COGNITIVE THEORY

Volume 1

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PREFACE

This book contains the content of the Indiana Conference of 1974. This Conference has met for each of the last seven years. At one time it was known as the "Midwestern Mathematical Psychology Meeting," but as interest drifted toward more experimental and theoretical, but less purely mathematical work, the title became the "Indiana Theoretical and Cognitive Psychology Meetings." Finally, this year the Conference was called the "Indiana Cognitive/Mathematical Psychology Conference."

The Conference has always been fairly small, rarely having over 100 people in an audience, but has one of the most sophisticated and interested audiences in the world. Speakers have come to expect penetrating questions and discussion. While we have not tried to include transcripts of these discussions in the book, the authors of chapters have been able to incorporate relevant ideas from the discussions into their chapters.

The contributors to this Conference were requested to emphasize the relatively broad theoretical significance of their work, to incorporate the work of others, and if they were willing, to speculate about future developments. Each of the chapters of this book has these characteristics of breadth and theory, rather than the mere report of new experiments. A number of the authors are relatively young, and that reflects the long-standing policy of the Conference to try to bring forth new ideas that might otherwise remain hidden for several years.

We, the editors, took the main responsibility for choosing the speakers, and acted as hosts for the Conference. Our role as editors has been most enjoyable, primarily because of the quality of the participants. We should like to express our appreciation to the Mathematical Social Science Board at the Center for Advanced Study in the Social Sciences for support of portions of the Conference in 1973 and 1974. We also wish to thank Ramona Swaine, Jam Waltz, and Karlene Ball for their secretarial and editorial aid and for helping to coordinate the efforts of all involved in assembling the book. Finally we would like to thank Lawrence Erlbaum for all his assistance.

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PART I

CONTEMPORARY ISSUES IN SPEECH PERCEPTION

David B. Pisoni

The study of speech perception is a rich and complex interdisciplinary field involving workers from psychology, linguistics, and speech science. Central to much of the current research in this area is the assumption that speech perception includes specialized processes and mechanisms that are not employed in the perception of other auditory stimuli. We can cite at least four reasons why this assumption seems to be true. First, the acoustic properties of speech sounds are much more complex than the stimuli typically used to study the functioning of the peripheral auditory system. As a consequence, the acoustic parameters important for distinguishing different classes of speech sounds (i.e., phonemes) are usually found in complex changes in the fine structure or spectrum of the signal. In addition, most investigators who study speech percetion are ultimately concerned with the way in which acoustic–phonetic information maps into the more general linguistic system the observer.

A second reason involves the unique characteristics of speech sounds as acoustic stimuli in the environment. Speech sounds are distinct from other acoustic stimuli because they are produced by a sound source that has well-known acoustic constraints for the listener. Research over the last few years has shown very close correspondences between changes in vocal tract shape and characteristics of the acoustic output. Indeed, a quick persual of the literature reveals that many of the descriptive categories used in speech perception and acoustic phonetics have been carried over from the traditional articulatory categories developed by phoneticians. As we shall see, a good deal of recent theoretical work has been directed toward the hypothesized link between speech perception and production.

The third reason why speech perception may be different from the perception of other auditory stimuli is that both speech perception and production appear to be mediated by processes that are lateralized in one cerebral hemisphere—usually the left. This suggests that distinct physiological mechanisms may underlie both speech perception and production. It also points to the possible existence of specialized neural structures for speech perception. Although research on the potential role of feature detectors in speech perception is only in the earliest stages, a sizable body of empirical data has already been obtained on some of the characteristics of these detectors.

The fourth reason deals with two related problems for speech perception theory: invariance and segmentation. One of the earliest observations that emerged about speech sounds was the lack of invariance between units in the acoustic signal and units of linguistic analysis. Examination of sound spectrograms showed that, in general, there were no segments in the speech signal that corresponded uniquely to segments in the message. The earliest perceptual experiments with synthetic speech stimuli at Haskins Laboratories showed that a single segment of the acoustic signal carried information about several successive segments. Thus, phonemes were not concatenated successively like the letters of the alphabet or beads on a string, but were represented by merged and overlapping parts of the acoustic signal. These initial findings have led investigators to suspect that there is something peculiar about speech and the processes involved in its perception—there is an intricate and complex restructuring of the linguistic message in terms of the acoustic signal.

We should point out that much of the theoretical work in speech perception has not been very well developed by the standards applied to other areas of experimental psychology, and the link between data and theory has often been quite weak. This situation probably arose because of the relatively few researchers in the field and the enormous difficulty in conducting experiments that almost inevitably require the use of synthetically produced speech stimuli. Fortunately, this state of affairs is changing quite rapidly. Judging by the increased number of publications that deal with speech perception in the major psychological journals, the area is now a well-integrated and accepted domain of study in modern experimental psychology. More and more cognitive psychologists have turned their interests to speech perception primarily because this is the earliest and most accessible stage of linguistic processing. Furthermore, in recent years it has be-come far easier to obtain very high quality synthetically produced speech stimuli for experimental purposes.

The focus of the four chapters in this part is on contemporary issues in speech perception. Each chapter deals with a somewhat different area of research in order to present a comprehensive picture of the types of questions that are currently under investigation and some of the problems to be considered in the immediate future. Although each chapter contains some background and review material, the emphasis for the most part in these contributions is on very recent empirical work or theoretical formulations.

The chapter by Michael Studdert-Kennedy is the most general and deals with the nature and function of phonetic categories. The main point here is that the sound categories (i.e., phonetic structure) of language are not arbitrary but bear a necessary relation to both the vocal apparatus which produces these sounds and the phonological structure onto which they are mapped. Studdert-Kennedy deals with a number of important issues in speech perception including categorical perception, auditory short-term memory, and various types of perceptual units. He concludes the chapter by considering how a young child might develop the knowledge of phonetic categories. In the course of this, a new version of the motor theory of speech perception is proposed which deals with the acquisition and development of speech perception.

The second chapter is by William E. Cooper, who presents a very comprehensive picture of recent work using selective adaptation procedures to study the possible existence of feature detectors in speech perception. The main focus of this chapter is first on describing the methodology used in the early adaptation experiments and then on detailing the particular locus of the adaptation effects. In the first part of the chapter, Cooper deals with perceptual adaptation in an attempt to map out some of the stages of processing involved in decoding speech sounds. Much of this research is quite recent and should be new to most readers although it has been circulating through the underground speech perception community since early 1974. The second part of the chapter is concerned with perceptuomotor adaptation, which has provided a novel way of examining the question of whether speech perception and production interact during early stages of perceptual processing. The work reported by Cooper in this section is perhaps the first time that direct evidence has been found in support of such an interaction between perception and production.

In the third chapter, Charles C. Wood presents a model for redundancy gains in speech discrimination. The emphasis in this chapter is on the organization of auditory and phonetic stages of processing in speech perception. Wood deals with the issue of serial versus parallel processing of auditory and phonetic information and their possible interaction. This chapter represents an important advance in speech perception work because of its quantitative treatment of this problem. Moreover, it brings research in speech perception somewhat closer to other more traditional areas of research in human information processing.

The final chapter, by David B. Pisoni, deals with dichotic listening. Work in this area has increased quite dramatically within the last few years primarily because it provides a simple way to study the speech perception system under stress. In this chapter, Pisoni is concerned with the types of interactions that occur between dichotic speech inputs. The right ear advantage is touched upon briefly at various times. In the first section, two types of dichotic interactions are considered: the feature sharing advantage and the lag effect. Both types of interactions appear to occur at different levels of perceptual processing. Results of several recent dichotic recognition masking experiments which focused on these interactions are presented. A rough model of the stages of processing in speech perception is proposed for these results. The model involves several stages where dichotic inputs can interact. Pisoni argues that the feature-sharing advantage in dichotic listening results after phonetic analysis when redundant phonetic features are maintained in a feature buffer. On the other hand, the lag effect is assumed to occur when the auditory features in both dichotic inputs interact before phonetic analysis. The model also can account for the various types of phonetic feature errors that occur in dichotic listening experiments.

1

THE NATURE AND FUNCTION OF PHONETIC CATEGORIES

Michael Studdert-Kennedy
Haskins Laboratories

Speech perception differs from general auditory perception in both stimulus and percept. Acoustically, the sounds of speech constitute a distinctive class, drawn from the set of sounds that can be produced by the human vocal mechanism. Perceptually, they form a set of "natural categories," similar to those described by Rosch (1973). The point is well made in a study by House, Stevens, Sandel, and Arnold (1962). They constructed several ensembles of sounds along an acoustic continuum from clearly nonspeech to clearly speech, and asked subjects to associate the sounds with buttons on a response panel. The time taken to learn these associations was least for the speech ensemble, and did not decrease with the acoustic approximation of the ensembles to speech. Among the reasons for this was presumably that subjects already possessed for speech, but not for nonspeech, a well-learned code into which they could transform the acoustic signals for storage and recall.

The term used by linguists to describe this code is "phonetic," a term derived from the Greek word for "sound." However, although phonetic events clearly have auditory correlates, no one has yet succeeded in describing them. On the contrary, phonetic description is almost invariably couched in articulatory terms, and the "phonetic transcription" of an utterance is generally agreed to be a sequence of shorthand instructions, not for hearing, but for speaking. The peculiarity of speech perception, then, is that it entails the rapid, automatic transformation of a distinctive sensory input into a distinctive nonsensory code.

Furthermore, the input bears a necessary, rather than an arbitrary, relation to the code. This is not true of the visual counterparts of phonetic entities. The forms of the alphabet are arbitrary, and we are not concerned that the same visual symbol, ω stands for [w] in the English alphabet, for [o] in the Greek. Alphabets, of course, are secondary, while the speech signal is primary, its acoustic pattern at once the natural realization of phonological system and the necessary source of phonetic percept. Among the goals of current research are to define the phonetic percept and to explore the mechanisms by which it is derived from the acoustic signal.

THE FUNCTION OF PHONETIC CATEGORIES

Every language has a dual hierarchical structure. At its base are a few dozen phonetic segments—or even fewer phonetic features—from which higher-order syntactic and semantic structures are formed. From a linguistic point of view, the function of segmental phonetic categories is to serve as the finite set of commutable elements of which language will make infinite use. However, if this were their only function, there would be no grounds for the universal linguistic division of segmental phonetic categories into consonants and vowels. But, in fact, every language makes a double demand on its elements: to convey a segmental message and to convey a suprasegmental, or prosodic, message. From this opposition there emerges the syllable. All languages are syllabic, and all languages constrain syllabic structure in terms of consonants and vowels, assigning the bulk of the segmental phonetic load to consonants, the prosodic load to vowels.

To fulfill linguistic function, a general perceptual process is invoked, namely, division into "stages." Among the functions of "perceptual stages"—whether defined in time or in neural locus—seem to be to isolate one process from another, and to store energy or information for later use. We may see this most clearly at the periphery. Every sensory system integrates energy: if the system were infinitely damped, threshold for activation would never be reached. Accumulation of energy over some finite period permits the mechanical response of the ear, for example, to develop. On the other hand, the period of integration must be finite to prevent physical destruction of the system: mechanical energy is therefore transduced into bioelectricity. Analogous cycles of integration and transformation presumably recur, as energy progresses through the system. Activity in afferent fibers gives rise to more central neural activity and, ultimately (jumping levels of discourse), to a preperceptual "image" (Massaro, 1972). The "image," in turn, must have some finite duration, long enough to institute further processing, short enough to prevent "babble."

Returning with this metaphor to language, we note that speech is arrayed in time, and that both syntax and meaning demand some minimum quantity of information before linguistic structure can emerge. The perceptual function of phonetic categories is then, on the one hand, to forestall auditory babble, on the other, to store information derived from the signal until such time as it can be granted a linguistic interpretation. In other words, the perceptual function of phonetic categories is that of a buffer between signal and message.

However, there are two forms of linguistic information to be conveyed, each with its characteristic temporal density: rapidly changing segmental features, and more slowly changing prosodic features. Accordingly, two forms of storage are required. For the vowels, to which both segmental and prosodic functions are assigned, both a relatively long-term auditory store and a rapidly accessed phonetic store. For the consonants, only the latter. The operation of both these stores has been repeatedly demonstrated in a variety of experimental paradigms.

CATEGORICAL PERCEPTION

The distinction between auditory and phonetic processes in speech perception is an old one (see, for example, Fry, 1956). But only recently have students discovered its theoretical worth. Among the leaders in this were Fujisaki and Kawashima (1969, 1970), who applied the distinction to the analysis of what has been termed "categorical perception." Let us begin with a description of the phenomenon.

Study of sound spectrograms reveals that portions of the acoustic patterns for related phonetic segments often lie along an apparent acoustic continuum. For example, center frequencies of the first two or three formants[1] of the front vowels, [i, ɪ, ɛ, æ], form a monotonic series; syllable-initial voiced–voiceless pairs, [b, p], [d, t], [k, g], differ systematically in voice onset time; voiced stops, [b, d, g], before a particular vowel, differ primarily in the extent and direction of their formant transitions.

To establish the perceptual function of such variations speech synthesis is used. Figure 1 is a sketch of a schematic spectrogram of a synthetic series in which changes of slope in second formant transition effect perceptual changes from [b] through [d] to [g]. Asked to identify the dozen or so sounds along such a continuum, listeners divide them into distinct categories. For example, a listener might consistently identify stimuli —6

[1] A formant is a resonance of the vocal tract, or its acoustic correlate: a concentration of energy in a limited band of the frequency spectrum. The relative positions of formants on the frequency scale are important acoustic cues in the perception of speech.