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# Distinctive Features and Errors in Short-Term Memory for English Consonants

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Errors in short-term recall of 23 English consonants were tabulated and related to three distinctive-feature systems. The consonants were always presented in initial position in a consonant–vowel diagram, and the vowel was always /a/. Subjects were instructed to copy a list of consonants as it was being presented, followed by recall of the list. Perceptual errors were excluded from the recall-error matrix by scoring for recall only correctly copied consonants. The data were also analyzed in such a way as to eliminate differences in response bias for different consonants. Having controlled for response bias, each feature system makes predictions about the rank order of different intrusion errors in recall. Each of the three feature systems was significantly more accurate than chance in these predictions, but the most accurate system was one developed in the present study. This system is a slightly modified version of the conventional phonetic analysis of consonants in terms of voicing, nasality, openness of the vocal tract (manner of articulation), and place of articulation. The results suggest that a consonant is coded in short-term memory, not as a unit, but as a set of distinctive features, each of which may be forgotten at least semiindependently.

## INTRODUCTION

INTRUSION errors in immediate recall of verbal lists are not random. Recent studies by Conrad[1] and Wickelgren[2,3] on short-term recall of lists of letters and digits have demonstrated that intrusions tend to have a vowel or consonant phoneme in common with the correct item. This indicates that the internal representative of a (verbal) item in short-term memory (STM) is not a single element, but a set of internal representatives of the phonemes composing the item. The phonemic-coding hypothesis permits partial forgetting of an item and accounts for the phonemic similarity of intrusions to the correct item.

If the STM representative of a letter or digit is a set of representatives of phonemes, it is natural to ask whether the representative of a phoneme is a set of representatives of its distinctive features. A previous study[4] indicated that this was the case for vowel phonemes, and almost perfect rank-order predictions were made of the frequency of different intrusion errors by a conventional distinctive-feature analysis on two dimensions: place of articulation (front, back) and openness of the vocal tract (narrow, medium, and wide). Peterson and Barney[5] and Miller[6] had found previously that the same dimensions are involved in the perception of vowels, suggesting that perception and STM use the same system of internal representatives. Although it is not possible at present to determine whether this system of internal representatives is sensory or motor, no support can be obtained from any of these studies for the more "abstract" (nonsensory and nonmotor) level of the Chomsky–Halle feature system.[7]

In auditory perception of consonants in noise, Miller and Nicely[8] demonstrated that errors are nonrandom and tend to correlate with their distinctive-feature analysis, described in Table I. The two purposes of the present study are to (a) determine if errors in STM for for consonants tend to have features in common with the correct consonant, and (b) determine what distinctive-feature system best predicts these errors. In

[1] R. Conrad, "Acoustic Confusions in Immediate Memory," Brit. J. Psychol. **55**, 75–84 (1964).

[2] W. A. Wickelgren, "Acoustic Similarity and Intrusion Erorrs in Short-Term Memory," J. Exptl. Psychol. **70**, 102–108 (1965).

[3] W. A. Wickelgren, "Similarity and Intrusions in Short-Term Memory for Consonant–Vowel Digrams," Quart. J. Exptl. Psychol. **17**, 241–246 (1965).

[4] W. A. Wickelgren, "Distinctive Features and Errors in Short-Term Memory for English Vowels," J. Acoust. Soc. Am. **38**, 583–588 (1965).

[5] G. E. Peterson and H. L. Barney, "Control Methods Used in a Study of the Vowels," J. Acoust. Soc. Am. **24**, 175–184 (1952).

[6] G. A. Miller, "The Perception of Speech,' in *For Roman Jakobson*, M. Halle, Ed. (Mouton & Co., The Hague, 1956), pp. 353–359.

[7] N. Chomsky and M. Halle, *Sound Pattern of English* (to be published).

[8] G. A. Miller and P. E. Nicely, "An Analysis of Perceptual Confusions among Some English Consonants," J. Acoust. Soc. Am. **27**, 338–352 (1955).

addition to the feature system proposed by Miller and Nicely (MN), a feature system proposed by Halle[9] (H) and Chomsky and Halle[7] for the parsimonious description of English sound structure and a feature system proposed by the author (W) are investigated. These feature systems are described in Tables II and III.

MN has five dimensions: voicing, nasality, affrication, duration, and place of articulation. Place has three values; the rest have two values. MN has only been defined for a set of 16 consonants. Within that set, each dimension is defined on every consonant, and all consonants have a unique characterization in terms of their values on each of the five dimensions. However, if MN were to be extended to all English consonants, it would require some additional dimensions or values to handle laterals, semivowels, and the consonants /č/, /ǰ/, and /h/.

H has eight binary dimensions on which consonants are classified. The rather large number of dimensions results from the decision to use only two values per dimension. Halle gives a moderately complicated articulatory description of the values of the dimensions in the H system, but the system is unnatural and inelegant as a description of articulation and no attempt is made by Halle to validate the system on these grounds.[9] The features should be considered to be "abstract," not necessarily having a simple acoustic or articulatory description, though recognition and production of speech demand that there be some, perhaps complex, relationship between the abstract features and their acoustic and articulatory counterparts. The H system is designed primarily to give a parsimonious description of the admissible sound sequences in English, but we are concerned with how accurate the H system is in predicting the rank order of different intrusion errors in short-term recall.

Table I. MN distinctive-feature system.

| Consonant | Voicing | Nasality | Affrication | Duration | Place |
|---|---|---|---|---|---|
| p | 0 | 0 | 0 | 0 | 0 |
| b | 1 | 0 | 0 | 0 | 0 |
| m | 1 | 1 | 0 | 0 | 0 |
| t | 0 | 0 | 0 | 0 | 1 |
| d | 1 | 0 | 0 | 0 | 1 |
| n | 1 | 1 | 0 | 0 | 1 |
| k | 0 | 0 | 0 | 0 | 2 |
| g | 1 | 0 | 0 | 0 | 2 |
| f | 0 | 0 | 1 | 0 | 0 |
| v | 1 | 0 | 1 | 0 | 0 |
| θ | 0 | 0 | 1 | 0 | 1 |
| ð | 1 | 0 | 1 | 0 | 1 |
| s | 0 | 0 | 1 | 1 | 1 |
| z | 1 | 0 | 1 | 1 | 1 |
| š | 0 | 0 | 1 | 1 | 2 |
| ž | 1 | 0 | 1 | 1 | 2 |

Table II. H distinctive-feature system.

| Consonant | Voicing | Nasality | Vocalic | Consonantal | Continuant | Strident | Grave | Diffuse |
|---|---|---|---|---|---|---|---|---|
| p | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| b | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| m | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| t | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| d | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| n | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| č | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| ǰ | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| k | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| g | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| f | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| v | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| θ | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| ð | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| s | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| z | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| š | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| ž | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| w | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| r | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| l | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| y | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| h | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

The W system, like the MN system, is more similar to conventional phonetic analysis of consonants than the H system. Only four dimensions are used, but openness of the vocal tract has three values for consonants, and place of articulation has five values. Voicing and nasality are exactly the same as in the other two systems. The single dimension of openness in the W system handles "manner of articulation," which is handled (in a somewhat different manner) by two dimensions (affrication and duration) in the MN system and by four dimensions (vocalic, consonantal, continuant, and strident) in the H system. Place of articulation is coded on a 5-point scale in the W system, on a slightly rougher 3-point scale in the MN system, and on two binary dimensions (grave and diffuse) in the H system.

Notice that the openness of the vocal tract and place of articulation are the same two dimensions that were so accurate in predicting the errors in STM for English vowels. Of course, the values of the openness dimension for vowels would begin with a value greater than that for the semivowels. Thus, openness is conceived to code on a single 6-point scale the difference between (1) stop

[9] M. Halle, "On the Bases of Phonology," in *The Structure of Language*, J. A. Fodor and J. J. Katz, Eds. (Prentice-Hall, Inc., Englewood Cliffs, N. J., 1964), pp. 324–333.

| Conso-nant | Voic-ing | Nas-ality | Open-ness | Place |
|---|---|---|---|---|
| p | 0 | 0 | 0 | 0 |
| b | 1 | 0 | 0 | 0 |
| m | 1 | 1 | 0 | 0 |
| t | 0 | 0 | 0 | 1 |
| d | 1 | 0 | 0 | 1 |
| n | 1 | 1 | 0 | 1 |
| č | 0 | 0 | 0 | 3 |
| ǰ | 1 | 0 | 0 | 3 |
| k | 0 | 0 | 0 | 4 |
| g | 1 | 0 | 0 | 4 |
| f | 0 | 0 | 1 | 0 |
| v | 1 | 0 | 1 | 0 |
| θ | 0 | 0 | 1 | 1 |
| ð | 1 | 0 | 1 | 1 |
| s | 0 | 0 | 1 | 2 |
| z | 1 | 0 | 1 | 2 |
| š | 0 | 0 | 1 | 3 |
| ž | 1 | 0 | 1 | 3 |
| w | 1 | 0 | 2 | 0 |
| r | 1 | 0 | 2 | 1 |
| l | 1 | 0 | 2 | 2 |
| y | 1 | 0 | 2 | 3 |
| h | 0 | 0 | 2 | 4 |

TABLE III. W distinctive-feature system.

consonants; (2) fricatives; (3) semivowels, laterals, and /h/, (4) high (narrow-opening) vowels, (5) medium vowels, and (6) low (wide-opening) vowels. Values of the place dimension for vowels lie within the range for consonants.

While the W system gives a *unique* articulatory description of every consonant, it does not attempt to give a *complete* description of the articulation of each consonant. Thus, lip-rounding, tongue-tip retroflection, lateralization, and pharynx width are not indicated explicitly, although some might consider these special features to be more characteristic of /w/, /r/, /l/, and /h/ than the W classification in terms of the general position of the mass of the tongue (place of articulation). Also, voicing is indicated as a two-valued dimension, even though the degree of effort necessary to produce voice is greater for stop consonants than for fricatives, nasals, and semivowels. If STM is primarily in a speech-motor system, rather than an auditory system, the degree of effort necessary to produce voice might be the more accurate dimension. However, the 2-valued voicing dimension is a reasonable first approximation in this case.

Since phonemic similarity has already been demonstrated to correlate with intrusion frequency, it is important to control phonemic similarity in the population from which lists are constructed. Thus, letters and digits are not appropriate populations in which to investigate intrusions as a function of feature similarity. On the other hand, a population of consonants (followed by the vowel /a/) has a constant degree of phonemic similarity between every pair of items.

Since feature similarity correlates with the errors in auditory recognition, it is important to ensure that all intrusions are errors in short-term recall, not errors in auditory perception. This can be accomplished by requiring subjects to copy the consonants while they are being presented, covering what they have copied, and then recalling the consonants. Only the consonants that are copied correctly are scored for recall. This procedure was adopted in the present experiments.

## I. 16-CONSONANT EXPERIMENT

Sixteen consonant–vowel (CV) items were used, consisting of the 16 consonants ptkfθsšbdgvðzžmn followed by the vowel /a/ (as in father). A set of 100 lists of six CV items each and a set of 100 lists of seven CV items each were constructed. No consonant was ever used twice in the same list. Subjects listened to a list of CV items presented at the rate of one item/sec. Subjects copied the initial consonant of each CV item while the list was being presented, covering what they had copied. After copying all items, they attempted to recall the entire list of consonants in the correct order (by filling in boxes). Time for recall of the list was about 18 sec, so one trial lasted about 25 sec.

Subjects were 33 Massachusetts Institute of Technology undergraduates taking psychology courses. They constituted a rather broad regional sampling of the United States of America. Seventeen subjects received the lists with six items each, and 16 subjects received the lists with seven items each. The speaker was a male who had grown up in Connecticut.

Careful instruction and numerous examples were given prior to the experiment on the distinction between /θ/ and /ð/ and between /z/ and /ž/. Subjects were instructed to write "th" for /θ/, "$\overline{\text{th}}$" for /ð/, "sh" for /š/, and "zh" for /ž/.

## II. 23-CONSONANT EXPERIMENT

When a subject recalls the wrong consonant in a particular position in a list, it is much more likely to be another consonant from the same list (intralist intrusion) than a consonant not presented in the list (extralist intrusion). Furthermore, the intralist intrusion tends to be from a nearby position. The previous experiment was not systematically controlled with respect to the frequency of occurrence of all pairs of consonants in the same lists at different degrees of adjacency. This could result in some random error in the frequency of different intrusions to any given presented consonant. The second experiment was designed to reduce this source of error and to obtain a short-term-recall error matrix for all 23 consonants that can occur in initial

TABLE IV. STM recall error matrix for 16 English consonants.

| | Intrusion (consonant recalled) p | b | m | t | d | n | k | g | f | v | θ | ð | s | z | š | ž | Omissions | Total intrusions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Consonant presented and copied correctly | | | | | | | | | | | | | | | | | | |
| p | 991 | 29 | 18 | 36 | 23 | 21 | 30 | 11 | 10 | 21 | 15 | 3 | 13 | 12 | 10 | 6 | 113 | 258 |
| b | 36 | 881 | 21 | 16 | 11 | 15 | 9 | 24 | 13 | 31 | 13 | 0 | 11 | 17 | 4 | 12 | 93 | 233 |
| m | 15 | 11 | 998 | 17 | 5 | 29 | 24 | 14 | 11 | 16 | 12 | 2 | 12 | 7 | 6 | 12 | 72 | 193 |
| t | 27 | 11 | 18 | 1055 | 8 | 23 | 19 | 20 | 21 | 8 | 26 | 9 | 18 | 18 | 9 | 12 | 86 | 247 |
| d | 39 | 20 | 18 | 21 | 994 | 45 | 21 | 35 | 17 | 16 | 27 | 11 | 11 | 20 | 11 | 11 | 83 | 323 |
| n | 14 | 9 | 18 | 23 | 10 | 856 | 17 | 13 | 13 | 19 | 14 | 5 | 13 | 14 | 5 | 10 | 62 | 197 |
| k | 35 | 12 | 16 | 18 | 8 | 11 | 954 | 10 | 20 | 12 | 13 | 3 | 14 | 14 | 11 | 14 | 83 | 211 |
| g | 20 | 25 | 23 | 18 | 25 | 14 | 21 | 831 | 22 | 7 | 18 | 2 | 11 | 19 | 5 | 5 | 101 | 235 |
| f | 23 | 12 | 25 | 16 | 1 | 24 | 31 | 16 | 744 | 16 | 19 | 7 | 19 | 9 | 12 | 3 | 84 | 233 |
| v | 23 | 23 | 23 | 20 | 20 | 37 | 16 | 10 | 26 | 922 | 19 | 9 | 19 | 22 | 8 | 7 | 105 | 282 |
| θ | 17 | 4 | 10 | 36 | 7 | 21 | 19 | 12 | 19 | 6 | 674 | 32 | 18 | 13 | 10 | 9 | 83 | 233 |
| ð | 4 | 6 | 5 | 9 | 7 | 15 | 6 | 5 | 7 | 16 | 65 | 571 | 4 | 8 | 6 | 7 | 38 | 170 |
| s | 16 | 13 | 19 | 21 | 9 | 13 | 16 | 13 | 18 | 12 | 25 | 4 | 911 | 22 | 35 | 13 | 69 | 249 |
| z | 13 | 9 | 11 | 18 | 13 | 7 | 14 | 32 | 10 | 31 | 17 | 11 | 37 | 816 | 9 | 46 | 98 | 278 |
| š | 12 | 7 | 18 | 19 | 16 | 13 | 19 | 11 | 11 | 15 | 33 | 13 | 42 | 17 | 993 | 17 | 73 | 263 |
| ž | 13 | 12 | 12 | 10 | 5 | 10 | 13 | 13 | 14 | 22 | 11 | 10 | 17 | 88 | 26 | 815 | 66 | 276 |

position in English (p,b,m,t,d,n,č,ǰ,k,g,f,v,θ,ð,s,z,š,ž, w,r,l,y,h), followed by /a/ as in father.

Lists consisted of nine different CV items, with a group of three items being presented in 1.5 sec followed by a 1.5-sec pause. Subjects copied the initial consonant of every item as it was being presented and covered what they had copied. During the presentation of the list, they kept the recall boxes covered. Following the 1.5-sec pause after the last group of three items, the subjects uncovered the boxes in which they were to attempt to recall the list. One consonant in every group of three had already been typed in its correct position in the recall boxes, so the subjects had to recall only six of the nine consonants. The typed-in consonants (called cue consonants) were in positions 1, 4, and 7 on some trials, in positions 2, 5, and 8 on other trials, and in positions 3, 6, and 9 on still other trials. Since subjects did not know during presentation of the list which consonants would be typed in, they had to pay attention to all nine consonants.

This relatively complicated procedure had three purposes. *First*, systematic errors are obviously not going to be obtained when the memory trace is so strong that the subject recalls correctly, and they are also not likely to be obtained when the memory trace has decayed completely. Thus, it would be desirable to test recall at an intermediate degree of strength of the memory trace. The serial-position effect works against this, because items at the beginning and end of a list are generally remembered perfectly, while items in the middle may be remembered only slightly better than chance. By making the list longer (nine instead of six or seven items), we reduce the probability of correct recall of beginning and end items, and by introducing cue items we increase the probability of recalling middle items. Thus, the probability of correct recall can be more nearly equated over the different positions of the list and set at some level that is nearly optimal for our purpose.

*Second*, we score the item in each position as if serial position were the only cue used in recall. Obviously, it is not. Subjects are also using the adjacent items that they have just recalled. By inserting cue items into every third position, we guarantee that subjects will never get very far off in the cue items that they are using in recall.

*Third*, by grouping the items to be recalled in three's, only two of which are to be recalled, we have a natural way of controlling for the frequency of different pairs of consonants in the same lists. We simply use every one of the $23\times22=506$ pairs (approximately) equally often as the pair to be recalled in a group of three consonants.

To use every one of these pairs once requires a reasonably large number of lists. It was decided to use every pair twice (and a few three times). At the same time, the frequency of occurrence of each consonant was equated at 94 (except two that occurred 93 times). Each consonant occurred (approximately) equally often in cue positions. No consonant appeared more than once in any two successive lists. Three sets of 120 lists each were used. 9 sec were allowed for recall of each list, 9

Table V. STM recall error matrix for 23 English consonants.

| | Intrusion (consonant recalled) | | | | | | | | | | | | | | | | | | | | | | | Omis-sions | Total intrusions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | p | b | m | t | d | n | č | ǰ | k | g | f | v | θ | ð | s | z | š | ž | w | r | l | y | h | | |
| Consonant presented and copied correctly | | | | | | | | | | | | | | | | | | | | | | | | | |
| p | 881 | 23 | 29 | 28 | 25 | 32 | 19 | 18 | 34 | 20 | 28 | 20 | 4 | 6 | 13 | 8 | 5 | 6 | 19 | 28 | 51 | 10 | 17 | 655 | 443 |
| b | 40 | 1051 | 32 | 29 | 21 | 25 | 12 | 17 | 21 | 26 | 32 | 19 | 5 | 5 | 13 | 14 | 5 | 10 | 16 | 30 | 31 | 8 | 27 | 548 | 438 |
| m | 36 | 8 | 919 | 20 | 13 | 55 | 11 | 4 | 16 | 18 | 32 | 18 | 5 | 3 | 8 | 11 | 9 | 8 | 17 | 37 | 35 | 21 | 27 | 660 | 412 |
| t | 38 | 19 | 27 | 877 | 22 | 44 | 13 | 13 | 25 | 23 | 26 | 15 | 6 | 19 | 9 | 13 | 10 | 14 | 17 | 24 | 34 | 13 | 24 | 646 | 448 |
| d | 19 | 24 | 32 | 28 | 892 | 46 | 10 | 20 | 21 | 27 | 30 | 19 | 6 | 7 | 8 | 20 | 9 | 7 | 17 | 49 | 29 | 19 | 19 | 621 | 466 |
| n | 23 | 17 | 53 | 26 | 23 | 987 | 10 | 12 | 27 | 14 | 21 | 21 | 5 | 5 | 6 | 10 | 2 | 1 | 13 | 35 | 44 | 15 | 17 | 669 | 400 |
| č | 31 | 13 | 18 | 24 | 11 | 17 | 659 | 25 | 40 | 18 | 29 | 13 | 9 | 13 | 12 | 16 | 14 | 25 | 16 | 25 | 30 | 14 | 22 | 792 | 435 |
| ǰ | 15 | 25 | 25 | 11 | 21 | 30 | 22 | 729 | 39 | 30 | 19 | 16 | 5 | 9 | 10 | 19 | 11 | 18 | 17 | 24 | 28 | 19 | 25 | 555 | 438 |
| k | 35 | 19 | 16 | 19 | 18 | 25 | 19 | 14 | 870 | 33 | 29 | 6 | 9 | 8 | 6 | 12 | 7 | 8 | 7 | 31 | 26 | 9 | 17 | 669 | 373 |
| g | 24 | 23 | 30 | 22 | 35 | 32 | 13 | 19 | 43 | 735 | 18 | 19 | 7 | 10 | 15 | 20 | 8 | 9 | 18 | 42 | 43 | 10 | 23 | 706 | 483 |
| f | 31 | 12 | 32 | 22 | 15 | 28 | 19 | 10 | 27 | 22 | 872 | 19 | 12 | 15 | 22 | 22 | 10 | 3 | 17 | 36 | 38 | 17 | 26 | 558 | 455 |
| v | 33 | 20 | 31 | 27 | 14 | 37 | 8 | 11 | 24 | 14 | 44 | 695 | 12 | 15 | 17 | 13 | 5 | 12 | 25 | 20 | 27 | 12 | 24 | 623 | 445 |
| θ | 6 | 3 | 4 | 2 | 6 | 1 | 4 | 4 | 9 | 1 | 7 | 3 | 232 | 10 | 6 | 0 | 2 | 5 | 1 | 5 | 3 | 2 | 2 | 118 | 86 |
| ð | 9 | 8 | 19 | 21 | 18 | 15 | 15 | 12 | 24 | 9 | 30 | 14 | 16 | 509 | 9 | 12 | 8 | 10 | 14 | 30 | 31 | 7 | 21 | 454 | 352 |
| s | 27 | 11 | 21 | 25 | 10 | 27 | 18 | 9 | 23 | 13 | 37 | 10 | 7 | 13 | 657 | 33 | 32 | 8 | 16 | 26 | 27 | 13 | 23 | 619 | 429 |
| z | 19 | 13 | 19 | 24 | 18 | 19 | 6 | 16 | 21 | 20 | 27 | 25 | 7 | 9 | 36 | 731 | 8 | 35 | 9 | 19 | 24 | 17 | 18 | 569 | 409 |
| š | 23 | 12 | 21 | 14 | 18 | 18 | 29 | 21 | 13 | 17 | 32 | 8 | 2 | 9 | 39 | 17 | 708 | 24 | 13 | 20 | 28 | 21 | 22 | 553 | 421 |
| ž | 9 | 4 | 19 | 10 | 3 | 8 | 17 | 8 | 9 | 13 | 13 | 9 | 4 | 4 | 9 | 27 | 16 | 789 | 10 | 17 | 12 | 12 | 9 | 331 | 242 |
| w | 35 | 19 | 33 | 15 | 15 | 26 | 15 | 10 | 20 | 20 | 20 | 16 | 0 | 7 | 9 | 15 | 9 | 10 | 835 | 47 | 38 | 24 | 26 | 570 | 429 |
| r | 24 | 17 | 37 | 19 | 19 | 33 | 9 | 12 | 16 | 23 | 33 | 17 | 6 | 7 | 15 | 9 | 2 | 7 | 16 | 950 | 31 | 13 | 17 | 660 | 382 |
| l | 23 | 13 | 29 | 23 | 22 | 37 | 18 | 22 | 35 | 18 | 25 | 15 | 6 | 9 | 10 | 19 | 5 | 7 | 24 | 47 | 914 | 26 | 28 | 633 | 461 |
| y | 23 | 20 | 35 | 13 | 22 | 46 | 10 | 12 | 18 | 10 | 22 | 20 | 5 | 9 | 8 | 9 | 6 | 8 | 26 | 30 | 52 | 735 | 21 | 667 | 425 |
| h | 27 | 13 | 34 | 22 | 20 | 28 | 10 | 12 | 28 | 15 | 34 | 12 | 6 | 6 | 16 | 9 | 5 | 7 | 22 | 30 | 43 | 24 | 841 | 609 | 423 |

TABLE VI. Ranking of 15 other presented consonants by percent substitution of each intrusion consonant.

| | Intrusion (consonant recalled) p | b | m | t | d | n | k | g | f | v | θ | ð | s | z | š | ž |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank of presented consonants | | | | | | | | | | | | | | | | |
| 1 | k 16.59 | p 11.24 | f 10.73 | θ 15.45 | g 10.64 | m 15.03 | f 13.30 | z 11.51 | k 9.48 | b 13.30 | ð 38.24 | θ 13.73 | š 15.97 | ž 31.88 | s 14.06 | z 16.55 |
| 2 | b 15.45 | g 10.64 | g 9.79 | p 13.95 | p 8.91 | d 13.93 | m 12.44 | d 10.84 | g 9.36 | z 11.15 | š 12.55 | š 4.94 | z 13.31 | s 8.84 | ž 9.42 | k 6.64 |
| 3 | d 12.07 | v 8.16 | n 9.14 | n 11.68 | v 7.09 | v 13.12 | p 11.63 | b 10.30 | v 9.22 | n 9.64 | t 10.53 | z 3.96 | f 8.15 | g 8.10 | k 5.21 | š 6.46 |
| 4 | t 10.93 | d 6.19 | b 9.01 | m 8.81 | š 6.08 | f 10.30 | g 8.94 | t 8.10 | t 8.50 | ð 9.41 | s 10.04 | t 3.64 | θ 7.73 | v 7.80 | f 5.15 | m 6.22 |
| 5 | f 9.87 | m 5.70 | v 8.16 | k 8.53 | n 5.08 | t 9.31 | n 8.63 | m 7.25 | θ 8.15 | m 8.29 | d 8.36 | ž 3.62 | t 7.29 | b 7.30 | θ 4.29 | s 5.22 |
| 6 | g 8.51 | k 5.69 | s 7.63 | s 8.43 | b 4.72 | θ 9.01 | θ 8.15 | f 6.87 | s 7.23 | p 8.14 | f 8.15 | d 3.41 | v 6.74 | t 7.29 | p 3.88 | b 5.15 |
| 7 | v 8.16 | s 5.22 | k 7.58 | g 7.66 | z 4.68 | ð 8.82 | t 7.69 | n 6.60 | n 6.60 | ž 7.97 | g 7.66 | v 3.19 | k 6.64 | n 7.11 | t 3.64 | n 5.08 |
| 8 | m 7.77 | f 5.15 | t 7.29 | š 7.22 | ð 4.12 | p 8.14 | š 7.22 | s 5.22 | m 5.70 | f 6.87 | n 7.11 | f 3.00 | n 6.60 | k 6.64 | ð 3.53 | t 4.86 |
| 9 | θ 7.30 | n 4.57 | p 6.98 | v 7.09 | k 3.79 | b 6.44 | d 6.50 | θ 5.15 | b 5.58 | š 5.70 | v 6.74 | n 2.54 | m 6.22 | š 6.46 | d 3.41 | ð 4.12 |
| 10 | n 7.11 | t 4.45 | š 6.84 | f 6.87 | s 3.61 | g 5.96 | s 6.43 | k 4.74 | d 5.26 | k 5.69 | m 6.22 | s 1.61 | ž 6.16 | d 6.19 | z 3.24 | θ 3.86 |
| 11 | s 6.43 | ž 4.35 | d 5.57 | b 6.87 | t 3.24 | s 5.22 | v 5.67 | ž 4.71 | ž 5.07 | d 4.95 | k 6.16 | k 1.42 | p 5.04 | θ 5.58 | m 3.11 | d 3.41 |
| 12 | ž 4.71 | ð 3.53 | ž 4.35 | d 6.50 | θ 3.00 | k 5.21 | z 5.04 | p 4.26 | š 4.18 | s 4.82 | z 6.12 | p 1.16 | b 4.72 | ð 4.71 | v 2.84 | v 2.48 |
| 13 | z 4.68 | z 3.24 | θ 4.29 | z 6.47 | m 2.59 | š 4.94 | ž 4.71 | š 4.18 | ð 4.12 | t 3.24 | p 5.81 | m 1.04 | g 4.68 | p 4.65 | n 2.54 | p 2.33 |
| 14 | š 4.56 | š 2.66 | z 3.96 | ð 5.29 | ž 1.81 | ž 3.62 | b 3.86 | v 3.55 | p 3.88 | g 2.98 | b 5.58 | g 0.85 | d 3.41 | f 3.86 | g 2.13 | g 2.13 |
| 15 | ð 2.35 | θ 1.72 | ð 2.94 | ž 3.62 | f 0.43 | z 2.52 | ð 3.53 | ð 2.94 | z 3.60 | θ 2.58 | ž 3.99 | b 0.00 | ð 2.35 | m 3.63 | b 1.72 | f 1.29 |

TABLE VII. Ranking of 22 other presented consonants

| | Intrusion (consonant recalled) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | p | b | m | t | d | n | č | ǰ | k | g | f |
| | Rank of presented consonant | | | | | | | | | | |
| 1 | k 9.43 | j 5.71 | n 13.22 | b 6.62 | g 7.25 | m 13.35 | ž 7.02 | č 5.75 | θ 10.47 | k 8.89 | v 9.89 |
| 2 | b 9.13 | p 5.19 | r 9.79 | n 6.48 | θ 6.98 | y 10.83 | š 6.89 | š 4.99 | č 9.19 | j 6.85 | r 8.73 |
| 3 | m 8.74 | d 5.15 | y 8.24 | p 6.32 | n 5.74 | d 9.82 | k 5.12 | l 4.77 | j 8.90 | r 6.08 | s 8.62 |
| 4 | t 8.48 | k 5.12 | h 8.04 | v 6.07 | p 5.64 | t 9.82 | j 5.02 | θ 4.65 | g 8.90 | b 5.94 | ð 8.52 |
| 5 | w 8.43 | g 4.76 | w 7.95 | d 6.01 | y 5.18 | r 8.73 | θ 4.65 | d 4.29 | p 7.67 | d 5.79 | θ 8.14 |
| 6 | v 7.46 | y 4.71 | ž 7.85 | ð 5.97 | ð 5.11 | v 8.31 | p 4.29 | p 4.06 | l 7.59 | ž 5.37 | h 8.04 |
| 7 | č 7.13 | w 4.58 | b 7.31 | z 5.87 | r 5.03 | l 8.03 | ð 4.26 | g 3.93 | ð 6.82 | t 5.13 | k 7.82 |
| 8 | θ 6.98 | r 4.50 | f 7.03 | s 5.83 | t 4.91 | p 7.22 | s 4.20 | z 3.91 | n 6.73 | z 4.89 | m 7.77 |
| 9 | f 6.81 | v 4.49 | v 6.97 | č 5.52 | k 4.85 | j 6.85 | f 4.18 | b 3.88 | h 6.62 | f 4.84 | š 7.60 |
| 10 | h 6.38 | t 4.24 | d 6.87 | h 5.20 | j 4.79 | k 6.74 | l 3.90 | k 3.77 | f 5.93 | w 4.82 | b 7.31 |
| 11 | r 6.35 | n 4.24 | p 6.55 | k 5.12 | b 4.79 | g 6.62 | w 3.61 | ð 3.41 | t 5.58 | p 4.51 | č 6.67 |
| 12 | s 6.29 | θ 3.49 | l 6.29 | r 5.03 | l 4.77 | h 6.62 | t 2.90 | ž 3.31 | v 5.39 | m 4.37 | z 6.60 |
| 13 | n 5.74 | z 3.18 | g 6.21 | l 4.99 | h 4.73 | s 6.29 | b 2.74 | r 3.17 | s 5.36 | č 4.14 | d 6.44 |
| 14 | š 5.46 | h 3.07 | t 6.03 | m 4.85 | z 4.40 | w 6.27 | g 2.69 | n 2.99 | z 5.13 | š 4.04 | p 6.32 |
| 15 | y 5.41 | č 2.99 | j 5.71 | f 4.84 | š 4.28 | f 6.15 | m 2.67 | t 2.90 | w 4.82 | l 3.90 | t 5.80 |
| 16 | l 4.99 | š 2.85 | ð 5.40 | g 4.55 | w 3.61 | b 5.71 | n 2.49 | h 2.84 | b 4.79 | h 3.55 | l 5.42 |
| 17 | g 4.97 | l 2.82 | š 4.99 | ž 4.13 | f 3.30 | z 4.65 | r 2.38 | y 2.82 | d 4.51 | n 3.49 | ž 5.37 |
| 18 | z 4.65 | f 2.63 | s 4.90 | w 3.61 | m 3.16 | š 4.28 | h 2.36 | v 2.47 | r 4.23 | v 3.15 | n 5.24 |
| 19 | d 4.08 | s 2.56 | θ 4.65 | š 3.33 | v 3.15 | ð 4.26 | y 2.35 | w 2.41 | y 4.23 | s 3.03 | y 5.18 |
| 20 | ž 3.72 | ð 2.27 | z 4.65 | y 3.06 | č 2.53 | č 3.91 | d 2.15 | f 2.20 | m 3.88 | ð 2.56 | w 4.82 |
| 21 | j 3.42 | m 1.94 | k 4.31 | j 2.51 | s 2.33 | ž 3.31 | v 1.80 | s 2.10 | ž 3.72 | y 2.35 | j 4.34 |
| 22 | ð 2.56 | ž 1.65 | č 4.14 | θ 2.33 | ž 1.24 | θ 1.16 | z 1.47 | m 0.97 | š 3.09 | θ 1.16 | g 3.73 |

sec for presentation and copying of the list, and 2 sec for the "ready" signal; so a trial required about 20 sec. Thus, each set required about 40 min. Approximately equal groups of subjects were run in each set, and there were 71 subjects altogether. The subjects were Massachusetts Institute of Technology undergraduates taking psychology courses. They constituted a broad regional sampling of the United States of America. The speaker was a female who spent the first 11 years of her life in Colorado and who went to high school on Long Island, New York.

Before the recall experiment started, the subjects were given careful instruction and examples regarding the pronunciation and way of writing of each consonant.

by percent substitution of each intrusion consonant.

| Intrusion (consonant recalled) v | θ | ð | s | z | š | ž | w | r | l | y | h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank of presented consonant | | | | | | | | | | | |
| z 6.11 | ð 4.54 | θ 11.63 | š 9.26 | ž 11.16 | s 7.46 | z 8.56 | v 5.62 | w 11.33 | y 12.24 | w 5.78 | m 6.55 |
| n 5.24 | v 2.70 | t 4.24 | z 8.80 | s 7.69 | ž 6.61 | θ 5.81 | l 5.21 | d 10.52 | p 11.51 | h 5.67 | w 6.27 |
| y 4.71 | f 2.64 | v 3.37 | θ 6.98 | f 4.84 | č 3.22 | č 5.75 | p 4.29 | l 10.20 | n 10.97 | l 5.64 | b 6.16 |
| p 4.51 | k 2.43 | f 3.30 | f 4.84 | j 4.34 | j 2.51 | š 5.70 | r 4.23 | m 8.98 | h 10.17 | m 5.10 | l 6.07 |
| r 4.50 | č 2.07 | s 3.03 | r 3.97 | d 4.29 | θ 2.33 | j 4.11 | ž 4.13 | n 8.73 | w 9.16 | š 4.99 | ð 5.79 |
| m 4.37 | z 1.71 | č 2.99 | v 3.82 | g 4.14 | ð 2.27 | t 3.12 | m 4.13 | g 8.69 | g 8.90 | ž 4.96 | f 5.7[illegible] |
| b 4.34 | ž 1.65 | z 2.20 | h 3.78 | l 4.12 | t 2.23 | ð 2.84 | ð 3.98 | ð 8.52 | ð 8.81 | j 4.34 | j 5.71 |
| f 4.18 | s 1.63 | k 2.16 | ž 3.72 | š 4.04 | f 2.20 | v 2.70 | t 3.79 | k 8.36 | m 8.50 | z 4.16 | v 5.39 |
| d 4.08 | r 1.59 | š 2.14 | g 3.11 | č 3.68 | m 2.18 | w 2.41 | f 3.74 | f 7.91 | f 8.35 | d 4.08 | t 5.36 |
| ð 3.98 | g 1.45 | y 2.12 | b 2.97 | w 3.61 | w 2.17 | b 2.28 | s 3.73 | h 7.09 | r 8.20 | f 3.74 | s 5.36 |
| g 3.93 | h 1.42 | g 2.07 | p 2.93 | ð 3.41 | z 1.96 | k 2.16 | g 3.73 | y 7.06 | t 7.59 | n 3.74 | š 5.23 |
| w 3.86 | t 1.34 | j 2.05 | č 2.76 | k 3.23 | d 1.93 | m 1.94 | b 3.65 | ž 7.02 | b 7.08 | r 3.44 | č 5.06 |
| ž 3.72 | l 1.30 | l 1.95 | ð 2.56 | b 3.20 | k 1.87 | y 1.88 | d 3.65 | b 6.85 | k 7.01 | č 3.22 | y 4.94 |
| j 3.65 | d 1.29 | r 1.85 | j 2.28 | v 2.92 | g 1.66 | s 1.86 | n 3.24 | p 6.32 | č 6.90 | s 3.03 | g 4.76 |
| θ 3.49 | n 1.25 | w 1.69 | l 2.17 | t 2.90 | y 1.41 | g 1.86 | š 3.09 | s 6.06 | š 6.65 | t 2.90 | k 4.58 |
| t 3.35 | m 1.21 | ž 1.65 | w 2.17 | m 2.67 | h 1.18 | r 1.85 | y 2.38 | θ 5.81 | j 6.39 | v 2.70 | r 4.50 |
| l 3.25 | y 1.18 | d 1.50 | t 2.01 | n 2.49 | b 1.14 | h 1.65 | z 2.20 | č 5.75 | s 6.29 | k 2.43 | z 4.40 |
| č 2.99 | j 1.14 | h 1.42 | m 1.94 | r 2.38 | p 1.13 | l 1.52 | h 2.13 | j 5.48 | d 6.22 | θ 2.33 | n 4.24 |
| h 2.84 | b 1.14 | p 1.35 | y 1.88 | h 2.13 | v 1.12 | d 1.50 | k 1.89 | t 5.36 | v 6.07 | p 2.26 | d 4.08 |
| s 2.33 | p 0.90 | n 1.25 | d 1.72 | y 2.12 | l 1.08 | p 1.35 | j 1.71 | š 4.75 | z 5.87 | g 2.07 | p 3.84 |
| š 1.90 | š 0.48 | b 1.14 | k 1.62 | p 1.81 | r 0.53 | f 0.66 | č 1.36 | z 4.65 | ž 4.96 | ð 1.99 | ž 3.72 |
| k 1.62 | w 0.00 | m 0.73 | n 1.50 | θ 0.00 | n 0.50 | n 0.25 | θ 1.16 | v 4.49 | θ 3.49 | b 1.83 | θ 2.33 |

Fifteen trials of copying practice were given, using the same type of lists and rate of presentation as in the recall experiment, with the experimenter writing and pronouncing the answers after the subjects had finished copying the list for that trial. To reduce graphic confusions, subjects were instructed to write "θ" for /θ/ and "th" for /ð/. The graphic symbols used for the other consonants were rather obvious choices: "ch" for /č/, "j" for /j/, "g" for /g/, "sh" for /š/, "zh" for /ž/, etc.

## III. RESULTS

In both experiments, only consonants that had been *copied* correctly in the correct position were scored for

TABLE VIII. Accuracy of binary predictions made by three feature systems.

| System | Dimension | STM 16 cons. %corr. | N | STM 23 cons. %corr. | N | Total STM %corr. | N | Auditory perception 16 cons. %corr. | N |
|---|---|---|---|---|---|---|---|---|---|
| all | Voicing | 70 | 98 | 60 | 168 | 64 | 266 | 100 | 98 |
| all | Nasality | 46 | 28 | 61 | 42 | 56 | 70 | 68 | 28 |
| MN | Affrication | 64 | 56 | 75 | 56 | 70 | 112 | 59 | 56 |
| MN | Duration | 54 | 28 | 57 | 28 | 55 | 56 | 61 | 28 |
| MN | Place | 66 | 152 | 67 | 152 | 67 | 304 | 59 | 152 |
| H | Vocalic & consonantal | ... | ... | 55 | 40 | 55 | 40 | ... | ... |
| H | Continuant | 71 | 28 | 63 | 84 | 65 | 241 | 57 | 28 |
| H | Strident | 54 | 28 | 50 | 42 | 51 | 70 | 46 | 28 |
| H | Grave | 67 | 70 | 61 | 125 | 63 | 195 | 63 | 70 |
| H | Diffuse | 54 | 56 | 62 | 84 | 59 | 140 | 57 | 56 |
| W | Openness | 64 | 56 | 71 | 185 | 69 | 241 | 59 | 56 |
| W | Place | 79 | 104 | 75 | 247 | 76 | 351 | 65 | 104 |
| MN | (A+D+P) | 64 | 236 | 68 | 236 | 66 | 472 | 59 | 236 |
| H | (V&C+C+S+G+D) | 62 | 182 | 60 | 375 | 60 | 557 | 58 | 182 |
| W | (O+P) | 74 | 160 | 73 | 432 | 73 | 592 | 63 | 160 |

recall. Thus, perceptual errors were eliminated from the recall data. Correctly copied consonants were scored for correct *ordered recall*. That is, a consonant was scored as correctly recalled, if and only if it was recalled in the correct box on the answer sheet. For all cases in which the consonant presented in a position was correctly copied in that position, Tables IV and V show the frequencies of correct recall, omission in recall, and each of the 15 or 22 intrusions in recall of each of the 16 or 23 consonants. Table IV is for the 16-consonant experiment, and Table V is for the 23-consonant experiment.

Each intrusion frequency in Tables IV and V was divided by the total number of intrusions for that particular presented consonant (i.e., it was divided by the intrusion total for that row). This yields the conditional probability that a subject recalls a particular incorrect consonant given a particular presented consonant, and given that he makes an intrusion error (rather than recalling correctly or making an omission). The purpose of this transformation is to adjust for differences in the frequency with which different consonants were presented, copied correctly, recalled correctly, or omitted in recall. We want the entries in one row to be directly comparable with those in another row.

Having adjusted for these extraneous differences in "opportunities for intrusions," we can now compare eth obtained conditional probabilities in one row with those in the same column in other rows. This comparison within a column (rather than within a row) equates for response bias—that is, the subject's bias to emit any particular consonant, independent of its strength in STM. With 16 or 23 consonants, the maximum differences in response bias could be quite large. Tables VI and VII present the conditional probabilities for the two experiments with the entries in each column being ranked from greatest to least probability that the intrusion consonant would be recalled instead of each of the 15 or 22 possible presented consonants. For example, let us examine the cases where /p/ was an intrusion in recall in the 16-consonant experiment (column labeled "p" in Table VI). /p/ was given incorrectly most often in response to the presented consonant /k/, next most often in response to /b/, next most often in response to /d/, etc. The conditional probability of recalling /p/ when /k/ was presented and when the subject recalled some incorrect consonant was 0.1659.

Each of the three feature systems makes binary (greater than) predictions about various pairs of consonants in each of the columns in Tables VI and VII. For example, according to MN, /k/ should rank above /g/ in column "p" (i.e., /p/ should be recalled for /k/ more often than /p/ is recalled for /g/), because /p/ and /k/ are both unvoiced, while /g/ is voiced, and /k/ and /g/ are identical in every other feature dimension. This prediction is referred to as a prediction made by the *voicing* dimension of the MN system, although clearly the other dimensions of MN play a rôle insofar as /k/ and /g/ must have the same values on these other dimensions. There is no way known at present to test whether one dimension is a significant predictor of error frequency completely independent of the other dimensions in a feature system. However, this way of testing a single dimension is at least partly independent of one's hypotheses about the other dimensions. For example, voicing and nasality are identical dimensions in all three feature systems, and the binary predictions made by voicing and nasality are also identical in all three feature systems, despite the fact that the other dimensions are rather different for the three feature systems. Nevertheless, it is the total accuracy of the predictions made by an entire feature system that is unambiguously interpretable, not the accuracy of each feature in the system. Table VIII gives the number of predictions made by each dimension of each of the three feature systems and also gives the percentage of these predictions that were correct for the recall data in Tables VI and VII. The auditory perception data of Miller and Nicely[8] were also analyzed in the same way, and the results are included in Table VIII.

The predictions of the dimensions that distinguish between the three feature systems (i.e., excluding voicing and nasality) are summed at the bottom of Table VIII to yield an over-all comparison of the accuracy of the three systems in predicting the errors in both perception and STM for English consonants. The accuracy of each of the three feature systems is consistently and significantly above chance, indicating that intrusion errors in STM tend to have distinctive features in common with the presented consonant.

Furthermore, the W system is consistently more accurate than the MN system, which is, in turn, consistently more accurate than the H system. The differences in accuracy are not statistically significant in the data of Miller and Nicely, but are highly significant in the total STM data of the present experiment. For the total STM data, W is significantly more accurate than MN at the 0.02 level ($\chi^2=6.17$) and significantly more accurate than H at the 0.001 level ($\chi^2=21.3$).

## IV. DISCUSSION

Regardless of which of the three distinctive feature systems one chooses, it is clear that consonant phonemes are not the most elementary units in which speech is coded in STM. Consonants are *not* remembered in an all-or-none manner. Some of the features of a consonant can be recalled when others cannot, producing a systematic tendency for the errors in short-term recall to have distinctive features in common with the correct consonant. This suggests that recall of a consonant means recall of a set of features that defines that consonant in memory, and each feature is recalled at least semiindependently of the other features.

The W feature system describes the errors in STM somewhat more accurately than the MN system and much more accurately than the H system. The W and MN systems are relatively easy to interpret in conventional articulatory dimensions. The H system was developed for the parsimonious description of the admissable sound sequences in different languages and has a more complex and less "natural" articulatory interpretation. The results of the present study suggest that, at least for random sequences of English consonants, STM uses an articulatory (or acoustic) code, not the more abstract H code. Distinguishing between an articulatory code and an acoustic code is very difficult at the present time and is not attempted here. However, it is clear that one does not need to postulate abstract levels that are not easily understood in acoustic or articulatory terms in order to predict the errors in STM for random sequences of English consonants. It remains to be seen whether errors in long-term memory or errors in STM for syntactically structured sequences of English consonants would be best described by the H system.

Why are the predictions of the W system not 100% accurate? There are many possible reasons. *First*, perhaps the dimensions of the system should be redefined slightly. One possibility that appears promising is to make voicing a multivalued dimension. This possibility was not investigated because it would have substantially reduced the number of predictions made by the W system under the present analysis, and I have not been able to think of a better method of analysis than the present one. *Second*, perhaps redundant articulatory dimensions should be included, such as tongue-tip retroflexion, lateralization, lip-rounding, etc. This was not investigated for the same reason as before. *Third*, estimating a large matrix of probabilities requires a very large number of trials before the random error is so low that one can believe the results of every individual paired comparison. The present experiment was not intended to achieve that objective. Thus, it is quite conceivable that the 73% accuracy of the W system is as high a repeatable accuracy as the variance in the data permits for that number of binary predictions.

Is the same feature system used in auditory perception of consonants as in STM for consonants? Comparison of the present findings with those of Miller and Nicely is consistent with this interpretation. But there is an ambiguity in the interpretation of error matrices for auditory perception that is not present in the interpretation of error matrices for memory experiments. The ambiguity concerns where the information that resulted in an error was lost. When auditory perception is tested under noisy conditions, as in the Miller and Nicely experiment, much of the information loss is undoubtedly occurring *outside* the subject. This could result in errors that follow a simple acoustic-feature system for reasons that have nothing to do with the nature of the organism. If one strives to make the conditions as noisefree as possible, it would take an unreasonably long time to obtain accurate estimates of the extremely low error probabilities.

When a subject correctly identifies a consonant and later recalls it incorrectly, one can be sure that the information loss has occurred inside the organism and the error matrix is providing information about the coding system used by the organism. Of course, the information may be lost at *several* different levels of the organism's control system, each of which has a very different code. If this is the case, then what we see in the STM error matrix is a composite of these codes, and precise interpretation becomes very complicated. However, even if there is multilevel information loss in the present STM experiments, it is likely that the amount of information lost at each level is not equal. If one level predominates in the information loss, its code will show up as the best predictor of the STM error matrix.

Thus, we are on reasonably safe ground in concluding that the W feature system (voicing, nasality, openness of the vocal tract, and place of articulation) is a good first approximation to the code used in STM for English consonants. Certainly, the other two feature systems are significantly less accurate in predicting the error matrices in short-term recall. However, it should be clear that we cannot conclude from this that the W system is optimal for predicting other types of behavior. The multilevel branching organization of individual modalities in the human nervous system indicates that there are many different codes for analyzing the same information. It is an open question whether all forms of speech behavior, syntactically structured and unstructured, are performed in one system that uses one code.

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