano (Quiripi). (EZRA STILES did work on the Quinnipiac dialect of Wampano.)

Unlike others who recorded Eastern Algonquian languages early on (such as Abraham Pierson, JOHN ELIOT, and ROGER WILLIAMS), Jefferson does not waver between various voiced and voiceless spellings for stops and fricatives (e.g., <t>, <tt>, <d>, <dt>, and <ddt>, which were all graphemes Williams used for /t/); Jefferson consistently used what are generally considered to be graphemes for voiceless consonants, such as <t> and <tt>.

Some Algonquianists interpret certain forms in Jefferson's notes as evidence for language contact between the Unquachog and the Montauk dialect of Mohegan-Pequot. Proto-Algonquian *θ and *l merged in Proto-Eastern Algonquian as *r, which, in turn, surfaced variously in the daughter languages as *n*, *y*, *r*, and *l* (cf. ROGER WILLIAMS's *Sound Shift* under WILLIAMS). In Wampano, the expected reflex of PEA *r is /r/; however, in six out of twenty relevant words in Jefferson's list, he writes <y> instead of <r>; in addition, for the word 'fire' he gives two possibilities: <ruht> and <yuht>. This is the sort of evidence which leads Algonquianists to hypothesize that there was contact with a neighboring Montauk dialect of Mohegan-Pequot where Proto-Eastern Algonquian *r regularly gives *y*.

Pierson (who worked in the 1600s on Wampano) always recorded Proto-Algonquian laryngeal consonant + *s* reflexes using the same graphemes that he used for intervocalic *s*. This would suggest that the Proto-Algonquian clusters were simplified to /s/ or /ss/ in Wampano. However, Jefferson, together with STILES, offers some evidence that these clusters were actually retained as /hs/ clusters in Wampano. For example, Jefferson has <wühnsa> 's/he kills it', where the <h> may be the reflex of PA *ne?l- 'kill'; alternatively, Jefferson may have used <hn> to represent a voiceless nasal.

One of the areas in which Jefferson has been of greatest help to modern linguists is in the area of reconstructing word stress. With few exceptions, Jefferson marked the stress on every word he recorded. Due to his detailed observations, Algonquianists have been able to reconstruct stress placement rules for Wampano, the basic one of which is: stress the first syllable of a word unless that vowel is a weak short vowel in an open syllable, in which case stress the second vowel. Jefferson records exceptions to this rule, of course, but even such words have reasonable explanations. For example, if the first syllable of a word is closed by an /h/, sometimes the rule is broken: Jefferson has <çúpsqwan> [kóhpskwan] 'your (sg.) back', and <ápacus> [áhpahku:hs] 'partridge' (both of which follow the rule) but <copút-te> [kəhpóti:] 'your (sg.) arm' and <mocússenus> [mahkósənos] 'moccasins', accented on the second syllable. This alternation can perhaps be taken as an indication that the intensity of [h] was becoming weaker in coda position. It is only from Jefferson's detailed recordings that we have evidence for such small sound changes. Other words whose exceptional stress can be reasonably accounted for include words with the diminutive suffix (e.g., <coquées> [hkəkwihs] 'pot' < PA *axkehkwā 'kettle' + PEA *-ins 'diminutive') and the locative suffix. Since Jefferson consistently put an accent on the same morpheme in these words, and since evidence from the scanty subsequent fieldwork on Unquachog supports his judgment, we can say with certainty that Jefferson's ear was accurate and that these morphemes always carried stress.

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PAULA KADOSE RADETZKY

JENKINS, JAMES J. (b. St Louis, MO, 29 Jul 1923). *Distinguished research professor, educator, experimental psychologist.*

PhD Psychology, 1950, U. of Minnesota. Instructor to Full Professor 1950-1982, U. Minnesota. Director, Center for Research in Human Learning 1966-1972. Prof. and Chair Psychology, Univ. of South Florida 1982-1988, Distinguished Research Professor 1988-present. Visiting positions, Yale, Haskins Laboratories, U. Colorado. Fellow, Center for Advanced Study in the Behavioral Sciences. Fellow, Amer. Psych. Assoc., Fellow, AAAS. Authored over 200 articles, book chapters and books in memory, communication, psycholinguistics and speech perception. Perceptual research includes cross-language speech perception of consonants and vowels and perception of American-English vowels.

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JAMES JENKINS

JOOS, MARTIN (GEORGE) (b. Fountain City, WI, 11 May 1907, d. Madison, WI, 6 May 1978). *Educator, linguist, phonetician.*

AM, PhD, Univ. Wisconsin, 1935, 1941; Field worker, Linguistic Atlas of the US and Canada, 1931-32; lecturer, Univ Toronto, 1938-42; technical consultant, Army Security Agency,

1942-46; assoc. to full prof., Univ. Wisconsin, 1946-67; prof. and dir., Cen. for Ling. Stud., Univ. Toronto, 1967-72; prof. emeritus, Univ. Wisconsin, 1972-1978; assoc. ed., *Studies in Linguistics*, 1942-46; director, Center for Applied Linguistics, 1964-65. Joos' first academic specialization after high school and the initial subject of his undergraduate studies was electrical engineering. He left in the middle of his undergraduate studies to work briefly for the Western Electric Company and, later, did phonetic transcriptions of New England dialects for the Linguistic Atlas of the United States and Canada. Upon returning to the university in 1933 he did not finish his degree in electrical engineering but rather immediately entered the graduate program in German. His doctoral dissertation, completed in 1941, was on *Statistical Studies in Gothic Phonology* which involved typing the entire vocabulary of Gothic (54,000 words) on punched cards for detailed statistical analysis by letters and by syllables. In 1942 he went to work for the Signal Security Agency and used his knowledge of electrical engineering, mathematics, German, and linguistics in the task of cryptanalysis and in devising secret communication systems. For this work he received the War Department's citation for Extraordinary Civilian Service, the highest military award a civilian could receive. He joined the faculty of the Department of German at University of Wisconsin in 1946 as an associate professor, being promoted to full professor in 1949 and serving as chair 1962-64. Joos' major work in phonetics was his timely and influential monograph, *Acoustic Phonetics* (Ling. Soc. Am., Monograph 23, 1948) which was one of the first works to introduce the sound spectrograph for linguistic phonetic research. His *Readings in Linguistics: The Development of Descriptive Linguistics in America since 1925* (1957) which he edited and annotated for the ACLS introduced structural linguistics to several generations of linguistics students.

UNIVERSITY OF WISCONSIN ACADEMIC SENATE; JOHN J. OHALA

KEATING, PATRICIA A.

Education: BA, Wellesley College, 1974; MA, 1976, PhD, 1980, Brown University. Patricia A. Keating is Professor of Linguistics and Director of the Phonetics Laboratory at UCLA. Her professional service activities have included organizing the Third Conference on Laboratory Phonology in 1991 and serving on the organizing committee for Conferences on Laboratory Phonology (1990-present), serving on the Linguistics Advisory Panel of the National Science Foundation from 1990-92, co-editing the Academic Press *Phonetics and Phonology* series (1988-1994), and serving on the boards of the journals *Language* (1989-90) and *Phonology* (1991-95). Major UCLA service includes the Provost's five-year review of the Dean of Humanities (1987-88), the Academic Senate Committee on Teaching (1995-98), and chairing the (Humanities) Dean's Advisory Committee on Technology (1995-present). Honors have included an NIH Individual National Research Service Award (1979-81), a UCLA Alumni Association Distinguished Teaching Award (1986), and nomination for the CASE Professor of the Year Award (1986, 1987). She gave a plenary address, "Phonetics in the Next Ten Years", at the 12th International Congress of Phonetic Sciences. Extramural funding has included research, dissertation, and undergraduate grants from NSF, and

training grants from NIH. Publications include over 30 articles in books, journals, and conference proceedings, another 30 working papers, the lead article on phonetics for the forthcoming *The MIT Encyclopedia of the Cognitive Sciences* and the phonetics chapter for a forthcoming introductory linguistics textbook edited by V. FROMKIN.

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PATRICIA A. KEATING

KENT, RAYMOND D. (b. Red Lodge, MT, 21 Dec 1942). *Educator, speech scientist*.

MA, 1969, PhD, 1970, Univ. of Iowa; Docteur Honoris Causa, 1998, Univ. de Montréal; Postdoc research fellow, MIT 1970-71; asst. to full prof., 1971- pres., Univ of Wisconsin-Madison. Temporary position at Boys Town Institute, Omaha NE. Pres., Am. Assoc. Phonet. Sci, 1986; Editor, *J. Speech Hear. Res.*, 1977-81, Assoc. Ed, *Folia Phoniat Logoped*, 1998- pres., Honors of Am. Speech- Lang.-Hear. Assoc., 1994; Claude Pepper Award (NIH), 1993, Alfred Kawana Council of Editors Award (Am. Speech-Lang.-Hear. Assoc), 1991; Fellow: Acoust. Soc. Am., Am. Speech-Lang.-Hear. Assoc, Int. Soc. Phonet. Sci. Kent's research pertains especially to speech production in typically and atypically developing children, normal adult speakers of English, and individuals with neurogenic disorders of communication (dysarthria, apraxia, aphasia). He has authored nearly 200 journal articles and book chapters and has published 14 books.

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ARTHUR J. BRONSTEIN

RAYMOND D. KENT

KENYON, JOHN S. (b. Medina, OH, 1874, d. Hiram, OH, 1959). *Phonetician, lexicographer.*

Kenyon's academic training included a BA degree from Hiram College in 1898 and a PhD from Harvard in 1908. His teaching career included a ten-year stay at Butler University from 1906-1916 and a professorship and chair of the Department of English at Hiram College from 1916 to 1944. His special areas of interest bridged Middle English, American English pronunciation, and general phonetics.

To students of the English language who grew up in this country in the early part of this century, Kenyon was the "Dean" of American phoneticians until after WW II when the field of phonetics began to expand into such other areas as speech perception, experimental, clinical, acoustic, auditory phonetics, phonological theory, and more. Kenyon's major text was his *American Pronunciation*, first issued in 1924. The twelfth edition appeared in 1997, as an expanded edition, edited by Donald Lance and Stewart Kingsbury. (That edition was reviewed by the author of this entry, ARTHUR BRONSTEIN, for *Dictionaries*, the publication of the *Dictionary Society of North America*, Vol. 9, 1998, pp. 238 – 242.)

What made Kenyon's work so special was his insistence on avoiding prescriptive usage decisions — a tradition established by his British phonetic colleagues Daniel Jones and Walter Ripman. It was Kenyon's *American Pronunciation* that contained the first detailed descriptive analysis of American English pronunciation in the first half of the twentieth century.

Two other reasons help account for Kenyon's predominant position as a scholar of American English pronunciation in the earlier part of this century. One is his co-editorship of *The Pronouncing Dictionary of American English* with Thomas A. Knott, first issued in 1944. It remains the only extant phonetic/pronouncing dictionary of American English still widely consulted as a major data source of American English pronunciation. It was modeled after his British contemporary's work: Daniel Jones' *English Pronouncing Dictionary*.

The other reason for Kenyon's reputable place in the history of American English phonetics is his extensive (56 page) essay in the Second Unabridged Edition of *Webster's New International Edition of the English Language*. The topics he covered in that essay bridged spelling, pronunciation, the effects of speech style on pronunciation, sounds in isolation and in context, the syllable, stress, vowel gradation, and how different orthoepists treated the pronunciation of certain special words. That essay has had an effect on every other major unabridged American English dictionary since — each of which has seen fit to include an extensive scholarly essay on the pronunciation of American English in their prefaces.

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For further biographical information on John Kenyon, the reader is referred to *The Biographical Dictionary of the Phonetic Sciences*, 1977, referred to elsewhere in this handbook.

KLATT, DENNIS H. (b. 31 Mar 1938, d. Cambridge, MA, 30 Dec 1988).

Dennis Klatt's fundamental contributions to acoustic phonetics were rooted in an unusually balanced combination of basic research into the mechanisms of human speech production and perception, and applied research leading to practical devices. His close study of the acoustic characteristics of the speech sounds of American English led to the development of a formant synthesizer, implemented as DECtalk, based on the theoretical work of Fant and of STEVENS. This synthesizer has been widely used, as a research tool for advancing our understanding of the overall filter transfer function of the vocal tract and for investigating human speech perception, as well as in industry for the development of commercial devices using speech and for use by the handicapped.

Klatt's early training in electrical engineering at Purdue University led to a 1964 doctoral thesis, *Theories of Aural Physiology*, with GORDON PETERSON in the communication sciences at the University of Michigan. He then joined the Speech Group at MIT's Research Laboratory of Electronics, where he developed a well-known laboratory course to provide students and visiting scientists in engineering and linguistics with a grounding in experimental methods in speech acoustics, production and perception, together with an understanding of the theories underlying these processes. His thorough analysis of the acoustics of English speech sounds in various contexts led to a ground-breaking series of papers on factors influencing phoneme duration, on the synthesis of English syllables, and on the variety of glottal waveforms observed in natural speech, the latter written with his daughter, Laura. His KLSYN formant synthesizer, described in a paper in the *Journal of the Acoustical Society of America*, formed the basis for the development of the complete system for synthesis of speech from English orthography which eventually became DECtalk. This system included the first serious attempt to capture the effects of prosodic structure, and its improved glottal source models made possible the synthesis of speech which is indistinguishable from naturally produced utterances, including female voices. Much subsequent work on synthesis by rule is based on the system or concepts developed by Klatt.

Klatt's quiet competence and humor — few who heard it will ever forget his synthesized version of "Oh how we danced" — and his firm grasp of the many threads that must be mastered in order to do speech science, from linguistic and acoustic theory to auditory perception and articulatory modeling, made him a dominant figure in acoustic phonetics. His integrity, his deep aversion for prejudice and intolerance, his passionate love of chocolate, his abilities as a carpenter (exercised in the renovation of the home he shared with his wife Mary) were well known to his colleagues, but it was his high level of scholarship, his sharing of ideas, and his practical abilities, always guided by both theoretical considerations and carefully collected acoustic data, that brought the field of speech communication to a new level of scientific excellence in the second half of the 20th century.

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STEFANIE SHATTUCK-HUFNAGEL

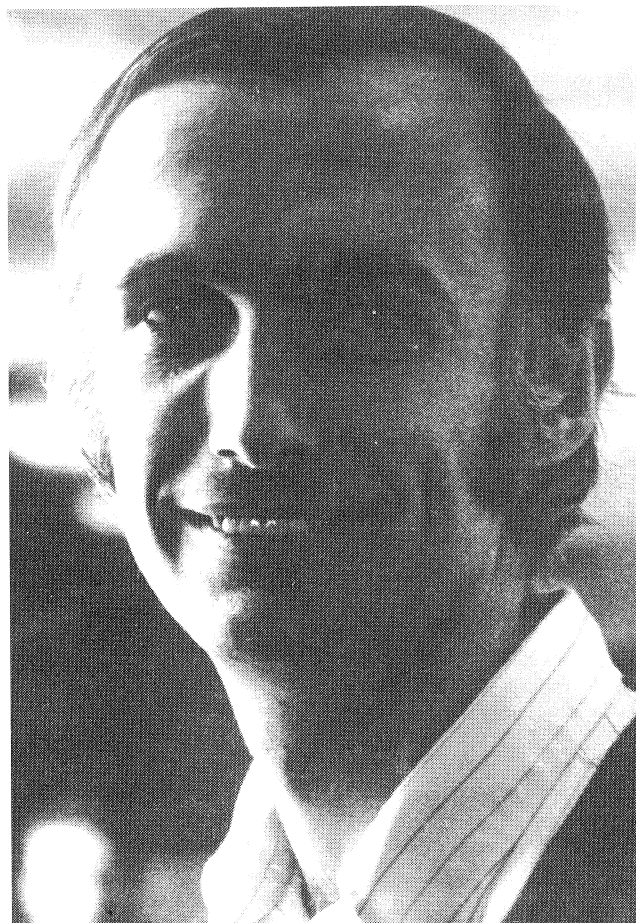


Fig. 13. Dennis H. Klatt (M.I.T., 1972).

KRAPP, GEORGE PHILIP (b. Cincinnati, OH, 1 Sep 1872, d. New York, NY, 21 Apr 1934). *Educator, linguist*.

AB, Wittenberg College; PhD, Johns Hopkins University. Among Krapp's books on the English language, of special interest to the phonetic sciences are: *Modern English, Its Growth and Present Use* (1909), *A Comprehensive Guide to Good English* (1927), and *The Knowledge of English* (1927). As reported in the entry in the *BDPS* (pp. 119-120), in these works he declared "that standards of speech should be based on the observation of current cultivated usage rather than on the often arbitrary rules of grammarians", a radical departure from the commonly held view of the time.

Krapp was a pioneer contributor to, and a major scholarly influence on, the study of English language usage in America during the first half of this century. His two books: *The Pronunciation of Standard English in America* (1919) and his *The English Language in America* (1925) "were based on firsthand observations of American speech. . . ." and were "the first comprehensive attempt to give to the study of American English a firm historical and scientific basis" (p. 120).

He was, additionally, a popular author of children's books that dealt with medieval lore and American history, among them: *In Oldest England* (1917); *Tales of True Knights* (1921);

and *America, The Great Adventure* (1924). And his edition of Chaucer's *Troilus and Criseyde* (1932) was chosen by the Literary Guild as a book of the month for that year!

EDS., BASED ON THE ENTRY IN *BDPS*
AUTHORED BY KRAPP'S SON, PHILIP KRAPP

KROEBER, ALFRED LOUIS (b. Hoboken, NJ, 11 Jun 1876, d. Paris, France, 5 Oct 1960). *Educator, anthropologist, and field worker*.

He received an AB in 1896 and an AM in 1897, both in English Literature, and a PhD in Anthropology from Columbia College in 1901. He was awarded honorary doctorates from the Universidad Nacional Mayor de San Marcos in Lima, Yale, University of California, Harvard, Columbia, and Chicago. He was Curator of Anthropology at the California Academy of Sciences (1900, and 1903-1911), Curator of the University of California Museum of Anthropology (1908-1925), and its Director (1925-1946). He held positions as Instructor (1901-1906) Assistant Professor (1906-1911), Associate Professor (1911-1919), and Professor (1919-1946) in Anthropology at the University of California, and as Visiting Professor at Harvard University (1947-1948) and Columbia (1948-1952).

Although certainly better known for his monumental presence as an anthropologist and ethnologist working particularly on the native cultures of the American West, Kroeber contributed significantly to the field of linguistics in general and to that of phonetics in particular. Indeed, a significant portion, by some estimates one sixth, of his enormous oeuvre (his bibliography comprises at least 535 entries) is dedicated at least partly to the study of language. This focus derived from his view of language not only as part of culture (certainly not even today an entirely banal or accepted claim), but moreover as its best understood and most successfully quantified aspect. Kroeber "entered Anthropology by the gate of Linguistics" (*The Nature of Culture*, 1952, p. 178), as evidenced by the completion of the predominance of his linguistic work during the first two decades of his career (and the 20th century), although he did return to speculation on issues of language and culture near the end of his career and life, in the 1950s.

His major contribution and focus in both anthropology and linguistics was the use of statistical methods in investigating American Indian languages, a fact that should not be surprising, considering that these were the topics of classes that were among the first he took from FRANZ BOAS as a graduate student at Columbia. He also inherited a dedication to empirical documentation and not theoretical speculation from his influential advisor. They both saw science as defined not by its theoretical import but rather its precise scholarship.

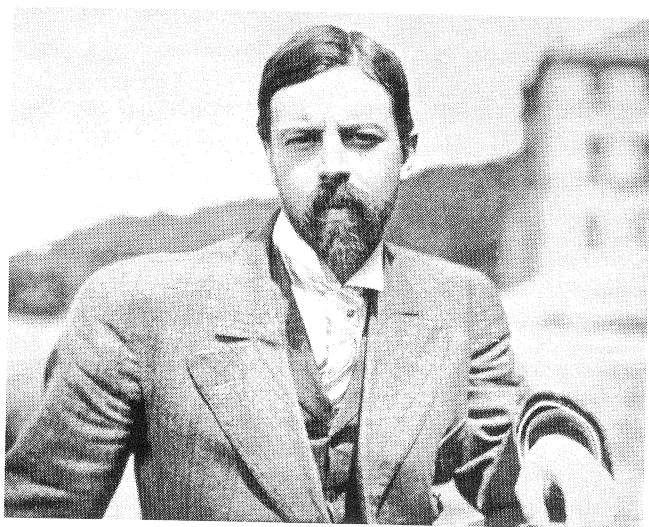


Fig. 14. Alfred L. Kroeber.

As in all of the other fields he studied, Kroeber's contribution to phonetics is through his work and his example, rather than through a particular theoretical school or students trained. In the first quarter of the century, he almost single-handedly documented languages of western America, publishing reports on 33 Native American languages (although GODDARD, Dixon, SAPIR, Waterman, and in later decades, Harrington, contributed a limited number of language studies). These documentations were of varying depth, depending on the accessibility of the speaker, and ranged from rough outlines of the phonological system along with a short word list or text to full accounts, complete with documentation with the most up-to-

date experimental tools available (kymography, palatography, and photography). These techniques were first used on American languages by his colleague PLINY EARLE GODDARD, appearing in publication in 1907 (on Hupa), who modeled his techniques after those of the Abbé Rousselot. Kroeber holds the distinction of being the first to document instrumentally a Polynesian language, Marshallese, but even though Goddard and Waterman made use of the same techniques on American Indian languages, Kroeber is distinguished by the much greater number of languages that he documented.

Additionally, he used instrumental means to determine the accuracy of the phonological claims of his contemporary field workers. Among these was the issue of "intermediates", stops which were perceived to vary between voiced and voiceless realizations. (Underlying this claim was the predisposition of Americans, even linguists, to view Native American languages as sloven and fluid, a belief that Kroeber fought to dispel.) Kroeber showed convincingly, through kymographic studies, that the segments in question, while different in voicing quality from their English counterparts, were in fact consistently realized in predictable allophonic patterns.

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BENJAMIN K. BERGEN

LADEFOGED, PETER N. (b. Sutton, Surrey, England, 17 Sep 1925). *Educator, phonologist, phonetician*.

MA, 1951, PhD, 1959, Univ. of Edinburgh, D. Litt. (Hon), 1993, Univ. of Edinburgh; Lecturer, Univ. of Edinburgh 1953-61; asst. to full prof., 1962-91, prof. emeritus, 1991- pres., UCLA. Temporary and visiting positions at Univ. of Ibadan, Nigeria; Speech Trans. Lab., KTH, Stockholm, Sweden. Pres., Ling. Soc. Am., 1978; Pres., I.P.A., 1987-91; Pres. Perm. Coun. ICPhS 1983-91; Gold medal, 12th ICPhS; Silver medal, Acous. Soc. Am. 1994; Fellow: Acous. Soc. Am, Am. Speech and Hearing Assoc., Am. Acad. Arts and Sci.; Corres. Fellow, Brit. Acad. 1992; Foreign Mbr, Royal Danish Acad. Sci. and Lett. 1993. Ladefoged's research has focused on experimental phonetics, especially the description of vowels, speech perception, speaker recognition, respiratory and other aerodynamic aspects of speech, phonetics pedagogy, the phonetic study of endangered languages, phonetic and phonological universals, and the intersection of phonology and phonetics in general. He has authored hundreds of articles in journals and seven books.

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JOHN J. OHALA

LEHISTE, ILSE B. (b. Tallinn, Estonia, 31 Jan 1922). *Educator, linguist, phonetician*.

Dr.phil. (philology), U. of Hamburg, Germany, 1948; PhD (linguistics), U. of Michigan, 1959; D.U. (honor.), U. of Essex, England, 1977; Dr.phil. (honor.), U. of Lund, Sweden, 1982; Dr.phil. (honor.), U. of Tartu, Estonia, 1989. Lecturer (Lehrbeauftragte), U. of Hamburg, 1948-49; Assoc. Prof., Kansas Wesleyan University, 1950-51; Assoc. Prof., Detroit Inst. of Technology, 1951-56; Research Associate, Communication Sciences Laboratory, U. of Michigan, 1958-63; Assoc. Prof. and full Prof., Ohio State University, 1963-87; Prof. Emer., Ohio State University, 1987-present. Visiting positions at U. Cologne, Germany, U. Vienna, Austria, and U. Tartu, Estonia. President, Linguistic Society of America, 1980. Fellow, Acoustical Society of America, American Association for the Advancement of Science, and the American Academy of Arts and Sciences (1990); Foreign member, Finnish Academy of Science (1998).

Lehiste's research has focused on the role played by prosody (pitch, stress, and duration) in communication by spoken language. Using acoustic phonetic techniques and perception tests, she has studied the prosodic systems of a great number of languages, especially English, Serbocroatian, and Estonian, but also Finnish, Swedish, Faroese, Icelandic, Lithuanian, Latvian, German, Czech, Slovene, and Japanese. She has also investigated the phonetic correlates to syntactic structure and the metrical structure of orally produced poetry. She is the author of 13 books and hundreds of articles and reviews.

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ILSE LEHISTE

LEVITT, HARRY (b. Johannesburg, South Africa, 19 May 1937). *Educator, researcher*.

BSc (Electrical Engineering) 1958 Univ. of the Witwatersrand; PhD, 1964, Imperial College of Science and Technology, Univ. London; Member research staff, Bell Laboratories, 1964-69; Assoc. Prof., City Univ. New York, 1969, Full Prof., 1973, Distinguished Prof., 1983 to present. Fulcrum Scholar, Univ. Witwatersrand, 1958; Beit Fellow for Scientific Research, Imperial College of Science and Technology, 1960-62; Oliver Lodge Scholar (Honorary) Institution Elect. Eng., London, 1962-63; Harvey Fletcher Award in Technical Application, League for the Hard of Hearing, 1975; World Rehab. Fund Fellow, 1980; Regional and National Winner, Johns Hopkins University First National Search for Applications of Personal Computing to Aid the Handicapped, 1981; Professional Achievement Award, N.Y. City Speech-Hearing Language Assoc., 1984; Honors of the Society, N.Y. State Speech-Hearing-Language Assoc., 1985; Javits Neuroscience Investigator Award, National Institutes of Health, 1988; Special Friend of People with Hearing Loss, Self Help for Hard of Hearing (SHHH) People, 1996; N.Y. City Mayor's Award for Excellence in Science and Technology, 1999; Fellow, Acoust. Soc. Am., Am. Speech-Hearing-Language Assoc., N.Y. Acad. of Medicine.

Levitt's research has focussed on measurement techniques in speech and hearing, modeling normal and impaired hearing, acoustic-phonetic structure of speech produced by normal-hearing and deaf individuals, sensory aids for people with hearing loss, and videophonetics.

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HARRY LEVITT

LI, FANG-KUEI (b. Canton, China, 20 Aug 1902, d. Oakland, CA, 21 Aug 1987). *Educator, field, historical and comparative linguist.*

Fang-Kuei Li left China to attend the University of Michigan in Ann Arbor in 1924. He entered University of Chicago in 1926, receiving his MA in 1927 and his PhD the following year. At Chicago, he studied with three of the most important American linguists: EDWARD SAPIR, LEONARD BLOOMFIELD, and Carl Darling Buck. He began his teaching career at Yale in 1937, later settling at the University of Washington at Seattle in 1949. He retired there in 1969, but then accepted an appointment at the University of Hawaii at Manoa, retiring again in 1974. He moved to Oakland, CA, in 1985.

As a field linguist, Li is known for the quantity and fine accuracy of his field data. Through the encouragement of SAPIR, Li was sent off on his own to record the Mattole language, his notes and his PhD dissertation constituting the only record of that now extinct language. Among other Native American languages, Li also worked on Wailaki, Hare, Sarcee and Eyak. From BLOOMFIELD's influence, Li made comparative linguistics one of the central focuses in his career. His greatest achievements lie mainly in Sino-Tibetan and Tai linguistics. He published numerous articles on the reconstruction of Archaic Chinese. He taught himself Thai during a four-month stay in Thailand and he then went to Guangxi to study the Tai-related languages there. He is recognized as a pioneer in the comparative study of the Kam-Sui languages, a language family closest to Tai proper in the Kadai family. His crowning work was the *Handbook of Comparative Tai*, an essential work in Tai linguistics.

Although the connection between tonal distinctions and the voicing of initial consonants was made as early as the 1850s by Edkins, Li was among the earliest to note this connection in the Tai family. Based on his knowledge of phonetics and his work on the comparative linguistics of Tai, Li (1947) argued that for Tai and other families of Southeast Asia low tones have developed in word classes with ancient voiced initials, and high tones in word classes with voiceless initials.

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ALAN C-L YU

LIBERMAN, ALVIN M. (b. St Joseph, MO, 10 May 1917). *Educator, researcher (psychology)*.

AM, MA, Univ of MO, 1938, 1939; PhD, Yale 1943. Instr, Yale, 1942-46, memb staff aero med res unit, 1942-44; asst prof, Wesleyan Univ, 1946-49; asst prof to prof & head dept psych, Univ of Conn, 1949-; fel, Center Advan Stud Behav Sci & US Pub Health Ser res fel, 1964-65; Guggenheim fel, summers 1964,

1965; adj prof, Yale, 1968-; res consult, Haskins Labs, 1944-; President, Haskins Labs, 1975-86; sr. scientist, Haskins Labs.

Liberman is one of the country's leading contributors to the acoustic analysis and perception of speech. The widely influential "motor theory of speech perception" and the idea that speech is a species-specific biological adaptation to the constraints that humans face in communicating have emerged from his more than half century of research.

In recognition of his scientific accomplishments, Liberman has received many awards and honors. He has been elected a member of the National Academy of Sciences, the American Academy of Arts and Sciences, the Society of Experimental Psychologists, is a fellow of the Acoustical Society of America and of the American Psychological Association and is a Senior Fellow, Japan Society for the Promotion of Science. He received the 1988 F.O. Schmitt Medal and Prize in Neuroscience, the Distinguished Scientific Contribution Award, American Psychological Association, the Warren Medal, Society of Experimental Psychologists and the Medal, College de France. He received honorary doctoral degrees from Universite Libre de Bruxelles and from State University of New York, Binghamton, New York.

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EDS.

LISKER, LEIGH (b. Philadelphia, PA). *Educator, phonetician, South Asian languages teacher.*

BA 1941, MA 1946, PhD 1949, University of Pennsylvania. Linguist instructor, US Army, Russian Language Training Program, Indiana University, 1945; assistant instructor in German, University of Pennsylvania, 1947-1948; linguist instructor in German, University of Pennsylvania, 1947-1948; linguist instructor in Hindustani, University of Pennsylvania, 1948-1950; assistant professor of linguistics and Dravidian languages 1947-1955, associate professor of linguistics and Dravidian languages, University of Pennsylvania, 1951-59, visiting lecturer in Hindi and Urdu, Georgetown University, 1953-1954; senior research scientist, Haskins Laboratories, 1953-present; associate professor Columbia University, 1963-1964; Director of language program, Ceylon Peace Corps Training Program, University of Pennsylvania, 1962; professor of linguistics, University of Pennsylvania, 1964-1989; visiting researcher at Pavlov Institute, Leningrad, USSR, 1968; chairman department of linguistics, University of Pennsylvania, 1970-1078; visiting professor of linguistics, Osmania University, Hyderabad, India, 1985; emeritus professor 1989-present. Member Linguistic Society of America; fellow: Acoustical Society of America; member: International Phonetic Association. Lisker's research in phonetics has focussed on relations between speech acoustics and perception, particularly with respect to English vowels and stop consonants.

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LISKER, L., F. S. COOPER, and A. M. LIBERMAN. 1962. The uses of experiment in language description. *Word*, 18, 82-106.

LEIGH LISKER

MACNEILAGE, PETER F. (b. Napier, New Zealand, 28 Sep 1934). *Educator, psychologist.*

MA, 1959, Univ. of Canterbury, N.Z.; PhD, 1962, McGill Univ.; Senior tutor, Univ. of Melbourne, 1959; Research Associate, Haskins Labs, 1961-67; Assistant Prof., Barnard College, 1961-67; Associate Prof., UC Berkeley, 1967-69; Associate Prof.- Prof., U. Texas at Austin, 1969-. Fellow, American Assn. for the Advancement of Science, Acoustical Soc. of America, Center for Advanced Study in the Behavioral Sciences. MacNeilage's research has focussed on the nature, evolution and acquisition of complex action systems, especially speech and manual function, and their associated brain organization.

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PETER F. MACNEILAGE

MARCH, FRANCIS ANDREW (b. Sutton (Millbury), MA, 25 Oct 1825, d. Easton, PA, 9 Sep 1911). *Educator, philologist, spelling-reformer.*

March spent the first four years of his professional life (from 1845 to 1849) as a school-teacher in New Hampshire and Massachusetts; he then trained and practiced as a lawyer in New York for a further five years. Ill health forced him to give up the legal profession, and he returned to teaching. In 1857 he was appointed Professor of the English Language and Comparative Philology at Lafayette College, Pa, where he remained until his retirement in 1906.

His published work — which also included studies of Greek and Latin authors, methodologies for the teaching of reading, and school grammar books — was centered mainly on Old English (cf. March 1870), a subject which he helped to foster and develop within the American college curriculum. Even so, his contributions were more those of the expounder and critic of the subject than of the original researcher.

March was one of the first members of the IPA, and his phonetic mentors appear to have been, primarily, Alexander Ellis ('our great authority in such matters'), SAMUEL HALDEMAN, and WILLIAM D. WHITNEY. He was particularly sympathetic to the view that phonetics should be part of a rigorous approach to the study of language ('the most active students of the English language or fonetists, students of vocal sounds and fonetic laws', March 1888), arguing additionally that descriptive phonetic studies should be undertaken of various urban forms of British and American English. However, his views on the need to have

— as well as to promulgate — a ‘standard’ form of English speech, over and against the colloquial varieties of the language, set him apart from colleagues elsewhere, for example Henry Sweet and August Western. The ‘rhythms and rimes of the poets’ and the speech of ‘living orators and actors’ represented, for him, ‘standard’ speech; colloquial speech was marked by certain ‘allowabl weakenings’. He accepted that some aspects of the phonetic structure of 19th-century English, both in America and Britain, had been altered by the prescriptive influences of Webster, Walker, and Worcester (March 1884).

Like several other 19th century linguists, March foresaw the need of a scientific method for describing vowel-sounds: ‘for accurate definition by means of description of the vocal organs curvs of the resonance chamber on a fine scale of decimals are needed’ (March 1886).

In the ‘phonology’ (i.e. historical phonetics) section of his *Comparative Grammar of the Anglo-Saxon Language* (1870), he provided a brief synchronic account of the pronunciation of Old English, alongside some comparative Germanic forms. Sweet, though quibbling at particular features of the *Comparative Grammar*, praised the ‘thorough way in which the phonetic laws are treated’ (Sweet 1870). The short paper on the pronunciation of Old English (March 1871/1877) deals exclusively with alliteration.

For nearly 30 years, from 1876 to 1905, March was President of the [American] Spelling Reform Association, during which time he moved from the radical position adopted by many linguists in the 1870s (in both America and Britain) that additional characters should be introduced into the alphabet (together with some respelling), to the mellower and more realistic position that limited adjustments should be made to the orthography — e.g., abuze, batl, fonetic, leag, lookt, tung (March 1893).

The *Thesaurus Dictionary of the English Language* that he and his son, Francis Andrew March Jr (1863-1928), published in 1902 has rarely been out of print this century, and it is by this work that they are generally remembered today. March Sr’s lexicographical work also involved him in acting as the organizer of the team of volunteer American readers for the *Oxford English Dictionary* in the late 1870s, and as consulting editor to Funk’s *Standard Dictionary of the English Language* (1893-1895).

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MIKE MACMAHON

MARSH, GEORGE PERKINS (b. Woodstock, VT, 15 Mar 1801, d. Vallombrosa, Italy, 23 Jul 1882). *Lawyer, businessman, politician, linguist, ecologist, diplomat*.

Marsh trained as a lawyer, subsequently becoming a businessman, a congressman, and a diplomat in various countries for the United States Government. He acquired a good knowledge of several European and Middle-Eastern languages.

In 1838 he published a grammar of Old Norse, based on the work of Rasmus Rask, but it failed to make a serious impression on the scholarly community. Much more successful were his publications on the cultural backgrounds of the Germanic peoples (e.g. Marsh 1843). During the winter of 1858-59, he lectured at Columbia College in New York on the past and present state of the English language. In 1860-61, he gave a further series of lectures, this time at the Lowell Institute in Boston, mainly on topics in medieval and early modern English literature. The Columbia lectures were published as *Lectures on the English Language* (1860), and the Lowell lectures as *The Origin and History of the English Language* (1862).

Despite having a fine ear for foreign languages, phonetics plays a relatively small part in his published work; there is no evidence of his having been significantly influenced by any particular type of phonetic theory. Lecture XXII (‘Orthoepical Changes in English’) in the *Lectures on the English Language* mostly focuses on the attempts made by earlier phoneticians to describe the pronunciation of English — he writes approvingly, for example, of the work of Alexander Gil in the 17th century; and he occasionally draws parallels with 19th-century American pronunciations. Lecture XXX, on American English, contains various statements, limited in detail, about differences between and within American and British English: for example vowel length, vowel qualities in unstressed syllables, the phonotactics of /h/, the phonotactics and phonetics of /r/, and intonation. His desire to appear descriptive in his analysis of English is often overshadowed by his socially constrained prescriptivism — although one should note, to his credit, his consistent support for American English pronunciations at a time when some of his fellow Americans still looked to Britain for a ‘standard’ pronunciation of the language.

His work on geography and ecology (1874 etc.) earned him the reputation, both in America and elsewhere, as a leading spokesman for the environmental conservation movement (cf. Lowenthal 1958).

Most of his extensive Nachlass is housed at the University of Vermont.

(http://sageunix.uvm.edu:6336/dynaweb/dwebdoc/marsh/@Generic_BookView).

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MIKE MACMAHON

MASSARO, DOMINIC W.

Trained in experimental psychology, Massaro applied experimental and theoretical tools to the study of phonetic sciences and language processing more generally. He used backward recognition masking to determine the perceptual units in speech perception and to trace the time course of language perception (Massaro 1972). He and his students developed an information-processing framework aimed at delineating the dynamics of language processing and applied it to speech perception, reading, and psycholinguistics (Massaro 1975). At the same time, he initiated a series of experiments in speech perception and reading. The novel features of this work was the use of factorial designs to manipulate both bottom-up and top-down sources of information independently of one another, and the testing of mathematical models of performance. This work falsified traditional views of categorical perception, and led to the development (in collaboration with Gregg Oden) of the Fuzzy Logical Model of Perception (FLMP). Research within this framework revealed that speech perception follows a general principle of pattern recognition in which perceivers evaluate and integrate multiple sources of information in order to perceive and understand spoken and written language (Massaro and Cohen 1991). The theoretical framework has proven particularly effective in accounting for multimodal speech perception (Massaro, 1987) and led to the development (with Michael M. Cohen) of a computer-animated talking head (Massaro 1998). This technology is now being used as a language tutor for children with hearing loss (Cole et al. 1998).

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DOMINIC W. MASSARO

MATTINGLY, IGNATIUS G. (b. Detroit, MI, 22 Nov 1927). *Professor, linguist.*

BA, 1947, PhD, 1968, Yale; MA, 1959, Harvard. Lecturer to full prof., 1966-96, prof. emeritus, 1996-, U. Conn. Research Associate, 1966-, Haskins Laboratories. Visitor, Joint Speech Research Unit, Eastcote, U.K.; Visiting Fellow, Kings College, Cambridge, U.K. Fellow, Acoustic Soc. Am. Mattingly has worked on speech production, speech perception, speech synthesis by rule, and the relation of speech to reading.

FURTHER READINGS

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IGNATIUS MATTINGLY

MERMELSTEIN, PAUL (b. Mukacevo, Ukraine, 1939). *Engineer, speech scientist.*

B. Eng. (McGill, 1959) Eng. Physics, M.Sc. D.Sc. (M.I.T., 1962, 1964) Electrical Engineering. Tech. Staff, Bell Laboratories, Murray Hill, N.J. 1964-73. Tech. Staff, Haskins Laboratories, New Haven, CT, 1973-77. Manager, Speech Communications Research, Bell-Northern Research, Montreal, Canada, 1977-1990. Manager, Personal Communications Research, Bell-Northern Research, Montreal, Canada, 1990-94. Professor, Bell/BNR/NSERC Industrial Research Chair in Personal Communications, INRS-Telecommunications, University of Quebec, Montreal, 1994 - present. Fellow, Acoustical Society of America, 1990. Fellow, Institute of Electrical and Electronics Engineers, 1994. Interests: man-machine communication, speech perception, speech recognition, speech coding, wireless communication.

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PAUL MERMELSTEIN

MILLER, DAYTON CLARENCE (b. Strongsville, OH, 13 Mar 1866, d. Cleveland, OH, 22 Feb 1941). *Physicist, acoustician, musician.*

Miller graduated from Baldwin University in 1886. He followed this with a D.Sc. in astronomy from Princeton in 1890. He then began a 50-year long association with the Case School of Applied Science in Cleveland. His *Laboratory Physics* (1903) was for many years a standard work in American universities and colleges.

Miller's concept of phonetics was rooted in physics and the instrumental analysis of sound; he makes only passing references to articulatory phonetics. His ideas were strongly influenced by Tyndall, Helmholtz, Koenig, and Rayleigh (see, further, Miller 1935). His analyses of speech were restricted mostly to isolated vowels or short monosyllabic words. However, his discussions, especially of vowels spoken, or 'intoned,' by different categories of speaker (see Miller 1916), reveal his understanding of the complexities of the source-filter model of speech production, the origin of which he attributed to Wheatstone and Helmholtz. He also undertook experiments in speech synthesis, using a sophisticated series of organ-pipes.

His phonodeik ('to show sound'), an instrument which allowed photographic records to be made of complex waveforms, was developed in 1908. It involved the movements of a mirror, illuminated by a light-source and attached to a very thin glass diaphragm at the end of a horn resonator, being photographed. Miller produced three versions of the phonodeik, one of them for field-work — in his case, studies of fog horns, gun- and rifle-shots. See Miller 1937 for a detailed description.

Miller contributed to the design, from an acoustic perspective, of several buildings in the USA, including the chapels at the Universities of Chicago and Princeton. Amongst other duties, he served as President of the Acoustical Society of America.

Throughout his life, he combined his interest in acoustics with that of music, and he bequeathed his magnificent collection of over 1600 flutes to the Library of Congress. (See: <<http://lcweb2.loc.gov/ammem/dcmhtml/dmhome.html>>.)

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MIKE MACMAHON

MINIFIE, FRED D. (b. Miles City, MT, Jan 1936). *Educator, speech scientist, phonetician.*

BA, 1958, Linfield College; University of Florida 1959; MA, 1962, PhD, 1963 Univ. of Iowa; research assoc., 1961-1963, Univ. Iowa; asst. to full prof., 1963-1971, Univ. of Wisconsin; full prof. 1971-1998, prof. Emeritus, 1998-pres; Univ. of Washington. Chair, Speech and Hearing Sciences dept., 1978-1989, Univ. Washington. Visiting position at Univ. of Arizona, 1983. Exec. Board, 1974-1976, Pres. Elect 1982, Pres, 1983, Past Pres. 1984, Am. Speech and Hearing Association; Brd. Trustees, 1974-1976, 1982-1994, Pres., 1989-1993, Am. Speech and Hearing Foundation; Representative, 1984-1996, Exec. Brd. 1985-1994, Pres. 1988, Honors, 1997, Council of Grad. Progs. in Comm. Sciences and Disorders. Fellow, 1968, Honors, 1990 Amer. Speech and Hearing Assoc.; member 1963 – pres., Acoust. Soc. Am.; pres. 1967, Hon. Life member Wisc. Sp. & Hrg. Assoc. 1971-pres.; Distinguished Alumnus Award, 1994, Sp. Path. & Aud, Univ. Iowa; Golden Eardrum Award, 1999, Bloedel Hrg. Res. Center, Univ. of Washington. Minifie is primarily recognized as an educator who has prepared many doctoral students for careers as university professors. His research as a speech scientist has focused on speech physiology, speech acoustics, and speech perception by normal and communicatively impaired talkers. His collaborative research with Thomas J. Hixon and Charles Kelsey in the use of diagnostic ultrasound in speech research in the late 1960s set the stage for modern applications of this technology in speech physiology research. He has published over 60 scientific and professional papers and has authored edited three books, two of which have become standard textbooks in the field of Communication Sciences and Disorders.

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FRED D. MINIFIE

MOLL, KENNETH L. (b. Jackson, MO, 16 Oct 1932). *Educator, speech scientist, speech pathologist.*

BS, 1954, Southeast Missouri State Univ.; MA, 1959, PhD, 1960, University of Iowa; Postdoctoral Fellow: Communication Sciences Laboratory, University of Michigan, 1965-66. University of Iowa, Department of Speech Pathology and Audiology: asst. to full prof. 1960-95; prof. emeritus, 1995-pres.; assoc. vice-pres., acad. affairs, U. Iowa, 1976-89. Fellow, American Speech-Language-Hearing Assoc; President, 1974; awarded Honors, 1984. Member, Acous. Soc. Am.

Moll's research has focused on the physiological aspects of speech, particularly the study of articulatory movements and velopharyngeal functioning in both normal and non-normal speakers (e.g., with cleft palate), using cineradiography, EMG, aerodynamics, and other techniques. He has authored numerous articles and book chapters.

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KENNETH L. MOLL

OHALA, JOHN J. See Editors' Page.

OLIVE, JOSEPH P. (b. Israel, 14 Mar 1941). *Speech researcher, composer of music.*

BS, MS Physics, 1964; PhD Physics 1969; MA Music Composition 1969 University of Chicago. Research at Bell-Labs 1969-present. NEA grant, 1974. Distinguished Member of Technical Staff, Bell Laboratories, 1986. Department Head - Language Modeling Department 1996. Olive's research involves various aspects of text-to-speech synthesis, including: speech analysis and synthesis techniques, speech parametrization, phoneme interactions and coarticulation effects, concatenative synthesis techniques and acoustic inventory selection criteria and speech intonation. His group developed a multi-lingual text-to-speech platform where all aspects of text-to-speech are incorporated and can support any language. Until 1976, Olive was also an active composer of instrumental and electronic music; many of his compositions were performed. One of his last compositions was a computer opera for chamber orchestra, soprano and a computer, where the computer sang one of the lead roles as well as the chorus. In this opera, Olive expressed his desire to enable computers to speak with feelings.

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JOSEPH P. OLIVE

PARMENTER, CLARENCE EDWARD (b. Kingman, KS, 23 Feb 1888, d. Chicago, IL, 15 Sep 1982). *Laboratory phonetician, philologist, Romance language teacher.*

When Clarence Parmenter died in his Hyde Park home in 1982, he did so as quietly as he lived: he fell asleep while waiting for a taxi to arrive to take him to the hospital, and he never re-awoke. His unassuming air and his modest list of publications would make it easy to let him slip into obscurity. But Parmenter deserves to be remembered as one of the leading American phoneticians from the first half of the century, because of his pioneering contributions to phonetic theory and methodology.

Parmenter influenced the field of American phonetics by promulgating new instrumental methods from France, where the experimental study of speech physiology was the most advanced in the world at that time. During his doctoral studies at the University of Chicago, he went to study in Paris at the venerable Institut de Phonétique, where he absorbed the innovative instrumental techniques being developed by Abbé Rousselot. Parmenter took these new methodologies and championed them in this country. He set up a thoroughly modern phonetics lab in Chicago, equipped for x-ray photography, oscillograms of speech, and airflow measurements, and he continued to improve on the design and use of his instruments throughout his career. For example, in the early 30s, Parmenter built an apparatus which could take x-ray pictures in which the position of both the subject's head and the film could be carefully controlled. He also tried to overcome the problem of poor resolution of soft tissues in x-ray tracings by draping a gold chain over the subject's tongue, and attaching a lead strip to the subject's soft palate. These two instrumental improvements allowed Parmenter to make what he and others considered his major contribution to phonetics: the first scientific description of the distinct articulatory postures of vowels. In this paper, he was able to demonstrate, contra G. OSCAR RUSSELL, that a particular articulatory posture necessarily yields a single, predictable vowel sound. His findings helped to establish the articulatory basis of the vowel triangle; previously, it had not been clear whether the dimensions of the vowel triangle were acoustic or articulatory.

Parmenter, however, was not just a theoretician, but also an eminently practical scholar. In fact, he was fond of remarking to his colleagues that anyone who drew a sharp divide between theoretical and applied phonetic research was an 'imbecile', because a successful practical application necessarily depends on

sound theoretical underpinnings. He demonstrated the practical nature of his knowledge by his ability to use the theory of phonetics to teach Romance languages. His *Handbook of French Phonetics* was one of the first works to lay out a systematic mapping between orthography and phonetic form in a way that was accessible to students. His descriptions of French segments in terms of constriction size and location, glottal configuration, as well as airflow, are remarkably modern, anticipating Pike's work some twenty years later.

When Parmenter retired from the University of Chicago after 30 years of teaching Romance linguistics and experimental phonetics, he continued to use his expertise in applied phonetics by teaching elocutionary techniques to actors at the Goodman Theater School of Chicago. This job was a perfect blend of his lifelong interest in acting, and his knowledge of articulatory phonetics.

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PETER VIECHNICKI

PETERSON, GORDON E. (b. Danville, IL, 14 Oct 1913, d. Santa Barbara, CA, 24 Jul 1967). *Educator, phonetician, speech and hearing scientist*.

Peterson's training was at DePauw University (BA, 1935) and at Louisiana State University (MA, 1937 and PhD, 1939). He held a research fellowship in psychoacoustics at Harvard University from 1944 to 1946 and was a member of the technical staff at Bell Telephone Labs from 1946 to 1953. He taught at the University of Michigan where he directed the Communication Science Laboratory (1953-1966) and he directed the Speech Communication Research Laboratory at Santa Barbara, 1966 - 1967.

Peterson edited the *Journal of Speech and Hearing Disorders* from 1955 to 1957 and was honored by the American Speech and Hearing Association in 1961. He served as Vice-President of the Acoustic Society of America (1966), was Associate Editor of *Phonetica*, and served as a member of the Permanent Council for the International Congress of the Phonetic Sciences. His published career covered more than seventy-five

published articles — among them such seminal papers as "The Phonetic Value of Vowels" (*Language*, 1951), "The Evaluation of Speech Signals" (*Journal of Speech and Hearing Disorders*, 1954), "Segmentation Techniques in Speech Synthesis," with W. S-Y WANG and E. Sivertsen (*Journal of the Acoustic Society*, 1958) and "Vowel Amplitude and Phonemic Stress in American English," with I. LEHISTE (*Journal of Acoustics*, 1959). Three special papers were co-authored with June Shoup for the *Journal of Speech and Hearing Research* in 1966 on physiological and acoustic phonetic theories, and an additional one, with Charles Fillmore on "The Theory of Phonemic Analysis" which appeared in the *Proceedings of the International Congress of the Phonetic Sciences* in 1962. A posthumous paper, co-authored with June Shoup on the "Units of Phonology" written in honor of his former professor at Louisiana State University, appeared in *Essays in Honor of C. M. Wise*, edited by ARTHUR BRONSTEIN, Claude Shaver and Cj Stevens, in 1970. Peterson's phenomenal career as a phonetician is more fully detailed in the *Biographical Dictionary of the Phonetic Sciences*, pp. 164-165.

EDS.

PICKERING, JOHN (b. Salem, MA, 7 Feb 1777, d. Boston, MA, 5 May 1846). *Lawyer, diplomat*.

One of John Pickering's many interests was the investigation of native American languages. To provide a functional system for recording them, he published in 1820 *Essay on a Uniform Orthography for the Indian Languages of North America*. For ease of use, the orthography included only the traditional Roman alphabet with the sole exception of an additional symbol 'cedilla' to mark nasality in vowels, as it does in Polish. Largely influenced by DU PONCEAU's description of English phonology (1818), Pickering included five vowel sounds (a, e, i, o, and u), two semi-vowels (y and w), and three diphthongs (ay, au, and iu or yu) described by DU PONCEAU. Also, Pickering added a few sounds to Du Ponceau's inventory of consonants, including the 'palatal nasal' and 'palatal lateral approximant', for a total of 35 consonants. In addition, Pickering made some interesting observations about vowels; (1) the exact pronunciation of a given vowel sound may vary from language to language, and (2) the boundaries between vowels are not discreet; rather, as with the terms for the colors of the prismatic spectrum, the terms for vowels refer to a continuum. Given these assumptions, Pickering claims that it is sufficient to represent only the 'principal sounds', as we represent only the focal colors. Pickering's system was applied to Hawaiian and to eleven native American and two African languages.

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TOMOKO YAMASHITA SMITH

PICKETT, J. M.

Pickett learned electrical engineering in U.S. Navy training schools and then served as Electronic Technician aboard the U.S.S. Battleship, Arkansas, and the destroyer, J.C. Owens. He returned to Oberlin in 1946 to resume study with R. H. STETSON, the psychologist/phonetician, as his last student (Kelso and Munhall, 1988: 15-22). Eventually he became a sort of guru in speech science and its applications for improved speech communication for the deaf. Before that he worked with Karl Kryter and Irwin Pollack in the US Air Force's Human Resources Research Laboratory on phonetic approaches to improving speech communication in intensely noisy situations. He and Irwin were the first to do experiments on the intelligibility of conversational speech. He then received a research fellowship from NIH to work for a year in Gunnar Fant's Speech Transmission Laboratory at the Royal Institute of Technology (KTH, Stockholm) to study tactile aids to lipreading by school children. KTH was a classy place to learn acoustic phonetics (see his account in Pickett 1995). He and his wife Betty H. Pickett (also a Brown psychologist) published the results of these studies. Two years later he received a Research Professorship at Gallaudet University. Upon retirement in 1987 Pickett worked as a consultant to Robert A. Berkovitz, President of Sensimetrics Corporation in designing, together with K. N. STEVENS and Michel T. T. Jackson, a CD-ROM course in acoustic phonetics and speech perception. At the same time he revised and expanded his 1980 textbook (Pickett et al. 1999).

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J. M. PICKETT

PIKE, KENNETH L. (b. Woodstock, CT, 9 Jun 1912). *Linguist, phonetician, Bible translator, teacher, poet*.

Summer Institute of Linguistics [SIL], 1935; teaching at SIL phonetics and grammatical analysis, 1936 to about 1987; president of SIL, 1942-79, (emeritus 1979-); PhD, University of Michigan, 1942; assistant Professor of Linguistics to full professor, Michigan, 1948-79, professor emeritus 1979-; president of the LSA, 1961; member American Academy of Sciences, 1974, member National Academy of Sciences of the United States of America, 1985 (now emeritus); various honorary doctorates, e.g. L'Université René Descartes 1978; author of a dozen or so books and numerous articles on linguistics, others on religion, and many published poems, lectures in many countries,

including Mexico, Peru, Papua New Guinea, Ghana, Nepal, Thailand, Malaysia, Russia, and China.

FURTHER READINGS

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KENNETH L. PIKE

PITMAN, BENJAMIN (b. Trowbridge, Wiltshire, England, 24 Jul 1822, d. Cincinnati, OH, 28 Dec 1910). *Stenographer, teacher*.

Pitman's career was to some extent eclipsed, as well as being heavily influenced, by that of his more famous brother, Isaac Pitman (1813-1897), the inventor of 'Pitman's Shorthand'. Benn (or Ben) learned the first version, 'Stenographic Sound-hand' (1837), even whilst Isaac was in the process of devising it. By 1842, he was teaching it publicly in England and was accorded the title of 'phonographic lecturer'. In 1846 he was made the manager of the firm in London that was responsible for publishing and promulgating the system, the 'Phonographic and Phototypic Depot'. (During the 19th century, questions of shorthand often became intertwined with questions of spelling-reform — hence 'Phonotypic' (sometimes also called 'Phonetic') alongside 'Phonographic'.)

In 1852, he was persuaded by Isaac to emigrate to America to popularize Pitmanic shorthand. In Cincinnati he established the Phonographic Institute, from where he published and taught the system. However, in 1857 when Isaac introduced several significant changes to the Tenth edition of the system, Benn remained faithful to the previous version and continued to teach this throughout the rest of his career. One change in the Tenth edition had to do with the representation of vowels. The positions on the three-point vertical scale now reflected the relative values of F₁ rather than F₂. The change was not without controversy, and the majority of American shorthand-writers followed Benn in adhering to the older scheme.

For many years he served as an official United States Government shorthand-reporter, one of his assignments being to cover the trial of the conspirators in the assassination of President Abraham Lincoln.

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MIKE MACMAHON

RABINER, LAWRENCE (b. Brooklyn, NY, 28 Sep 1943). *Author, electrical engineer, scientist (speech communications)*.

BS, MS, PhD in Electrical Engineering, MIT, in 1964, 1964, and 1967 respectively. AT&T Bell Labs staff member, 1962-1972, supervisor, 1972-1985, department head, 1985-1990, director, 1990-1995. AT&T Labs functional vice president, 1996-1998, research vice president, 1998-present. Fellow of the IEEE (Institute of Electrical and Electronic Engineers), ASA (Acoustical Society of America), Bell Labs, and AT&T Labs. Member of the National Academy of Engineering and the National Academy of Sciences. Recipient of the Biennial Award of the ASA, 1974, the Piore Award of the IEEE, 1980, the IEEE ASSP Society Award, 1980, the IEEE Centennial Award, 1984, and the AT&T Patent Award, 1995. Rabiner's research has focused on speech synthesis, speech recognition, and digital signal processing. He is the co-author of four books in speech and signal processing, has authored hundreds of papers in journals, and is a co-inventor on more than 30 patents in the area of speech processing and communications.

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LAWRENCE RABINER

REMEZ, ROBERT E. (b. New York, NY, 22 Jun 1950). *Educator, perceptual psychologist, psycholinguist*.

BA, 1971, Brandeis University; PhD, 1978, University of Connecticut; NICH D Research Trainee in Psychology and Language, Haskins Labs, 1975-1977; Visiting Instructor, Trinity

College, Hartford, 1976-1977; Visiting Assistant Professor, Indiana University 1978-1980; Assistant to Full Professor, Barnard College, Columbia University 1980-present; Visiting Assistant Professor, Cognitive Science University of California Irvine, 1982; Visiting Scientist, Haskins Labs, 1994-1995. Associate Editor, *Perception and Psychophysics*, 1996-1998; Associate Editor, *Journal of Experimental Psychology: Human Perception and Performance*, 1999-present. Remez's studies describe the sensory causes of speech perception and the perceptual organization of speech. The research has aimed to evaluate the speculative neurophysiology of speech perception, and to explain the perceptual coherence of an acoustically diverse speech signal. Empirical projects have focused on the sensory ingredients evoking the concurrent perception of phonetic attributes and of the personal and idiolectal attributes of the talker.

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ROBERT E. REMEZ

REPP, BRUNO H. (b. Vienna, Austria, 27 Oct 1944). *Experimental psychologist*.

Dr. phil., 1969, Univ. of Vienna; PhD, 1973, Univ. of Chicago. Research scientist, Haskins Labs, New Haven, CT, 1976-pres. Fellow, Acous. Soc. Am.; Editor, *Lang. Speech*, 1988-1994. Until 1991, Repp conducted research on the perception and acoustics of phonetic segments and published some 80 papers in various journals. Since 1991, his research has been concerned with music perception and performance.

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BRUNO H. REPP

ROSENBERG, AARON E. (b. Malden, MA, 9 Apr 1937). *Engineer, researcher.*

S.B., S.M. in Electrical Engineering, 1960, Massachusetts Institute of Technology; PhD in Electrical Engineering, 1964, University of Pennsylvania. Member, Technical Staff, AT&T Bell Laboratories, 1964-1996; Technology Leader, AT&T Labs, 1996-present. Fellow, Acoustical Society of America; Fellow, IEEE. IEEE Signal Processing Society: Technical Committee on Speech Processing, Member and Chairman, 1978-1981; Associate Editor for Speech Processing, 1981-1983; Administrative Committee, 1983-1985; Senior Award, 1987. Rosenberg's research activities have included auditory psychophysics, speech perception, speech quality, and speech and speaker recognition. He has authored or co-authored some 100 papers and has been granted six US patents.

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AARON E. ROSENBERG

RUSH, JAMES (b. Philadelphia, PA, 15 Mar 1786, d. Philadelphia, PA, 26 May 1869). *Elocutionist, psychologist, physician.*

Rush (a 'peevis', 'prickly' and 'embittered' man, according to his contemporaries) trained as a doctor at the University of Pennsylvania, graduating MD in 1809. He then spent the next two years in Britain, mostly in Edinburgh and London, where he

appears to have developed his interest in speech, particularly the phonetics of public speaking. This may have derived from his training in physiology and the contacts he made in Britain with, for example, Dugald Stewart (1753-1828), professor of moral philosophy at Edinburgh and a fine public speaker, and Sir Charles Bell (1774-1842), the distinguished London surgeon and neurologist.

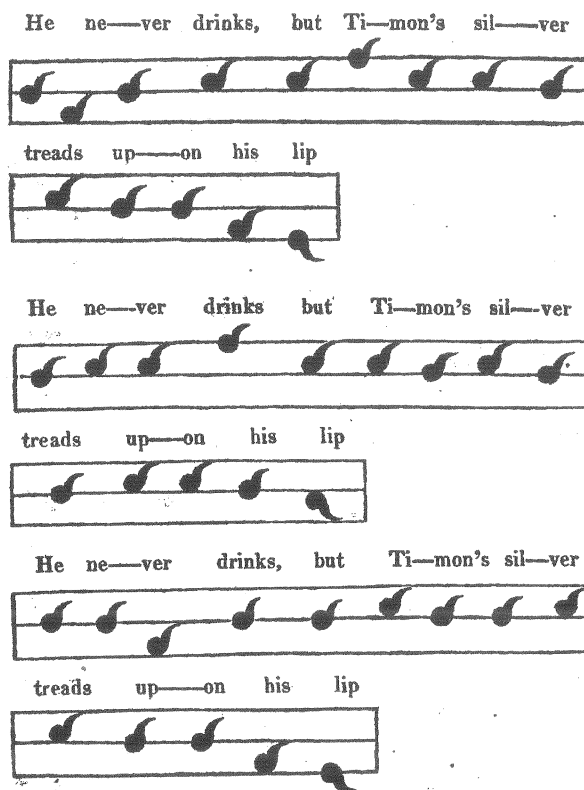


Fig. 15. Three possible intonation patterns for a line from Shakespeare's *Timon of Athens* (Rush 1827).

Rush's major work was *The Philosophy of the Human Voice*, first published in 1827, but planned some years earlier. Its central thesis is that the practice of elocution should be placed on a firm scientific foundation, namely a conscious understanding of how the five elements which make up the 'human voice' are utilized in public speaking. These are: *quality* (e.g. 'rough', 'smooth'), *force* (e.g. 'loud', 'soft'), *time* (e.g. 'long', 'short'), *abruptness* (e.g. 'the sudden and full discharge of sound', 'its more gradual emission'), and *pitch* (e.g. 'rise and fall', 'high and low'). Detailed attention is paid to (in 20th-century terminology) sentence-accent, intonation, voice qualities and voice qualifications; mostly elaborated by means of a chromatic musical scale in which the gaps between lines represent whole-tone intervals (see Fig. 15 above) and by some idiosyncratic terminology (e.g. 'vocule', 'atonic', 'equable concrete'). Advice is given on how to correct faults in the use of these five elements in elocutionary contexts.

There is other evidence of his skills as a phonetician, including insights into the release phases of stop articulations, the nature of double voice, the 'elementary sounds' (i.e., broadly, phonemes) of American English, and a concept of the syllable which in some respects anticipates STETSON's views of almost 100 years later.

The work was popular, as can be gauged from its remaining in print, in various editions, for almost the whole of the 19th century. Its subject-matter strongly influenced elocutionary techniques in North America (see Wolff 1952). Additionally, its usefulness was recognised in 1845, when many of Rush's ideas were incorporated into a more practical format by the elocutionist James Murdoch (1811-1893), the educationalist William Russell (1798-1873), and the musician George Webb (1803-1887) in their joint work *Orthophony; or, The cultivation of the voice, in elocution*.

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MIKE MACMAHON

RUSSELL, G(EOERGE) OSCAR (b Conejos, CO, 21 Nov 1890, d. Salt Lake City, UT, 19 Mar 1962). *Educator, phonetician*.

BA, Brigham Young U, 1915, MA, PhD, Columbia U, 1918, 1928. During World War I Russell served as Assistant to the Military Attaché in Brazil and in the Military Intelligence Division of the General Staff. Following the war, he taught at various institutions before joining the faculty at Ohio State University in 1925 as an assistant professor of Spanish. His PhD came from Columbia in 1928. (In Russell n.d. [1959] he recounts that his aim in attending Columbia was to study with E. W. SCRIPTURE but that when he first arrived there he found Scripture had abruptly departed for Europe shortly before, abandoning his students and his wife.) Following his PhD he became chairman of the Division of Phonetics and Director of Language Laboratories at Ohio State in 1930. He held these posts until 1941, at which time he became director of the Utah State Research Laboratories. Late in life he moved to Washington, DC, becoming head of the phonetics lab there and serving as editor of *Deaf and Blind Research Monographs*. He also served as editor of the *Journal of Speech Disorders*.

He published extensively in the areas of language and phonetics and developed and pioneered the use of modern techniques for speech research. Among these devices and techniques were the laryngoperiscope, X-ray photography, and

palatography. He developed a method for projecting palatograms onto a flat surface while preserving idiosyncratic information about the curvature of the palate. He also introduced a research technique which simultaneously yielded information about direction of tongue movement and points of lingual contact with the palate.

One of the major conclusions from his research (hotly debated at the time and not accepted without much qualification today) is that there was little consistent relation between phonetic vowel quality and tongue position within the vocal tract.

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ROBERT BRUBAKER IN THE *BDPS*; EDS.

SAPIR, EDWARD (b. Lauenberg, Germany (modern Lebnork, Poland), 26 Jan 1884, d. New Haven, CT, 4 Feb 1939). *Anthropologist and linguist*.

Sapir's family emigrated to the U.S. in 1890 and eventually settled in New York City. He received his doctorate in anthropology in 1909 under FRANZ BOAS. In 1909 and 1910 he did research at the University of Pennsylvania and the University of California, Berkeley. In 1910 he became head of the Division of Anthropology of the Geologic Survey of Canada in Ottawa. From 1925 to 1931 he was a professor of anthropology and linguistics at the University of Chicago, and from 1931 until his death in 1939 was the Sterling Professor of Anthropology and Linguistics at Yale.

Sapir was the preeminent American anthropological linguist of his age. He is remembered for introducing a new level of professionalism in descriptive linguistics, and for his work on American Indian languages and cultures, more than thirty of which he researched in the field. In addition to his contributions to virtually every area of linguistics, Sapir trained a generation of American linguists, many of whom continued the Boasian project of 'salvage linguists,' i.e., documenting the dwindling stock of American Indian languages. He also made a variety of proposals for the genetic classification of American Indian languages and their possible relationship to Old World languages.

Sapir's name, along with that of his student and colleague Benjamin Lee Whorf, is often associated with linguistic relativity, the controversial theory that language constrains thought and culture (the 'Sapir-Whorf' or 'Whorfian' hypothesis.) However, since this view is developed almost entirely in Whorf's writings, the extent to which Sapir should

share credit for these ideas is unclear. His other published works include literary criticism, musicology, poetry, and toward the end of his life, psychiatry. He was also involved in the movement for an international auxiliary language. Sapir was deeply troubled by the growth of anti-semitism in American academia of the 1920s and 1930s (especially at Yale) and addressed this problem in a number of popular essays.

Sapir chaired a committee of the American Anthropological Association responsible for considering standardization of the orthography used for research in American Indian languages. (Other committee members were A. L. KROEBER, PLINY GODDARD, BOAS, and J. P. Harrington.) Most researchers considered some degree of standardization desirable, both to facilitate comparative studies and to bridge the gulf between American and European phonetic usages. Sapir drafted the committee report, which advocated a measure of standardization but also left much to the discretion of the individual linguist. His comments clarify that he considered full standardization somewhat premature and thought it more important in any event that linguists carefully describe their use of orthography. The report was approved and adopted after a third draft in 1915, but Sapir, apparently put off by the politics of the process, declined to participate in subsequent revisions.

Sapir's most important achievement in the history of phonetics and phonology was the role he played in the development of the concept of the phoneme. In his seminal paper on the subject (Sapir 1933) he recalls that an early insight (in 1910) into the phonemic principle came when he noticed that his Southern Paiute informant heard two distinct but related sounds as the same. In a 1916 letter to A. L. KROEBER, he suggested that the inability of an informant to read Kroeber's narrow transcriptions was perhaps not the informant's fault: 'As a matter of fact, however, the native informant would be sure to be puzzled, as the difference between the two [sounds], while real from an analytical standpoint, is a purely secondary consequence of mechanical factors'. He added that if the informant invented an alphabet for his language, 'he would undoubtedly use the same character for both sounds' (Golla, Ed. 1984: letter 208). This straightforwardly psychological or mentalistic conception of the phoneme was actually somewhat out of step with Sapir's times, during which the social sciences were becoming increasing behavioristic, and is more in tune with later generative and cognitive approaches to linguistics.

Sapir was also a pioneer in the psycholinguistic study of "sound symbolism" (Sapir, 1933), the notion that in some cases there is a non-arbitrary association between sound and meaning. He required subjects to assign nonsense words like [gil] and [gɔl] as names for either smaller or larger versions of objects. There was a significant tendency for forms like [gil] to be assigned to smaller objects and [gɔl] to the larger.

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WILLIAM F. WEIGEL

SCHROEDER, MANFRED R. (b. Ahlen, Westphalia, Germany, 12 Jul 1926). *Physicist, engineer, educator*.

Manfred Schroeder studied mathematics and physics at the University of Goettingen in Germany. In his thesis he investigated the distribution of resonances in concert halls using microwave cavities as models. The chaotic distribution he found is now recognized as characteristic for complex dynamical systems.

In 1954 Schroeder joined the research department of AT&T's Bell Laboratories in Murray Hill, NJ. From 1958 to 1969 he directed research on speech synthesis and recognition. Since 1969 he has also served as a Professor of Physics at Goettingen, commuting between the university and Bell. In 1979 Schroeder also served as a Visiting Professor at the University of Tokyo.

Schroeder is a founding member of the Institut de Recherche et Coordination Acoustique/Musique of the Centre Pompidou in Paris. In the late 1950s he helped to formulate the U.S. standards for stereophonic broadcasting, now used worldwide. Schroeder holds 45 U.S. Patents in various fields.

In 1991 Schroeder was awarded the Gold Medal of the Acoustical Society of America for "theoretical and practical contributions to human communication through innovative application of mathematics". He also received the Rayleigh Medal of the British Institute of Acoustics, the Helmholtz Medal of the German Acoustical Society, and the Gold Medal of the Audio Engineering Society. As one of the pioneers of computer graphics, Schroeder won First Prize at the 1969 International Computer Art Competition in Las Vegas.

Schroeder is a Fellow of the American Academy of Arts and Sciences and the New York Academy of Sciences. He is also a member of the National Academy of Engineering and the Goettingen Academy of Sciences. Schroeder's hobbies are languages, bicycling, down-hill skiing, and computer graphics.

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MANFRED R. SCHROEDER

SCRIPTURE, EDWARD WHEELER (b. Mason, NH, 21 May 1864, d. Bristol, England, 31 May 1945).

Scripture's education was at the College of the City of New York (BA, 1884), and then the Universities of Berlin, Zurich, and Leipzig, where he was granted a PhD in 1891. He later received an MD from the University of Munich (1906). He should first be remembered as a life-long advocate of experimental methodology. In one of his earlier published works, "Education as a Science," he advocated the use of experimental methods for the discovery of useful pedagogical techniques. His belief in laboratory science over intuitive "armchair science" continued through his careers in psychology, phonetics, and medicine. One of his interests was the use of mechanical apparatus for precise measurements: in *The New Psychology*, he presents both his own inventions, including an apparatus for measuring reaction-time to the millisecond, and a mechanical test for color-blindness, and the inventions of others, particularly for measurement of sensory perceptions. *Thinking, Feeling, Doing* may be thought of as a layperson's introduction to experimental methodology. In both of these works, he argues eloquently for the use of scientific observation over mere introspection. *The New Psychology* in particular is notable for its explicit arguments for — and instructions on — the use of statistical analyses.

His first full-time faculty appointment was at Yale (1893). While there, he directed the Yale Psychology Laboratory and edited the journal *Studies from the Yale Psychology Laboratory*, in which he published his own working papers. While he did some early work on perception and sound (most notably, developing a system for indicating intensity — including variable intensity — of musical notes by using different heads of the notes), his work during this period is on the psychology of perception in general.

However, by 1900, he had specialized in phonetics. His 1902 textbook, *Elements of Experimental Phonetics*, arguably his most important work, reports on the methodology and results of phonetic experiments in four general areas: a) "speech curves" (wave forms), b) "perception of speech" (covering the physiology of the ear to the processes of sound-meaning association) c) "production of speech" (articulatory mechanisms), and d) "factors of speech" (articulatory and acoustic correlates of parameters such as accent, melody, duration, and loudness). His medical school thesis (1906) analyzed changes in air pressure and pitch of vowels in various contexts.

After several years at Yale, having been dismissed due to the experimental vs. armchair psychology debate, he served as an Associate in Psychiatry and Director of the Research Laboratory of Neurology at Columbia University. Later on, having returned to Europe, he worked as a speech pathologist at the West End Hospital, London, as a professor of phonetics at the University of

Vienna, and as a lecturer at King's College, London. His published work on speech pathology (*Stuttering and Lispings*, 1912, 2nd ed. 1923) combines discussions of case-studies and results of experimental work (kymographic apparatus to measure oral and nasal air pressure, tongue and lip movement, etc.) with more general discussions of theories of both physiological and psychological causes of these disorders and options for therapy.

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MONICA CORSTON-OLIVER

SEQUOYAH (b. Taskigi, North Carolina Colony, 1770?, d. near San Fernando, Mexico, Aug 1843). *Creator of the Cherokee syllabary*.

Although he was also a silversmith, warrior, painter, trader, and hunter, Sequoyah, also known by his English name, George Guess, is most often remembered as the creator of a syllabic writing system for the Cherokee language.

Around 1809, Sequoyah became convinced that the utility of his language would greatly increase if it could be recorded on "talking leaves", as he had seen with English. Since Cherokee, an Iroquoian language, had no writing system, he put himself to the task of developing a means by which it could be written. His initial attempts found him creating a separate character for each word, a plan he abandoned after reaching several thousand symbols.

Sequoyah eventually decided to approach the problem by developing a character for each syllable. In some cases he created his own symbols, in others he used or modified letters of the English alphabet, although given that he did not know how to read or speak English, the borrowed graphemes did not represent their original sounds. By 1821, with the assistance of his daughter, he had created a writing system consisting of 86 symbols representing an equal number of syllables. The effectiveness of this new writing system was convincingly

demonstrated through the exchange of correspondence between Cherokees who had moved west under the Cherokee Treaty of 1817 and their friends and relatives who at that time remained in the ancestral lands.

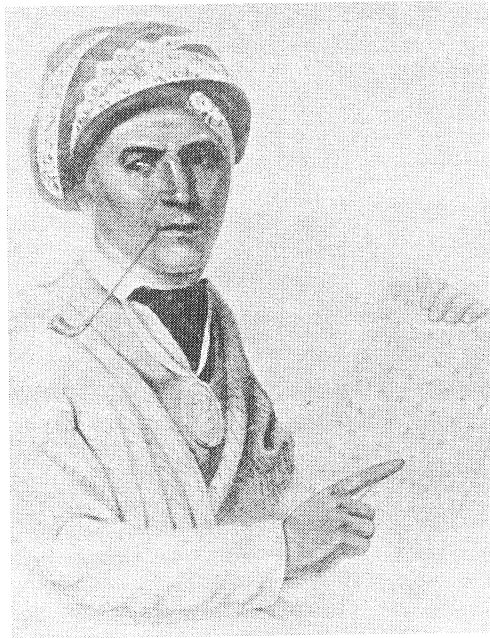


Fig. 16. Sequoyah, circa 1828.

As Sequoyah's writing system spread, it soon became apparent that one of its greatest strengths was the relative ease with which it could be learned by Cherokee speakers, a task often accomplished in as little as a few days. By the 1830s, Sequoyah's script was being widely used in personal correspondence, official documents, and a newspaper, with estimates suggesting literacy rates in excess of 50% among Cherokee speakers at that time. Widespread use of the syllabary continued through the 19th century after the tribe was forcibly removed to Indian Territory (present day Oklahoma), but has diminished considerably during the 20th century.

The syllabary, which has no separate upper or lower case, is written from left to right. There are six characters that represent vowels, one that represents a consonant, and 79 that represent consonant(s) plus vowel. Of the latter, one is considered archaic and is no longer in use. Although Sequoyah proposed a certain order for grouping the symbols, a more widely accepted arrangement was devised in the 1820s by missionary Samuel Worcester. This configuration, shown in Figure 17, divides the script into six columns, each headed by a vowel. Beneath each vowel are the combinations of consonant(s) plus that particular vowel. In seven cases, similar syllables are grouped in the same location. As an example, the characters named 'da' and 'ta' are grouped together since they are distinguished only by a voicing contrast, which, in Cherokee, is unaspirated and aspirated, respectively. Despite its efficiency, one criticism of the syllabary is its failure to account for phonemic differences in vowel

duration. For example, [ama] (water) and [a:ma] (salt) are written identically.

D	R	T	o	u	i
a	e	i	o	u	v
S	F	Y	A	J	E
ga	ge	gi	go	gu	gv
h	h	h	h	h	h
ha	he	hi	ho	hu	hv
W	le	li	G	M	A
la	le	li	lo	lu	lv
ma	me	mi	mo	mu	
o t G	A	h	o	u	o
na hna nah	ne	ni	no	nu	nv
qua	que	qui	quo	qu	quv
sa s	se	si	so	su	sv
da ta	de te	di ti	do	du	dv
dla tla	L	C	h	h	P
tsa	tse	tsi	tso	tsu	tsv
wa	we	wi	wo	wu	wv
ya	ye	yi	yo	yu	yv

Fig. 17. Sequoyah's syllabary for Cherokee.

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JEFFREY T. REEDER

SMITH, HENRY LEE, JR. (b. Morristown, NJ, 11 Jul 1913, d. Buffalo, NY, 13 Dec 1972). *Linguist, anthropologist, American English dialectologist*.

Smith taught at Brown University and at State University of New York at Buffalo, where he served as chair of the Depts. of Anthropology and Linguistics. He also taught at Indiana

University, Harvard, and the University of Pennsylvania. Smith's publications bridged the areas of phonology, morphology, syntax, semantics, prosody, applied English linguistics and American English dialectology. His radio program on station WOR in New York City, known as "Where Are You From" was an impressive demonstration of how a superbly trained American English dialectologist could identify where people came from in the United States by having them respond to a few specially prepared questions. He guessed correctly close to 80% of the time, a phenomenal demonstration of his expertise in the area. Smith's "Outline of English Structure," which he co-authored with George Trager in 1951 was one of the most widely used linguistic texts in the 1950s and 1960s, prior to the advent of transformational-generative grammar. It was an analysis of English linguistics following Bloomfieldian structural linguistics. He was a widely sought-after lecturer in many university departments of linguistics and anthropology.

EDS., BASED ON THE ENTRY IN THE *BDPS*

STETSON, RAYMOND HERBERT (b. North Ridgeville, OH, 1 Mar 1872, d. Oberlin, OH, 4 Dec 1950). *Educator, phonetician.*

Stetson graduated from Oberlin College in 1893 where he obtained a Bachelor of Philosophy (Ph.B) degree with a major in chemistry. Between 1893 and 1894 he served as instructor in chemistry at Oberlin College. While an assistant in chemistry he studied zoology, obtaining an MA degree in zoology in 1896, after which he taught biology at Tabor College (Hillsboro, KS) for three years (1896-99). From 1899 until 1901 he worked under James, Royce and Munsterberg at Harvard where he displayed his inclination to laboratory work. He prepared a dissertation under Munsterberg and obtained a PhD in 1901.

He spent the following years at Beloit College (Wisconsin), where he was professor of psychology and philosophy. There are conflicting reports pertaining to the actual period he spent at Beloit College although it is clear he returned to Oberlin in 1909. When Stetson returned to Oberlin he organized a separate department of psychology. He became professor of psychology and head of the department from 1909 to 1939.

Stetson was both an outstanding educator and researcher. It was at Oberlin where he developed one of the most outstanding undergraduate departments of psychology in the country. According to Hartson (1951) "This record may be attributed, in part, to his encyclopedic scholarship and scientific objectivity, together with ability to combine research with teaching, thus stimulating the spirit of inquiry in his students."

Stetson is said to have been an objective psychologist and one of the first to appreciate the contributions of Bechterev, Max Meyer and Watson. Hartson says, 'Referring to the mind as substantive, he [Stetson] used to say: "I believe in total abstinence. I wouldn't want to be caught dead with a mind"'. While using Watson's book as a text, he was critical of its atomism and saw in configurationism a wholesome corrective because it emphasized the pattern. His was a molar behaviorism which considered the postural set not only as a basic determinant of skilled movements but as an integral part of the mechanism of the thought processes. Perception, he said, is anticipatory response; it involves tentative movements; it is an experimental

aspect of thinking. The organization of the response originates in the stimulus pattern, requiring pattern rather than a path in the brain. In fact, he maintained that the symbolic processes and their residual traces involve "fields" so extensive that "they cannot be confined to any definite set of sense organs, or nerves, or muscle fibers." "Pangram," he said, "would be a better term than engram to represent the memory trace."

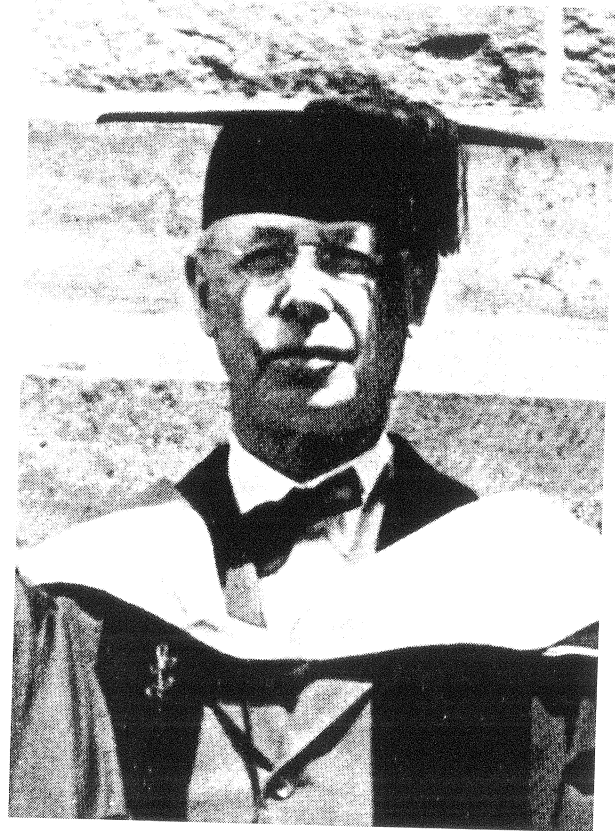


Fig. 18. Raymond Herbert Stetson.

His dissertation, in which he developed a motor theory of rhythm, provided a theme for a half century of research on the process of producing skilled movements.

When Stetson took his sabbatical from 1922 to 1923, he spent that year working with the Abbé Rousselot in Paris. It was at this point when he seriously pursued his life-long interest in language, specifically, the subject of phonetics. (He is said to have collected alphabets at the age when youngsters usually collect stamps). His monograph, *Motor Phonetics*, published in 1928, was distinctive for its analysis of the processes of producing sounds rather than the analysis of their sensory effects. He argued that a "phonetics based on movements is primarily concerned with the nature of the syllable". A revision of the book, in collaboration with C.V. Hudgins, was completed shortly before his death. *The Bases of Phonology*, a monograph, printed in 1945, was in great demand among students of language. His publications in this field and papers presented before the International Congress of Phonetic Sciences were responsible for

his appointment to membership on the permanent committee (Permanent International Council) of the Congress.

At the time of his retirement, papers by a number of his students were published as a Festschrift, which appeared as a number of the *Journal of General Psychology*.

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GALEN SIBANDA

STEVENS, KENNETH N. (b. Toronto, ON, Canada, 23 Mar 1924).

Education: BA, MS, Univ. of Toronto, 1945, 1948; DSc, MIT, 1952. The phonetically-oriented research of Kenneth Stevens has spanned several areas, ranging from the acoustics and aerodynamics of speech production to the mapping between the discrete phonological representation and the articulatory and acoustic manifestations of speech. The more acoustically-oriented research examined the mechanisms whereby respiratory energy is converted either to a quasi-periodic source at the glottis or to noise due to turbulence in the airflow in the vicinity of a constriction in the vocal tract. The nature of filtering of these sources by vocal tracts with different shapes was also studied both experimentally and with theoretical models. More detailed analysis of the relations between articulation, airflow, and acoustics led to the observation that the articulatory-acoustic mapping is not monotonic, and sometimes shows discontinuities, in terms of both source characteristics and the filtering of the sources. It was suggested that the plateaus and discontinuities in the mapping relations are matched to the discrete phonetic categories that exist in languages. Work with M. Halle and J. Keyser has examined how words are represented in memory, and mechanisms whereby speakers (and languages) enhance the perceptual distinctions between contrasting phonological features.

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KENNETH N. STEVENS

STILES, EZRA (b. North Haven, CT, 29 Nov 1727, d. New Haven, CT, 12 May 1795). *Minister, attorney, professor, president of Yale College*.

Stiles received both a bachelor's and a master's degree from Yale and later became a tutor there. He finally accepted a position as minister to a congregation in Newport, Rhode Island, and later in Portsmouth, until he was elected seventh president of Yale College in 1777. He was considered one of the most erudite men in New England and received honorary degrees from the University of Edinburgh and most of the colleges in the northern states. He continued as president and professor of ecclesiastical history until his death.

Ezra Stiles is one of the few people aside from ROGER WILLIAMS who recorded anything of Narragansett. When he collected his short word list, he used the Hebrew alphabet to supplement his English notations. (One reason for this is that Stiles — like many others, including Roger Williams—thought that Native Americans were possibly descended from the Lost Tribes of Israel.) Because the Hebrew system of vowel points makes vowel distinctions that English orthography cannot, Stiles' vocabulary has turned out to be invaluable for determining the phonetic nature of the sounds Williams had transcribed earlier.

There is some question as to which dialect of Narragansett Stiles was recording. GODDARD has suggested that it is Eastern Niantic, but Pentland calls it Western Narragansett, as opposed to the dialects familiar to WILLIAMS, which were mainly Northern Massachusetts and Narragansett proper. (For a phonetic inventory of Narragansett, see ROGER WILLIAMS.) The dialects are distinguished by their reflex of Proto-Algonquian *k before *i and *e:. Williams' transcriptions for the most part have either /k/ (Narragansett proper) or /t/ (Northern Massachusetts). However, Stiles usually has /t̥/ (written <ch>).

Stiles seems to have had a good ear and provides extremely detailed transcriptions on occasion. For example, while WILLIAMS almost never caught word-final /h/ (even when contrastive), Stiles does. Stiles was also detailed enough to include emergent stops in his transcriptions, even word-finally. Finally, Stiles was more consistent than Williams in indicating nasalization on vowels (by using a following <n> or <m>). His transcriptions have therefore contributed to the debate over whether /a:/ was in reality pronounced [ã:] (see WILLIAMS).

Perhaps the most valuable contribution Stiles has made to the reconstruction of Narragansett comes from his use of vocalized Hebrew script to transcribe Narragansett sounds. For example, he writes Hebrew <s^án^su^wm> for *sācim* 'chief' and <s^án^š sk^uw^á> for *sāc skwāw* 'chief's wife.' Pentland has taken Stiles' use of alef (ʔ, which he reads as [a:]) and short gamets (ă, low back [ɑ]) as further evidence—together with his English transcription, which includes an <n> (as does the

Hebrew) — that the vowel was indeed nasalized. According to Pentland, Stiles' English and Hebrew transcriptions also support the phonetic reconstruction of /a/ as ranging from [a] to [a̠] and maybe to [ɔ].

After his encounter with Narragansett, Stiles continued to do some fieldwork, collecting a short word list in the Quinnipiac dialect of Wampano in 1787, four years before THOMAS JEFFERSON worked on the Unquachog dialect. There, too, Stiles used the Hebrew alphabet to supplement his English transcriptions.

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PAULA KADOSE RADETSKY

STRANGE, WINIFRED (b. Red Bluff, CA, 5 Mar 1945). *Educator, phonologist, perceptual psychologist*.

PhD, 1972 (Psychology), University of Minnesota; Research Associate and Adjunct Asst. Prof. Psychology, U of Minn. 1972-1982; Assoc. Prof. to Full Prof. Communication Sciences and Disorders, University of South Florida, 1982-1998; Director, Interdisciplinary PhD Program in Psych. and Comm. Sci., USF, 1984-1996; Professor, Program in Speech and Hearing Sciences, Graduate Center, CUNY, 1998 to present. Visiting positions: Haskins Laboratories, U. Colorado, Advanced Telecommunications Research Laboratories (Japan). Fellow, Acoust. Soc. Amer.; Fellow, Amer. Psych. Assoc. Author of numerous articles, book chapters and books on speech perception. Her research work has been concentrated in three major areas. 1) Acoustic and perceptual studies of the dynamics of American English vowels produced in a variety of contexts. 2)

The development of speech perception capabilities in children. 3) Perceptual and acoustic studies of the phenomena of cross-language speech perception. In addition she and her students have conducted basic studies of the efficacy of training procedures in improving cross-language speech perception.

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WINIFRED STRANGE

STUDDERT-KENNEDY, MICHAEL G. (b. Worcester, England, 15 Mar 1927). *Educator, experimental psychologist, researcher*.

BA (Classics: Greek and Latin literature, Greek archaeology), Cambridge Univ. 1951; PhD (Experimental Psychology), Columbia Univ. 1961; Instructor in Psychology, Bowdoin College, ME, 1960-61; Assist. Prof. of Psychology, Barnard College, Columbia Univ., 1961-66; Assoc. Prof. of Psychology, Inter-American Univ., San German, Puerto Rico, 1966-67; Assoc. Prof. of Communications, Annenberg School, Univ. of Pennsylvania, 1967-69; Assoc. Prof. of Communications, 1969-72, Prof. 1972-86, Prof. Emeritus, 1986-pres. Queens College and Graduate Center, City Univ. of New York; Prof. of Psychology, 1987-92, Prof. Emeritus, 1992-pres., Univ. of Connecticut; Adj. Prof. of Linguistics, Yale Univ., 1987-92; Research Associate, Haskins Laboratories, New Haven, CT 1961-pres.; President, Haskins Laboratories, 1986-92. Fellow, Acoust. Soc. Amer., 1980-pres.; Fellow, Center for Interdisciplinary Research, Univ. of Bielefeld, Germany, 1977-78; Fellow, Center for Advanced Study in the Behavioral Sciences, Stanford, CA, 1985-86. Studdert-Kennedy's research has focused on speech perception, hemispheric specialization for speech perception, early development of links between speech perception and production (vocal imitation), and the evolution of spoken language.

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MICHAEL STUDDERT-KENNEDY

THORNTON, WILLIAM (b. Jost van Dyke, West Indies, 20 May 1759, d. Washington, DC, 28 Mar 1828). *Physician, architect, painter, inventor, first US Superintendent of Patents*.

Thornton's principal fame derives from his prize-winning entry in the 1792 competition for a design of the Capitol Building in Washington, DC. His work in phonetics is limited to a 47-page monograph entitled *Cadmus, or a treatise on the elements of written language, illustrating, by a philosophical division of speech, the power of each character, thereby mutually fixing the orthography and orthoepy* (1793). He proposed a universal phonetic alphabet of 30 characters but illustrated its use only with English. His proposals were not very influential but there is speculation that DUPONCEAU may have written his *English Phonology* in response to Thornton's ideas.

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JOHN J. OHALA

UMEDA, NORIKO (b. Kobe, Japan, 10 Jan 1933). *Researcher in speech acoustics*.

MA, 1959, completed PhD program, 1962, Univ. of Tokyo; PhD, 1975, Tohoku Univ.; Member of Research Staff, Electrotechnical Labs, Tokyo, 1962-1971; Member of Technical Staff, Bell Labs, 1969-1981; full research professor, 1981-1983, full professor, 1983-1996, Director, Inst. Speech and Language Sciences, 1986-1999, NYU; chair, technical committee on speech communication, 1976-1979, fellow, Acous. Soc. Am.; visiting scholar, 1989-1990, Electrical Communication Labs, NTT, Tokyo; research professor, 1992-present, Chiba Inst. of Technology, Japan.

Umeda's research on speech acoustics has spanned around the idea that speech is a manifestation of human nature and cognition, and her objective is to discover such human faculty and its subconscious controls. Text-to-speech synthesis, which she has engaged in over 30 years, was an excellent means for leading her to such discoveries. She postulated many linguistic rules for speech synthesis. Her recent research interest has been focused on spontaneous talking and its integration to a higher-

level framework. She has authored many technical articles and one book. Two more books are under way.

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NORIKO UMEDA

WAKITA, HISASHI (b. Yonago, Japan, 10 Jan 1934). Electrical engineer, electrical communication engineer, speech scientist.

After the introduction of the linear prediction method in 1969 as a powerful speech analysis method, Hisashi Wakita, in 1971, demonstrated theoretically and experimentally that this new method is equivalent to the acoustic tube model of speech production. He further demonstrated that it is possible to estimate the vocal tract area functions directly from acoustic speech waveforms based on the linear prediction method. This work had a great impact on researchers worldwide and stimulated further work to better understand, improve and extend the method. Later he also developed a method for estimating the vocal tract length of vowel sounds, and then applied the method to vowel normalization by the vocal tract length. He then applied the nonlinear dynamic programming (DP) matching technique to study the spectral differences between male and female vowel sounds and concluded that the differences are mostly linear if two vowel sounds are phonetically equivalent. The study was extended to investigate the effects of incremental changes in the vocal tract area function from one vowel to the other on the changes in the formant frequencies, and confirmed a speculation that a bend at the boundary between the oral and pharyngeal cavities was necessary during the course of evolution of the vocal tract so that humans could produce various vowel sounds.

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HISASHI WAKITA

WANG, WILLIAM SHI-YUAN (b. Shanghai, China, 14 Aug 1933). *Educator, linguist.*

BA, 1955, Columbia; MA, 1956, PhD, 1960, University of Michigan. Full Prof. of Linguistics, 1966-1995, University of California at Berkeley. Current appointments (1999): Professor of Graduate School (Berkeley), Professor of Language Engineering (City University of Hong Kong), Adjunct Professor (Hong Kong University of Science and Technology, Nankai University, Lanzhou University). Fellowships from Guggenheim Found. (1978), Stanford Center for Adv. Stud. Behavioral Sci. (1969, 1983), Rockefeller Found. (1991). Founding Pres., Int. Assoc. Chinese Ling. (1992). Academician, Academia Sinica, elected 1992. Wang's interests include the application of engineering concepts to language, e.g., speech recognition and synthesis. Currently, his research centers on evolutionary aspects of language and speech, with special emphasis on Chinese linguistics. He has published extensively in these areas.

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<http://www.ee.cityu.edu.hk/~wsyw>

WILLIAM S-Y. WANG

WARREN, DONALD WILLIAM (b. Brooklyn, NY, 22 Mar 1935). *Educator, clinician, speech scientist, physiologist, administrator.*

BS, 1956, DDS, 1959 Univ. of North Carolina at Chapel Hill, MS, 1961, PhD, 1963 (Physiology) Univ. of Pennsylvania,

D Odont (Hon), 1992, Kupio University, Finland. Resident, Lancaster Cleft Palate Clinic and Univ. of Pennsylvania 1959-61; Asst. Prof. to Prof. Univ. of North Carolina at Chapel Hill 1963-1980; Kenan Prof. 1980 to present. Director, UNC Craniofacial Center 1963 to present, Schools of Dentistry and Medicine. Research Prof. School of Medicine 1969 to present. Pres. Cleft Palate Foundation 1976-77, Pres. American Cleft Palate/Craniofacial Assoc. 1982, Fellow, Amer. Sp. Hear. Lang. Assoc. 1971, Fellow Amer. Assoc. Adv. Sci. 1986, Fellow, Internat. Coll. Dent. 1990, Honors, Am. Cleft Palate/Craniofacial Assoc. 1992, Distinguished Service Award, Am. Cleft Palate/Craniofacial Assoc. 1984. O. Max Gardner Award, UNC Bd. Of Governors, 1993, Editors Award, Am. Sp. Hear. Lang. Assoc. 1998, Honors, Angle Orthod. Soc. 1998. Warren's research has focused on the effects of structural deficits on speech production, respiratory and aerodynamic components of speech, active and passive compensatory speech behaviors. He has authored over 100 journal articles and 30 book chapters.

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DONALD W. WARREN

WEEKS, RAYMOND (LESLIE) (b. Tabor, IA, 1863, d. Manakin, VA, 16 Feb 1954). *Philologist, phonetician.*

Weeks received his doctorate in philology from Harvard University in 1897. He was Professor of Romance Languages at various universities: Missouri, Illinois, and Columbia. He served as president of the Modern Languages Association, the American Dialect Association, and the Spelling Reform Association.

While still a graduate student he published in 1893 an account of how he obtained graphical records of the movement of the soft palate during connected speech. His device consisted of a small (1.4 cm) disk attached by suction to the back margin of the soft palate, to which disk there was a flexible connection to a wire bent to go around the speaker's teeth in a way to avoid the movements of the tongue. The outer end, projecting through the lips, was attached to a Marey's tambour which in turn moved a lever making traces on a kymograph. Using this device he found,

among other things, vowel-specific positions of the velum, nasalization of vowels near nasal consonants, and attenuation of the amplitude of velic movement as a function of speech rate. Fig. 19 shows the traces obtained for the words "pant", "banana", "blanch", "branch", and "can't".

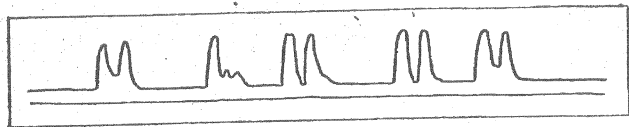


Fig. 19. Kymographic traces from Weeks' device for tracking movements of the velum; from left to right: "pant", "banana", "blanch", "branch", and "can't". The elevation of the line correlates with velic elevation.

In 1912 he co-authored (with J. W. Bright and C. H. GRANDGENT) *The N.E.A. Phonetic Alphabet with a Review of the Whipple Experiments*, a pamphlet defending a phonetic alphabet for American English devised by a National Education Association committee (of which he was a member) and a detailed critique of the phonetic alphabet proposed by the publisher of the Webster's Dictionary, an alphabet much like those still used today in U.S. dictionaries. The N.E.A. alphabet was similar to, and influenced by, the phonetic alphabet promoted by the International Phonetic Association.

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WHITNEY, WILLIAM DWIGHT (b. Northampton, MA, 9 Feb 1827, d. New Haven, CT, 7 Jun 1894). *Sanskritist, linguist*.

A chance encounter with one of Franz Bopp's publications on Sanskrit led Whitney into linguistics and away from his anticipated vocation, namely natural history — particularly botany, ornithology, and geology. A year's study of Sanskrit at Yale was followed by almost three years' in Berlin and Tübingen. He went on to become North America's foremost 19th-century Sanskritist and general linguist, occupying the chair (variously titled) of Sanskrit and Comparative Philology at Yale from 1854 to 1894. Four works on linguistic principles and issues (including phonetics), written mainly for the non-specialist, helped establish his reputation as a general linguist (Whitney 1867, 1873, 1875a, 1875d; cf. Alter 1993). He was a prodigious scholar, with a wide range of intellectual interests, whose publications encompassed not only Sanskrit and general linguistics, but also lexicography, the grammars of English, French, and German, astronomy, and geology.

Like Henry Sweet, Whitney regarded the phonetic domain of language as one of the central topics that any theory of language use and language change must address: "a thorough understanding of the mode of production of alphabetic sounds,

and of their relations to one another as determined by their physical character, has become an indispensable qualification of a linguistic scholar" (1875b). His more specialized interests in phonetics focused on the design of a phonetic notation, and the contemporary pronunciation of English — both in America and elsewhere. His theoretical position in phonetics was based on a critical sympathy for the concepts and practices of phonetics developed by Ernst Brücke ("no phonetic investigator of the present time [1866] is entitled to more respect and confidence") and Alexander Ellis ("the profoundest phonetist of the day" [1875]). Ironically, one finds no discussion of the phonetic and phonological theories of Panini and other Sanskritic phoneticians.

Lepsius' "Standard Alphabet," despite the revisions of the 1863 edition, does not fully meet Whitney's expectations for a phonetic notation: he finds fault with some of the phonetic data as well as with the choice of some aspects of the notation (1861, 1866). He is even less sympathetic to BELL's "Visible Speech," making shrewd and telling criticisms, particularly of the articulatory definitions of certain consonants and the imposed symmetry of the vowel schema (1868). The question of the validity of the distinction between the categories of vowel and consonant within general phonetics is discussed at length in 1875c.

The Elements of English pronunciation (1875b) is a careful exposition of numerous phonetic and phonological features of Whitney's own New England accent (with digressions into other accents as well). It concludes with calculations of the frequency of occurrence of the "sounds" (i.e., phonemes) of the accent.

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MIKE MACMAHON

WILLIAMS, ROGER (b. London?, 1603?, d. Providence, RI, Apr 1683). *Religious leader, political dissident, diplomat, founder of Rhode Island*.

After university, Williams left for America with the Puritans. However, due to his radical stances (including defending the rights of Indians), he was soon banished from Massachusetts. He escaped into the wilderness to avoid deportation and founded Providence.

Williams began to learn various local Algonquian languages in 1632. His linguistic interests culminated in his *A Key into the Language of America*. Aside from a few short word lists, his transcriptions are all we have left of these dialects. However, linguists have been able to reconstruct some Narragansett and piece together how Williams dealt with the phonetic and phonological aspects of Narragansett.

Narragansett had the following phones:

Consonants

p, b	t, d	tʰ	č, ĵ	k, g
	s, z		š, ž(?)	h
m	n			
w		y		

Vowels

i, i:	
e, e:	o, o:
a, a:	

As in other Algonquian languages, an /h/ could combine with the plain (lenis) stop and fricative series to yield preaspirated (fortis) sounds.

For /p/, Williams wrote <p> both initially and medially; he also used <pp> and , but only medially. Of course, English orthography uses both the graphemes <p> and <pp> medially for the same sound; Williams seems to have kept the convention of using two graphemes to represent the same phone in Narragansett. For the /h/+p/ cluster, Williams uses <p> and <pp> as well. Thus, if Williams had never used to transcribe /p/, we would not have known whether he was able to differentiate between preaspirated and non-preaspirated phones. However, with the presence of —and also with evidence from his transcription of other stops, such as <ht> for /h/+t/—we can assume that he (at least part of the time) noticed the preaspiration. Since he wavered between <p>/<pp> (= [p]) and (= [b]) for /p/ in medial position—sometimes with the same lexical item—we know that there was allophonic voicing of this and other obstruents. In addition, we can tell that he either (1)

took extremely phonetically detailed field notes, detailed enough to record the speaker's allophonic variation for a particular token, or that (2) he was working from his own knowledge of the language(s) when writing *A Key* and could not decide which orthographic symbol to use for what were, to the Narragansett speaker, not contrastive sounds. Williams made similar subphonemic distinctions for other points of articulation.

Williams seems to have had difficulty distinguishing /s/ and /ʰs/: he often varies between <s>, <ss>, and <sh>; this is taken to indicate that Narragansett /s/ and /ʰs/ were phonetically much closer than they are in English. He occasionally uses <z> for medial /s/; for /ʰs/, however, Williams always uses <s>, <ss>, or <sh>. It is unclear whether he meant for <sh> to stand for both [ʃ] and [ʒ] and was constrained by the English orthographic system, which has no unique grapheme for [ʒ], or whether /ʃ/ was never voiced intervocally and therefore [ʒ] was just missing from the phonetic inventory of Narragansett.

Some Algonquianists believe that all eastern Algonquian languages (including Narragansett) merged *i: and *i as i: and *o: and *o as *o:, leaving a system of two short vowels, /a/ and /e/, and four long vowels, /i:/, /e:/, /a:/, and /o:/. However, careful analysis of Williams' data by Aubin has shown that this merger did not occur in Narragansett. For example, while Williams uses <e>, <ee>, and <ei> for /i:/, he only uses <e> and <i> for /i/; also, /o:/ is always written <o> or <oo>, while /o/ is spelled with <o>, <u>, or <a>.

Williams' representation of the low vowel *a: has raised some controversy as to its true phonetic nature. Some linguists believe that Proto-Algonquian *a: became nasalized in all environments. However, Williams uses <a>, <o>, <au>, <aw>, etc. to represent what has been reconstructed as [ã:]; only sometimes does he write a nasal consonant after the vowel. Linguists fall into at least three camps on this issue: those who believe Williams should be trusted for his transcriptions; those who believe he was just plain inconsistent; and those who believe that he was trying to be consistent but was constrained by English orthography, which can indicate vowel nasalization in some cases (<ramp> for [rãp]) but not in other instances (before [w], for example). (See also STILES.)

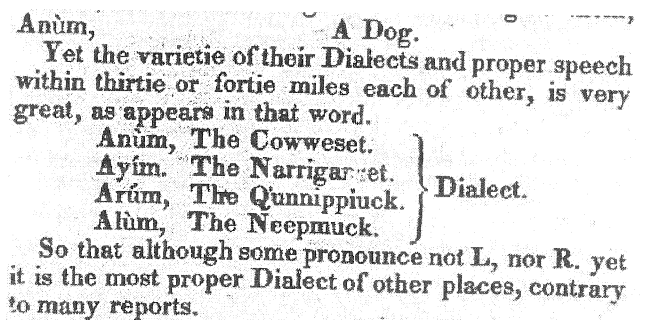


Fig. 20. Passage showing Williams' discussion of dialectal variance.

Mention should also be made of what Mary Haas had dubbed *Roger Williams's Sound Shift*. Proto-Algonquian *θ and

*l merged in Proto-Eastern Algonquian as *r, which in turn surfaced variously in the daughter languages as n, y, r, and l. In *A Key*, Williams gives a cognate set from four dialects for the word 'dog':

Thus, although he did not hit upon the idea of historical reconstruction, Williams is one of the earliest to recognize sound correspondences in related languages.

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WISE, CLAUDE MERTON (b. Memphis, MO, 21 Dec 1887, d. New Orleans, LA, 4 Jan 1966). *Educator, phonetician, dialectologist*.

C. M. Wise received his MA from the University of Chicago and his PhD from the University of Wisconsin. His early career included positions as a lower grades school teacher, principal of a high school, and superintendent of schools. He moved to college teaching at Louisiana State University and served as chair of the Department of Speech from 1928 to 1958. He continued his affiliation with LSU as an Emeritus Professor until 1966, the year of his death. He authored numerous articles in such journals as *Le Maître Phonétique*, *American Speech*, *The Quarterly Journal of Speech*, and *Speech Monographs* — all of which continued his contribution to the understanding and application of descriptive phonetics and the details of American English dialectology, especially the dialects of the speech of the Southeastern United States. He was also a publisher-author of short stories, a playwright, and the author of three books on dramatic art. Professor Wise was the editor of *The Quarterly Journal of Speech* (1936-1938); he helped found the Southern Speech Association, serving as its president in 1934-1935, and as the president of the Speech Association of America in 1942.

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ZIPF, GEORGE KINGSLEY (b. Freeport, IL, 7 Jan 1902, d. Massachusetts, 25 Sep 1950). *Comparative philologist*.

George Kingsley Zipf, a Harvard lecturer from 1929 till his death in 1950, spent his academic career arguing that much of human behavior, including language, was explained by an economy of effort: *the principle of least effort* (also known as the *principle of relative frequency* in his earlier work, or *Zipf's Law* posthumously). This principle correlates the complexity of a phenomenon (or the amount of effort needed to produce it) with the phenomenon's frequency of occurrence. Zipf demonstrated this principle to be in effect in many fields including literature (longer words occur less frequently than shorter words) and demographics (most people tend to live close to their place of birth). Zipf's contributions to phonetics and phonology include an attempt to quantify the articulatory complexity and perceptual saliency of phones/phonemes and an account of phonological change which conformed to his principle of least effort.

Zipf tried to quantify phones and phonemes with respect to their ease of articulation and their perceptual saliency (Zipf lumped both attributes under the cover term of *conspicuousness*).

With experimental phonetics unable to provide him with absolute numeric values for either of these attributes, Zipf placed phones/phonemes on a relative (subjective) scale of conspicuousness. Phones/phonemes having all but a few features (e.g. aspiration, voice, duration) in common could be compared. Then those comparable phones/phonemes were ranked based on the conspicuousness of their differing features. Hence, *t* was considered less conspicuous than a *d* or *tʰ* because in the first case *t* lacked voice (which Zipf saw as requiring more effort), and in the second case lacked aspiration (which Zipf considered more perceptually salient), but had all other features in common. He tentatively suggested other comparisons as well, such as diphthongs with their constituent monophthongs, *m* with *n*, and stops with homorganic fricatives. As evidence that these rankings were valid, Zipf gathered statistical data from lexicons, manuscripts, and other linguistic corpora from various languages and showed that, with few exceptions, more conspicuous phonemes were less frequent than the less conspicuous ones.

Zipf saw the phonological system as a balance between the conspicuousness of a phoneme and the frequency of its occurrence. Too many occurrences of a conspicuous phoneme would require too much effort on the part of the speaker and thus would begin to lenite or change into other less conspicuous

phonemes in certain phonetic/phonological environments. Too many occurrences of a very inconspicuous phoneme may burden the listener and thus would tend to fortify in certain environments. Hence the lexicon, morphology, pragmatics, and even syntax played a significant role in phonological change as each influenced the frequencies of a phoneme's occurrence.

Zipf's work was valuable for ushering statistical analysis into linguistics and for his efforts at trying to explain linguistic, including phonological, phenomena in extra-linguistic terms.

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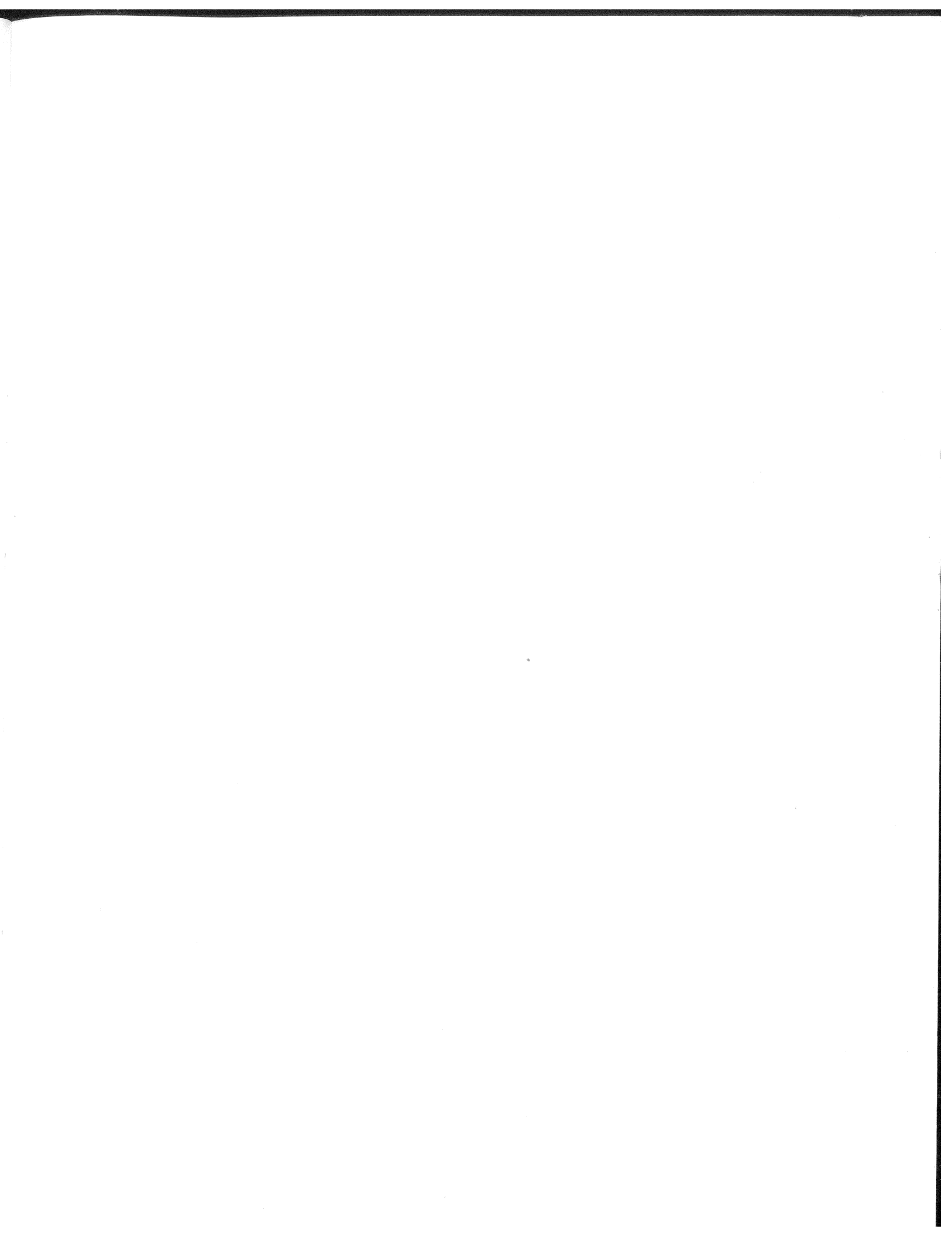
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Unquachogs, about 20, souls
 they constitute the Pussipáloch
 settlement in the town of Brookhaven
 S. side of Long island.

The language they speak is a
 dialect differing a little from
 the Indian settled near South
 ampton called Shinicocks &
 also from those of Montoch
 called Montoch. The three tribes
 can hardly understand each other

- cow, cowson
- horse, hofses
- sheep, sheppr.
- hog, hof,
- dog, arsum
- fox, squirmiter
- squirrel, moccás.
- rabbit, nich-tua
- deer, hátt
- bird, a-ássas.
- crow, concónkus.
- gull, arrix
- goose, hátiénok
- eagle, wequaran.
- duck, naqás-cus.
- dove, ma-owks.
- fish hawk, manamaquas.
- quail, ohócotees
- partridge, apacus
- chippewill, whacorees.
- snake, skuk
- bug, feuker
- worm, húgler
- fly, mucháwas.
- musketo, murráquitck
- tree, péewye.
- pine, cw
- oak, híchemus

- wheel, marooman
- bread, ap.
- ye, nye
- oats, oati.
- tobacco, tobac.
- homing, samp.
- meat, weéows.
- stone, sun.
- clay, (pickwe
- (squorok
- sand yaac
- water, núp
- dirt, pickwe
- the world, ^{small} weámapamakú.
- sky, ke-isk
- cloud, pamayauxen
- rain, sükemur
- snow, soachpro
- ice, copátn
- hoil, mosécar
- sun, háquagua
- moon, neépa.
- star, aragusac
- fire, rukht, yukt.
- whale oil, púttapapúm.
- greese, pum.
- púttap, sheli.
- fish, opéramac
- oyster, apóonahac.
- clam, poquehoe.
- a man, run.
- woman, squah.
- child, peewitstut
- boy, maciwhaz.
- lad, runqumy.
- girl, squasset.
- lads, yunksquas.
- head, ohéyunnuc.
- hair, wé-usk
- eyes, shasuc.
- nose, coohoy
- mouth, itts