Published in final edited form as:
J Acoust Soc Am. 1974 February ; 55(2): 328–333.

Categorical and noncategorical modes of speech perception along the voicing continuum*

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Abstract

Native speakers of English identified and then discriminated between stimuli which varied in voice onset time (VOT). One group of listeners identified a randomized sequence of stimuli; another group identified an ordered sequence of stimuli, in which stimuli from the VOT continuum were presented in a consecutive order. Half of the *Ss* in each group then received one of two discrimination formats: the ABX discrimination test in which X was identified with A or with B, or 4IAX test of paired similarity in which two pairs of stimuli—one pair always the same and one pair always different—were presented on each trial. Noncategorical perception of the voicing distinction, reflected by an improvement in discrimination within phonetic categories, was obtained for the group of listeners who experienced both the sequential identification procedure and the 4IAX discrimination test. The results are interpreted as providing evidence for separate auditory and phonetic levels of discrimination in speech perception.

INTRODUCTION

Voice onset time (VOT)—the time interval between the release from stop closure and the onset of laryngeal pulsing in the following vowel—has been shown to be a sufficient dimension for distinguishing between voiced and voiceless stop consonants in many different languages (Lisker and Abramson, 1964; Abramson and Lisker, 1965; Lisker and Abramson, 1967). For example, in English, when a stop consonant in initial position is voiced, voicing onset coincides with or briefly lags behind the closure release. If the stop is voiceless, the onset of voicing lags behind the release by 40 msec or more.

The voicing feature has been shown to have several interesting perceptual properties. Early studies employing synthetic speech sounds indicated that the voiced-voiceless distinction is perceived in a categorical mode. That is to say, the listener responds to the speech sound as if he set perceptual boundaries around the range of sounds that will be identified as a single phonetic segment.

In one study, Liberman and his colleagues at Haskins Laboratories found that synthetic speech stimuli which varied in acoustically equal steps through the range sufficient to produce the initial stop consonants /d/ and /t/ were perceived as members of discrete categories (Liberman, Harris, Kinney, and Lane, 1961). When listeners heard adjacent pairs of these stimuli in an ABX discrimination test, they were able to discriminate between stimuli drawn from different phonetic categories, but could not discriminate between stimuli drawn from within the same phonetic category, even though the acoustic differences were comparable in the two cases.

*An earlier report of these findings was presented at the 84th meeting of the Acoustical Society of America, Miami Beach, Fla., 1972.

Categorical perception is an unusual result to obtain in psychophysical experiments with nonspeech sounds (Liberman, 1970). Stimuli that vary along physical continua, such as frequency or intensity, ordinarily are perceived in a continuous mode; that is, the discrimination functions are usually monotonic with the physical scale, and the listeners can discriminate many more stimuli than they can reliably identify in absolute terms (Pollack, 1952, 1953).

The distinction between categorical and continuous modes of perception has played an important role in theoretical discussions of speech perception. Several investigators have been led to propose that the perception of speech may involve specialized perceptual processes that are basically different from the process involved in the perception of auditory stimuli unlike speech (Liberman, 1970; Liberman, Cooper, Shankweiler, and Studdert-Kennedy, 1967; Stevens and House, 1972). When listeners are exposed to certain classes of speech sounds their ability to identify and discriminate between them on an auditory basis is somehow constrained. Listeners do not perceive these stimuli as isolated acoustic events but rather respond to them with reference to their linguistic knowledge (Studdert-Kennedy, 1973).

The phenomenon of categorical perception and several of the arguments for some type of “special” perceptual processing for speech sounds have recently taken on added significance in light of findings reported by Eimas and his associates on speech perception in young infants (Eimas, Siqueland, Jusczyk, and Vigorito, 1971). They found that infants respond in a “linguistically relevant manner” to synthetic speech stimuli that vary along the voicing continuum. Their infants showed a form of categorical perception comparable to that found with adults. They could not discriminate between stimuli selected from within the same (putative) phonetic category, but they could discriminate between stimuli selected from different phonetic categories (see also Stevens and Klatt, 1971). Eimas *et al.* suggest that the mechanisms underlying categorical perception are not only operative at a very early age, but also may be a part of the “biological makeup of the organism.” Additional findings with adults (Eimas and Corbit, 1973; Eimas, Cooper, and Corbit, 1973) suggest the existence of specialized complex linguistic- phonetic feature detectors which have characteristics similar to those found in vision (Blakesmore and Cambell, 1969; Blakesmore and Sutton, 1969).

We concur with the view that speech perception may entail specialized mechanisms for perceptual processing and that these may have deep biological roots. However, we also feel that it is equally important to clarify the status of speech perception as a “special” process and to define its relation to other types of perceptual processes.

In the present study, we sought to determine whether the categorical perception for voicing is a unique phenomenon, or whether it might be dependent upon the particular set of experimental procedures employed in previous studies. Categorical-like perception of vowels, at least, is dependent on the experimental procedures used in past studies. Vowels tend to be perceived categorically if they are short in duration or in the context of a steady-state reference vowel, or noncategorically if they are long in duration or presented in isolation (Fujisaki and Kawashima, 1970; Pisoni, 1971, 1973).

Specifically, the present experiment is concerned with the following question: Can the same stimuli be perceived in either a categorical or a noncategorical mode ? To answer this question, discrimination functions were obtained under several experimental conditions, using as stimuli a set of synthetic syllables which ranged along the voicing continuum from /ba/ through /pa/. Our main goal was to attempt to direct *Ss* toward phonetic coding on the one hand or the detection of stimulus differences on the other hand. Procedural differences were introduced which aimed to emphasize either a categorical (i. e., phonetic) or a continuous (i. e., auditory) mode of processing for these speech sounds.

I. METHOD

A. Stimuli

The stimuli were generated by the parallel-resonance speech synthesizer at Haskins Laboratories. The basic set of stimuli consisted of seven syllables with onsets resembling bilabial stop consonant releases and vocalic nuclei. In each case the final 250 msec was a steady-state formant pattern (F_1 = 770 Hz, F_2= 1230 Hz, F_3 = 2525 Hz) appropriate for American English /a/, and the initial 50 msec was characterized by formant loci and transitions appropriate for generating bilabial stops. The seven stimuli differed in VOT, varying from zero VOT through + 60-msec VOT in 10-msec intervals. For each successive stimulus in the set, the amplitude of F_1 was reduced (i.e., "cutback") and the excitation source was switched from buzz to hiss. The values of the synthesizer control parameters were similar to those employed by Lisker and Abramsom (1967).

B. Experimental material

All of the stimuli were digitized and their waveforms were stored on the Pulse Code Modulation System at Haskins Laboratories (Cooper and Mattingly, 1969). The seven stimuli were recorded on magnetic tape and manipulated under computer control to produce four different types of test materials, two identification and two discrimination tests.

Each 70-item identification test consisted of ten replications of each of the seven basic stimuli. One test was prepared with the stimuli arranged in a random order (Random Condition); the other test had the stimuli arranged in a nominal sequential order from /ba/ through /pa/ based on VOT (Sequential Condition). There was a 3-sec interval between stimuli for the Random Condition and a 2- sec interval for the Sequential Condition.

In the discrimination test the stimuli were arranged in triads for ABX presentation, where A and B are different stimuli and X is either A or B. In the other discrimination test, the stimuli were arranged in two pairs for 4IAX presentation, where one pair, A-A, is always the same, and the other pair, A-X is always different. Both discrimination tests used differences that were one step and two steps apart (i. e., differed by 10 or 20 msec) on the VOT continuum used in the study. All possible arrangements of stimuli were used in constructing the triads and pairs in the discrimination tests. Three different random arrangements were prepared for each type of discrimination test.

C. Procedure

The tests were combined to form four experimental conditions, each consisting of an identification test followed by a discrimination test. Seven listeners were assigned to each of the four conditions; listening was an hour a day on three separate days. The order of discrimination tests were counterbalanced appropriately over days and groups.

The experimental tapes were reproduced on a high-quality two-track tape recorder/reproducer (Ampex AG-500) and were presented diotically through matched and calibrated headphones (TDH-39). The gain of the tape recorder was adjusted to give a voltage across the earphones equivalent to 70 dB/SPL for a 1.0-kHz calibration tone. Levels were checked with a VTVM (Hewlett Packard model 400) before the presentation of each experimental tape. *Ss* were tested in groups in a small experimental room; responses were recorded in prepared booklets containing IBM forms for later analyses.

Instructions for the Random Condition were identical to those used in previous speech perception experiments. The stimuli were presented in a random order and *Ss* were required to identify each stimulus as either a /ba/ or a /pa/. In the Sequential Condition, the stimuli were presented in order from 0 VOT through + 60 VOT and *Ss* were told to listen very carefully to the difference between each successive stimulus in the continuum and to try To determine how each stimulus differed from the preceding one. *Ss* were not told to categorize or identify the stimuli.

This procedural contrast in the identification task was designed to produce the expectation of more nearly categorical responding to stimuli in the Random presentation condition and the expectation of more nearly continuous responding to stimulus differences in the Sequential presentation condition. We assumed that labeling the stimuli when presented randomly would force *Ss* to ignore acoustic differences, thus emphasizing phonetic similarity in the subsequent discrimination task. On the other hand, instructions to attend to stimulus differences under Successive presentation were aimed at encouraging *Ss* to focus on the acoustic differences between stimuli in discrimination.

In the ABX discrimination test, *Ss* reported whether the third stimulus was most like the first or most like the second. In the 4IAX discrimination test, *Ss* reported which pair of stimuli was the same, the first pair or the second pair. This procedural contrast was designed to facilitate a more nearly categorical mode of discrimination in the ABX test and a more nearly continuous mode of discrimination in the 4IAX test. We assumed that the ABX test is less sensitive to acoustic differences among stimuli than the 4IAX test since the *S* must respond to the absolute differences between two stimuli. In contrast, with the 4IAX procedure, the *S* can base his decision on a pairwise comparison and thus can respond to the magnitude of differences between pairs of stimuli (see Pisoni, 1971).

D. Subjects

The listeners were 28 undergraduate students at Indiana University who were fulfilling a course requirement. All were right-handed native speakers of English and reported no history of a hearing or speech disorder. No *S* heard any synthetic speech before the present experiment.

II. RESULTS

A. Absolute identification

The average identification functions for the two Random Identification conditions are shown in Fig. 1. Each panel represents the later discrimination test. With only two response categories, the functions within each panel are complementary.

Categorical partitioning of the stimulus continuum may be said to have been obtained for both groups of *Ss*: the shift from one response category to another is reasonably abrupt. The phonetic boundary, or crossover point, is obtained at about +30-msec VOT for each group. These findings are in close agreement with those previously reported by other investigators (Liberman, Harris, Kinney, and Lane, 1961; Lisker and Abramson, 1967).

B. Discrimination

The average one- and two-step discrimination functions for the two Random ID conditions are shown in Fig. 2. Discrimination with the standard ABX test is shown in the left panel while discrimination with the 4IAX test of paired-similarity is shown in the right panel. The abscissa represents the value of VOT in msec.

Each of the seven *Ss* in each group provided 48 judgments for a given stimulus comparison along the VOT continuum. The dashed lines represent predicted discrimination functions. They were derived from the identification functions under the strong assumption that *S* categorized each of the stimuli in the discrimination test, and bases his discrimination response upon the outcome of the labeling. These functions were obtained using the procedure originally developed by investigators at Haskins Laboratories (see Liberman, Harris, Hoffman, and Griffith, 1957; Studdert-Kennedy, Liberman, Harris, and Cooper, 1970 Pollack and Pisoni, 1971).

Discrimination performance shows a peak close to the phonetic boundary at 30-msec VOT, and a trough within phonetic categories at the extremes of the continuum. The obtained one- and two-step functions for both ABX and 4IAX tests are consistently better than the predicted discrimination functions, although the form of the obtained and predicted functions do match each other reasonably well. The operational definition of "pure" categorical perception would be an exact matching of the obtained and predicted discrimination functions. These data show somewhat less categorical perception than earlier studies. The discrepancy is slightly greater for the 4IAX test than the ABX test, but only for the two-step comparisons. The difference between the obtained and predicted two-step discrimination scores is significantly larger for the 4IAX test than the ABX test, $t(8) = 2.54$, $p < 0.05$. This finding suggests that even with initial Random Identification the desired procedural contrast within discrimination was manifested, although weakly.

The corresponding ABX and 4IAX discrimination functions for the Sequential ID conditions are shown in Fig. 3. The obtained discrimination functions from Fig. 2 which were secured under Random ID have been replotted for comparison. Since *Ss* did not partition the stimuli into phonetic categories in the Sequential Identification condition predicted discrimination functions were not derived.

Examination of this figure reveals several interesting findings. First, the one- and two-step discrimination functions for the 4IAX test are somewhat flatter than the corresponding functions obtained with the ABX test. Second, the 4IAX functions reveal higher levels of discrimination performance, particularly in the two-step case. The 4IAX discrimination test shows a less categorical mode of discrimination in the sense that listeners can discriminate within category differences much better than would be expected if they based their discrimination decision on only absolute identification.

C. Statistical analysis

A three-factor analysis of variance was performed separately for the one- and two-step discrimination scores. The three main effects under consideration in each analysis were: Identification Condition (Random vs Sequential), Discrimination Test (ABX vs 4IAX) and Stimulus Comparison along the continuum. There were six stimulus comparisons for the one-step discrimination data and five stimulus comparisons for the two- step data.

The analysis of variance of the one-step scores indicated that only the Stimulus Comparison variable reached significance, $F_{(5,120)} = 26.45$, $p < 0.01$. The other main effects and all of the higher-order interactions failed to reach significance.

The results of the analysis of the two-step discrimination scores showed a large and significant difference between the two discrimination tests, $F_{(1,24)} = 8.87$, $p < 0.01$. Regardless of the type of identification condition, discrimination performance is better with the 4IAX test than with the ABX test. The main effect for Identification Condition not only failed to reach significance in this analysis but did not interact with the type of discrimination test. As in the one-step analysis, the Stimulus Comparison variable also produced a significant effect, $F_{(4,96)} = 55.41$, $p < 0.001$.

Two of the higher-order interactions reached significance. First, the Discrimination Test-by-Stimulus Comparison interaction was significant, $F_{(4,96)} = 4.48$, $p < 0.005$, indicating that the 4IAX test produces a larger advantage in discrimination at some points along the stimulus continuum than others. Inspection of Fig. 3 indicates that "within" phonetic category comparisons benefit more from the 4IAX test procedure than across category boundary comparisons relative to the ABX performance.

The triple-order interaction of Identification Condition × Discrimination Test × Stimulus Comparison was also significant $F_{(4,96)} = 5.14$, $p < 0.001$. This result implies that the identification will only have a differential effect upon one type of discrimination performance, and then only for some parts of the stimulus continuum rather than others. Inspection of Fig. 3 (right panel) shows that the Sequential Identification test improves discrimination in the 4IAX test more for the "within" category comparisons than for the between category comparisons. Thus, these procedures only benefit stimulus comparisons presumably based on auditory information rather than those based on phonetic information (i. e., the across category comparisons). It is assumed that if an *S* discriminates between two stimuli selected from within a phonetic category, the decision must be based on auditory information. Similarly, if an *S* discriminates between two stimuli selected from across a phonetic boundary, the decision is based on phonetic information (see Fujisaki and Kawashima, 1970; Pisoni, 1971, 1973).

To insure that the findings obtained with the 4IAX test were reliable and not due to possible subject selection factors, an additional group of six *Ss* were run in the Sequential Identification—4IAX discrimination condition. The results of this replication experiment are shown in Fig. 4.

Substantial improvement in discrimination performance within phonetic categories is again obtained when the Sequential Identification Condition is combined with the 4IAX discrimination test. The shape and relative level of the discrimination scores is more nearly "continuous" than "categorical" suggesting that with relatively simple manipulations of the experimental procedures *Ss can* discriminate between stimuli selected from within a phonetic category.

III. DISCUSSION

The results of the present study on the discrimination of voice onset time are relevant to several previous findings dealing with perception of speech and non-speech sounds. In a study by Cross and Lane (1964) the /do/ to /to/ stimuli from Liberman *et al.*, (1961) were presented to listeners for ABX discrimination under two conditions: speech instructions and nonspeech instructions. Listeners who received the speech instructions were told that the experiment was concerned with the discrimination of speech sounds and that they would hear synthetic approximations of the syllables /do/ and /to/. Listeners in the nonspeech group were told only that the experiment was concerned with tone discrimination. The discrimination functions obtained under speech instructions were nearly categorical and comparable to those found in the present study with the ABX test. There was a peak at the phonetic boundary between /do/ and /to/ and a trough within phonetic categories. In contrast, the discrimination functions obtained under nonspeech instructions were so close to chance performance as to suggest that *Ss* were essentially responding in a random manner under nonspeech instructions. In other words, the listeners could find no *acoustic* basis for discrimination of these stimuli even though they were identical to those used in the speech instructions condition.

The Cross and Lane (1964) results may be contrasted with the discrimination functions obtained in the present study under the 4IAX test procedure shown in Fig. 3. Performance is above chance for both the one- and two-step functions. This result suggests that *acoustic* information must have been available for the decision process. Additional support for this argument may be obtained by comparing the level of within-category discrimination under the ABX test with the 4IAX test as shown in Fig. 3. Although the peaks in the functions at +30-msec VOT are comparable in both cases, the level of performance within categories is very different for the two discrimination procedures. Discrimination performance is higher with the 4IAX test than the ABX This would support the notion that *Ss* can discriminate the acoustic cues that underlie the voicing feature in a more nearly continuous, nonphonetic or auditory mode of perception.

One additional finding should be considered since it is relevant to results recently reported by Eimas on the categorical-like perception of the voicing feature in young infants (Eimas *et al.*, 1971). In a recent paper Stevens and Klatt (1971) proposed an auditory basis for the finding that infants cannot discriminate different stimuli selected from within the same phonetic category, but can discriminate the presence of the same physical difference when the stimuli were selected from across phonetic categories. According to Stevens and Klatt (1971), the infants may have responded to the presence *or* absence of the F_1 transition after the onset of voicing. They suggest that:

> the auditory system provides one kind of response when there is a significant transition in F_1 after onset of voicing, thereby creating a rapid spectrum change or transient, and another kind of response when there is no such transient. Stimuli that differ in this property yield different responses; if both members of a pair of stimuli have either one property or the other, they are identified as being the same. (p. 196)

It is possible that a rapid change in the spectrum or transient in F_1 could serve as the primary acoustic cue underlying the categorical discrimination observed with the infants in the Eimas experiments. However, we should note that the earlier identification and discrimination study by Liberman *et al.* (1961) did not employ variations in the F_1 transition with the /do/ – /to/ stimuli. The only stimulus variable that cued the voicing feature was the delay in the onset of the first formant relative to the second and third formants, the well-known “cutback” cue.

The F_1 transition cue to *voicing* may be one of the acoustic cues employed in discrimination by the adult listeners in the present study. For example, inspection of the two-step data in Figs. 3 and 4 reveals that discrimination with the 4IAX test is somewhat better in the /ba/ range of the stimulus continuum where the voicing lag is relatively short (i. e., 0–20-msec comparison) than in the /pa/ range where the voicing lag is much longer (i.e., 40–60-msec comparison). This asymmetry is also shown although less strongly in the one-step discrimination functions. Since the stimuli employed in this study had 50-msec formant transitions into the following vowel, we might expect discrimination of stimuli with shorter lags to be somewhat better than those with longer lags. *Ss* may base their decision on the duration and onset frequency of the F_1 transitions and the relative onset of F_1 for stimulus comparisons involving short voicing lags; whereas *Ss* may be responding only to the absolute duration of VOT for comparisons of longer voicing lags. Comparable asymmetries in discrimination along the voicing continuum have also been reported recently by Glanzman and Pisoni (1973) and Eimas *et al.* (1973) who used similar stimuli but somewhat different experimental procedures.

To summarize, speech stimuli which have previously been shown to be perceived in a nearly categorical mode can also be perceived in a more nearly continuous mode with relatively simple manipulations of the experimental procedures. These findings suggest two main conclusions. First, speech sounds varying in the voicing feature may be processed on either an auditory or phonetic basis. However, the degree to which auditory or phonetic information can be used in discrimination will depend to a large extent on the type of information-processing demands of the discrimination test facing the listener. We suggest that the 4IAX discrimination procedure employed in the present study provides listeners with access to auditory information which is obscured by the traditional ABX procedure. Differences in discrimination may be due to the relatively greater demands placed on short-term memory in the ABX procedure which requires that *Ss* respond to the absolute rather than comparative differences between stimuli. Thus, listeners may be forced to rely on a phonetic rather than auditory coding in order to respond in the ABX discrimination test.

The results of this study also indicate that categorical and continuous modes of speech sound perception may *not* be completely dichotomous. Rather, these two modes of responding to speech stimuli may represent processing of information at two, among many, levels of perceptual analysis for speech sounds.

Acknowledgments

This research was supported in part by a PHS Bio-Medical Sciences grant (S05 RR 7031) to Indiana University and in part by NIMH research grant MH-24027 to the first author. We are grateful to Dr. Franklin S. Cooper for making the unique facilities of Haskins Laboratories available to us for the preparation of stimulus materials used in this study and to A. S. House, M. Studdert-Kennedy, and I. Pollack for comments and suggestions on the manuscript.

References

Abramson, AS.; Lisker, L. Voice Onset Time in Stop Consonants: Acoustic Analysis and Synthesis. Proc. 5th Intl. Cong. Acoust; 1965.

Blakesmore C, Campbell FW. On the Existence of Neurons in the Human Visual System Selectively Sensitive to the Orientation and Size of Retinal Images. J Physiol. 1969; 203:237. [PubMed: 5821879]

Blakesmore C, Sutton P. Size Adaptation: A New Aftereffect. Science. 1969; 166:245. [PubMed: 5809598]

Cooper FS, Mattingly IG. Computer-Controlled PCM System for Investigation of Dichotic Speech Perception. Status Report on Speech Research, Haskins Labs. 1969; SR-17/18:17.

Cross, DV.; Lane, HL. Progress Report No 6 Behavior Analysis Lab. Univ. Mich; 1964. An Analysis of the Relations Between Identification and Discrimination Functions for Speech and Non-Speech Continua.

Eimas PD, Corbit JD. Selective Adaptation of Linguistic Feature Detectors. Cog Psychol. 1973; 4:99.

Eimas PD, Cooper WE, Corbit JD. Some Properties of Linguistic Feature Detectors. Percep Psychophys. 1973; 13:247.

Eimas PD, Siqueland ER, Jusczyk P, Vigorito J. Speech Perception in Infants. Science. 1971; 171:303. [PubMed: 5538846]

Fujisaki, H.; Kawashima, T. Annual Report of the Engineering. Vol. 29. Research Institute Faculty of Engineering, Univ; Tokyo: 1970. Some Experiments on Speech Perception and a Model for the Perceptual Mechanism; p. 207

Glanzman, DL.; Pisoni, DB. Decision Processes in Speech Discrimination as Revealed by Confidence Ratings. Paper presented at the 85th meetings of the Acoust. Soc. Am; Boston. 1973.

Liberman, AM. Some Characteristics of Perception in the Speech Mode. In: Hamburg, DA., editor. Perception and Its Disorders Proceeding of ARN MD. Willams and Wilkins; New York: 1970.

Liberman AM, Cooper FS, Shankweiler DS, Studdert-Kennedy M. Perception of the Speech Code. Psychol Rev. 1967; 74:431. [PubMed: 4170865]

Liberman AM, Harris KS, Hoffman HS, Griffith BC. The Discrimination of Speech Sounds within and across Phoneme Boundaries. J Exp Psychol. 1957; 54:358. [PubMed: 13481283]

Liberman AM, Harris KS, Kinney J, Lane H. The Discrimination of Relative Onset-time of the Components of Certain Speech and Non-speech Patterns. J Exp Psychol. 1961; 61:379. [PubMed: 13761868]

Lisker L, Abramson AS. A Cross Language Study of Voicing in Initial Stops: Acoustical Measurements. Word. 1964; 20:384.

Lisker, L.; Abramson, AS. The Voicing Dimension: Some Experiments in Comparative Phonetics. Proc. 6th Intl. Cong. Phonetic Sci; Prague. 1967; Prague: Academia; 1967. 1970

Pisoni DB. On the Nature of Categorical Perception of Speech Sounds. Status Report on Speech Research Haskins Labs. 1971; SR-27:101.

Pisoni DB. Auditory and Phonetic Memory Codes in the Discrimination of Consonants and Vowels. Percep Psychophys. 1973; 13:253.

Pollack I. The Information in Elementary Auditory Displays. J Acoust Soc Am. 1952; 24:745.

Pollack I. The Information in Elementary Auditory Displays II. J Acoust Soc Am. 1953; 25:765.

Pollack I, Pisoni DB. On the Comparison between Identification and Discrimination Tests in Speech Perception. Psych Sci. 1971; 24:299.

Stevens, KN.; House, AS. Speech Perception. In: Tobias, J., editor. Foundations of Modern Auditory Theory. Vol. II. Academic; New York: 1972.

Stevens, KN.; Klatt, DH. Quarterly Progress Report No 101. Research Lab. of Electronics, M.I.T; 1971. The Role of Formant Transitions in the Voice-Voiceless Distinction for Stops.

Studdert-Kennedy, M. The Perception of Speech. In: Sebeok, TA., editor. Current Trends in Linguistics. Vol. XII. Mouton; The Hague: 1973.

Studdert-Kennedy M, Liberman AM, Harris K, Cooper FS. The Motor Theory of Speech Perception: A Reply to Lane's Critical Review. Psychol Rev. 1970; 77:234. [PubMed: 5454133]

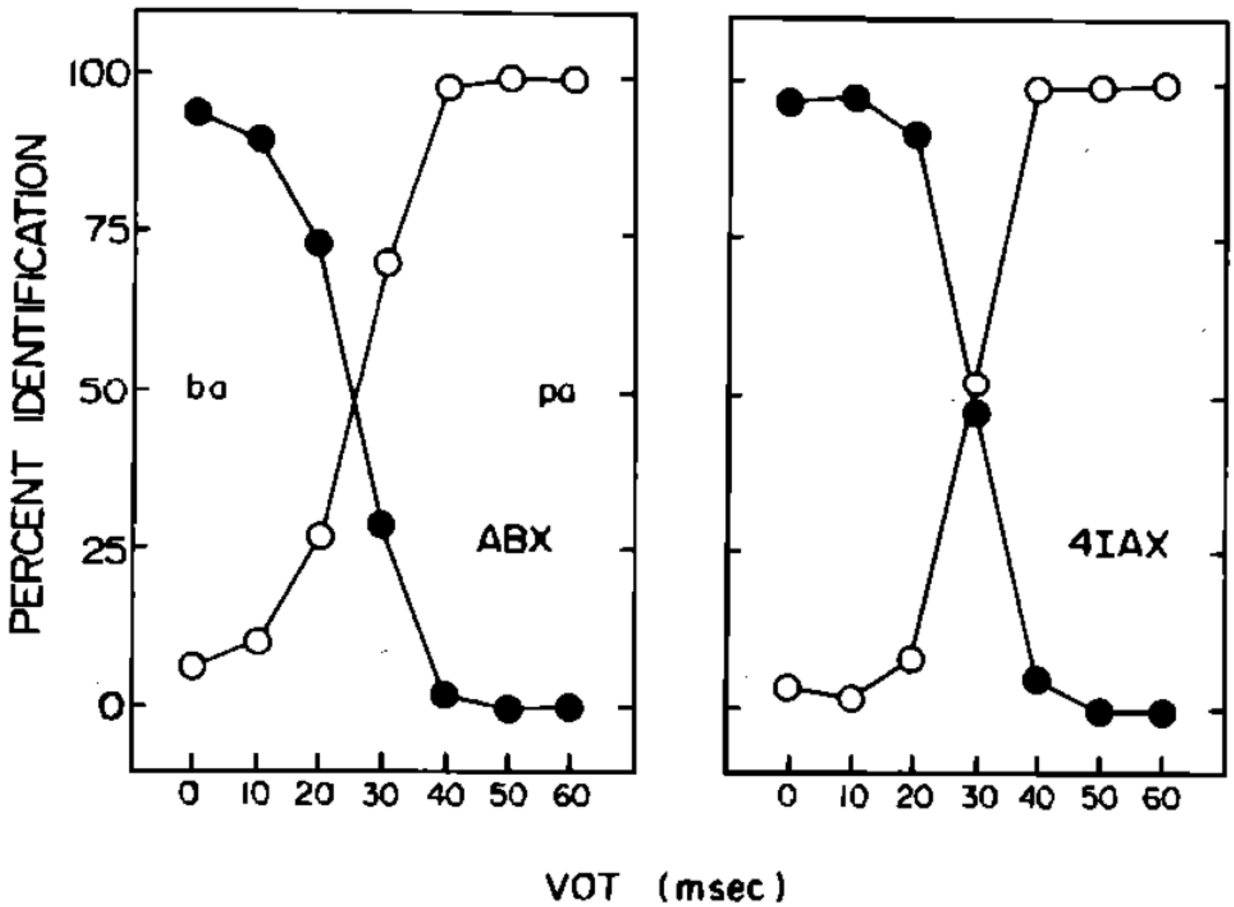

FIG. 1.
Average Identification Functions for the Randomized Identification Condition. On the right are the identification data for 7 *Ss* with the ABX discrimination test; on the left is the function for 7 *Ss* with the 4IAX test. Each point is based on 30 responses per *S* pooled over *Ss.*

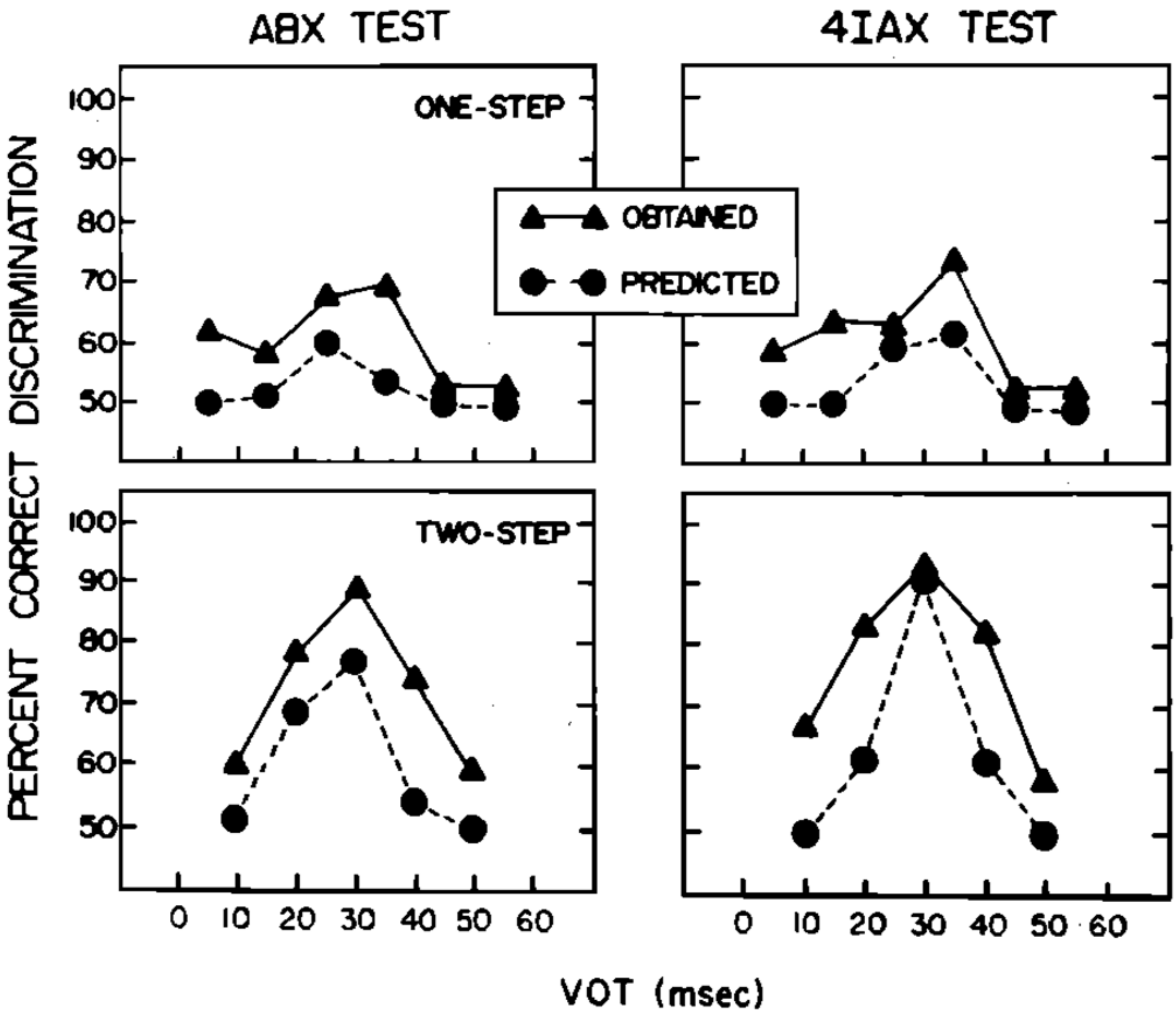

FIG. 2.

Average one- and two-step discrimination functions obtained with the ABX and 4IAX tests for the Random Identification Conditions. The predicted functions, derived from identification, are shown by the dashed lines in each panel.

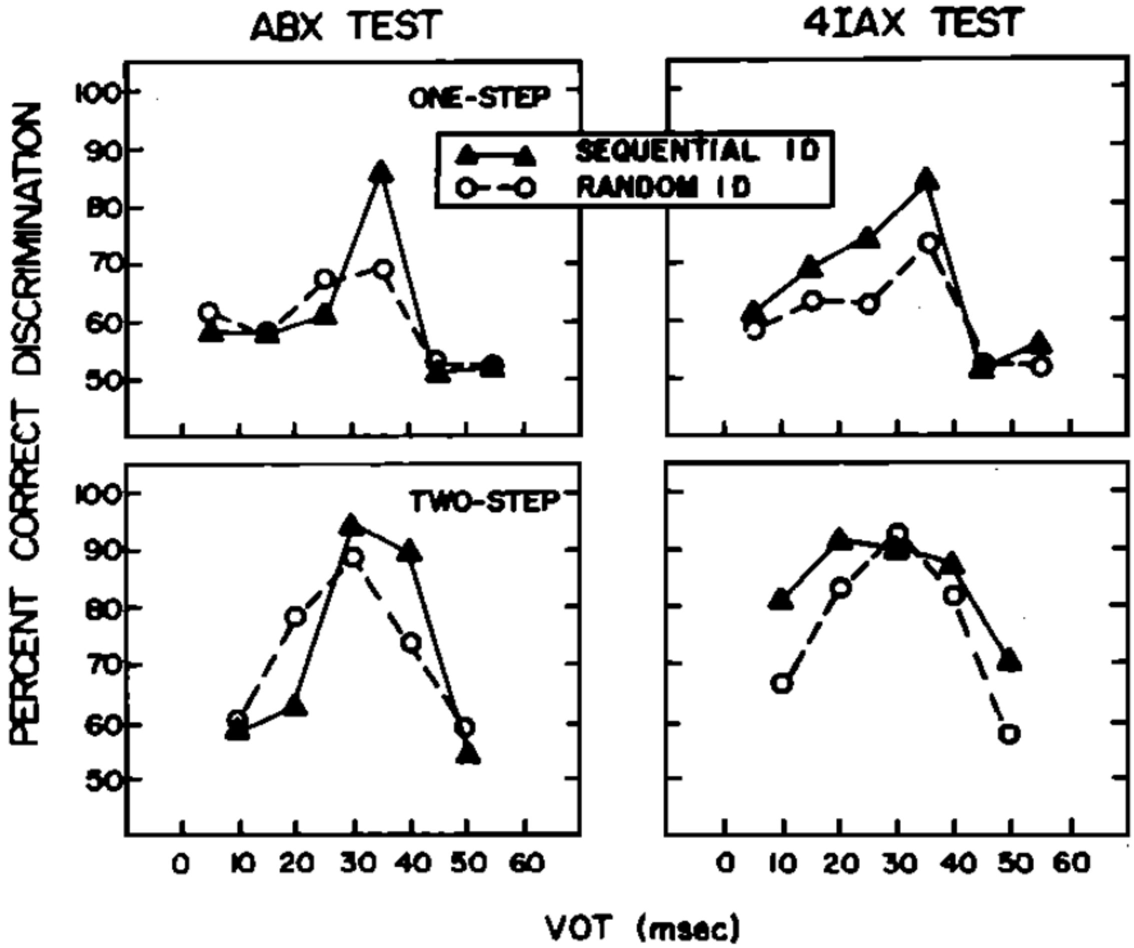

FIG. 3.

Average one- and two-step discrimination functions obtained with the ABX and 4IAX tests for the Sequential Identification Conditions. The discrimination functions secured under the Random Identification condition have been replotted as the dashed lines in each panel.

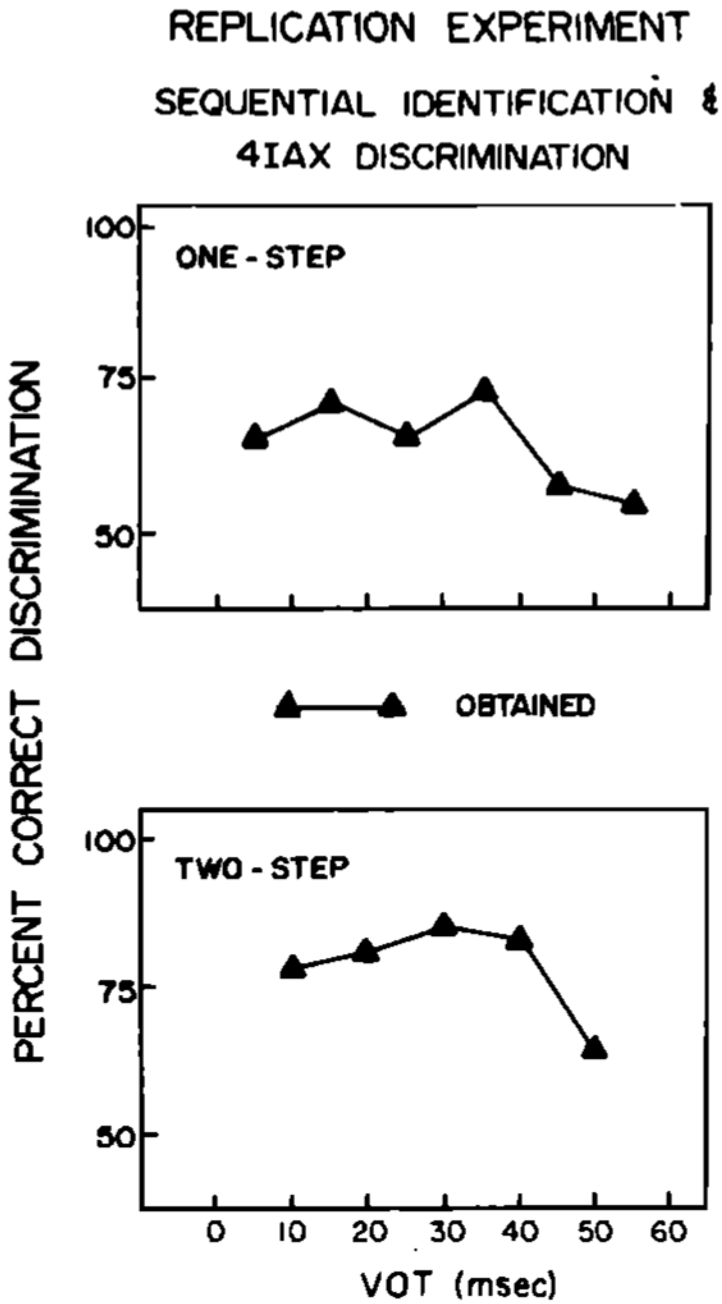

FIG. 4.

Average one- and two-step discrimination functions for the replication experiment involving only the Sequential Identification and 4IAX Discrimination test conditions.