Mechanisms of aural encoding: VIII. Phonetic interference and context-sensitive coding in short-term memory

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In previous experiments Ss were presented for ordered recall with sequences of five consonant phonemes paired with /a/ in which the middle three consonant phonemes shared the same manner of articulation (voiced, unvoiced, nasal), the same place of articulation (front, middle, back), or neither the same manner nor place of articulation (control sequences). Compared to performance in control sequences, the middle consonant phoneme was always more difficult to recall in manner of articulation sequences but not in place of articulation sequences. The results suggested that for these sequences consonant phonemes were not remembered in terms of their place of articulation. In the present experiment, sequences of consonant-vowel (CV) or vowel-consonant (VC) syllables were presented for recall in which each consonant phoneme was paired with a different vowel. When consonant phonemes in the different sequence types were presented for recall with different vowels, phonetic interference was observed for the middle consonant in place of articulation sequences as well as manner of articulation sequences, and the effect was observed in both CV and VC groups. It was suggested that vowels are encoded in short-term memory in terms of their place of articulation and that presenting consonant phonemes for recall with different vowels caused Ss to use this dimension to code consonant phonemes in short-term memory.

Previous experiments have demonstrated that the phonetic similarity of a series of sounds affects a S's ability to recall the sounds (Cole, Haber, & Sales, 1968; Cole, Sales, & Haber, 1969). Specifically, when three sounds sharing the same manner of articulation (e.g., voicing, nasality) are presented in adjacent serial positions in a recall sequence, the middle sound is more difficult to recall relative to recall performance in a control condition where the identical sound is not embedded between similar sounds. Thus, /ma/ is more difficult to recall in Example 1 than in 2, since in Example 1 it occurs between two other nasal consonants. Example 1: /ba na ma ɲa ta/; Example 2: /ba ta ma ga na/.

Phonetic interference in short-term memory has been demonstrated for the voiced stops /b, d, g/, the unvoiced stops /p, t, k/, and the nasals /m, n, ɲ/. The results suggest that voicing and nasality features are used to discriminate among consonant phonemes in short-term memory. When the consonant phonemes in a sequence have an identical feature in common, this feature cannot be used to discriminate among them, and this is reflected in recall performance.

A second result of these experiments (Cole et al, 1968, 1969) is that place of articulation does not appear to be an essential feature for discriminating among

consonant phonemes in short-term memory. There is no decrement in recall for the middle consonant phoneme when three adjacent phonemes share the same place of articulation, either front (/ba, pa, ma/), middle (/da, ta, na/), or back (/ga, ka, ɲa/). This is illustrated in Fig. 1, which displays the error scores for sequences sharing the same manner of articulation or the same place of articulation. In this figure, error scores for consonant phonemes in manner or place of articulation sequences are subtracted from error scores for the same consonants in control sequences. Thus, points above the horizontal line indicate that more errors occurred in the similar feature than in the control sequence. The results of four independent experiments reveal that the middle sound is always more difficult to recall in a similar manner of articulation sequence than when it is in a control sequence, while phonetic interference does not occur for phonemes in place of articulation sequences relative to control sequences.

In previous experiments demonstrating phonetic interference, consonant phonemes were presented for recall paired with the vowel /a/ in CV syllables. Pairing all consonant phonemes in a sequence with the same vowel may have forced Ss to attend to individual distinctive features in order to discriminate among the consonant phonemes in short-term memory. The present

Fig. 1. Percentage differences for the manner and place of articulation sequences and the comparable sounds appearing in the control sequences as a function of position. Data at each point are summed over sounds in the three manner of articulation sequences and the three place of articulation sequences. The panel on the far left is taken from Cole, Haber, and Sales (1968), while the remaining panels represent the results of three independent conditions in an experiment by Cole, Sales, and Haber (1969).

experiment examines the phonetic interference phenomenon in short-term memory in sequences of CV or VC syllables in which each consonant phoneme is paired with a different vowel. Thus, in a similar feature sequence (e.g., /pI, mæ, nʊ, ŋɔ/), the consonant phonemes in Positions 2, 3, and 4 still share an identical feature (nasality) but are each paired with a different vowel.

It may be expected that presenting a series of CV or VC syllables with varying consonants and vowels would reduce or eliminate phonetic interference due to the distinctive feature similarity of consonant phonemes in adjacent syllables. It could be argued, for example, that by presenting consonant phonemes paired with different vowels Ss should be able to form associations between the phonemes in each syllable, or else form an association to the entire syllable. Moreover, if Ss are able to code an entire syllable as a single perceptual unit in short-term memory, phonetic interference due to individual consonant phonemes should be attenuated. However, if the phonemes within a CV syllable are independently coded as sets of distinctive features in short-term memory, as recent research suggests (Cole, 1973), then phonetic interference among consonant phonemes in adjacent syllables may still be expected to occur.

METHOD

Subjects

Fifty students from the University of Rochester introductory psychology course served as Ss. Their participation fulfilled 1 h of course requirement. The Ss were randomly divided into two groups of 25 Ss per group. Each S was tested individually in a session that lasted about 1 h.

Stimuli

The consonant phonemes /b/, /d/, /g/, /p/, /t/, /k/, /m/, /n/, /ŋ/ and the vowel phonemes /ɪ/, /æ/, /ʊ/, /ɔ/ were used as stimuli. A series of 108 sequences was constructed according to the distinctive feature composition of the consonants in the sequence. In all sequences, the consonant phoneme in the initial syllable shared neither the same place nor manner of articulation as the consonant phoneme in the second syllable. For 36 sequences the second, third, and fourth consonant phoneme shared the same manner of articulation (voiced, /b, d, g/; unvoiced, /p, t, k/; or nasal, /m, n, ŋ/). In an additional 36 sequences, the consonant phoneme in these positions shared the same place of articulation (front, /b, p, m/; middle, /d, t, n/; or back, /g, k, ŋ/). In the remaining 36 sequences, the adjacent consonant phonemes shared neither the same place nor manner of articulation (e.g., /b, t, m, g/).

Vowels were randomly paired with consonants in each sequence, with the restriction that each vowel occurred equally often with each consonant in each serial position and that no vowel was repeated twice in a single sequence.

The 108 sequences were randomly ordered and recorded on magnetic tape by a trained articulatory phonetician at the rate of one syllable per second. Thus, all Ss in a group heard the 108 sequences in the same order. Following the last syllable in each sequence, there was a 3-sec pause followed by a "click" which served as the signal for the S to report. This pause was included in order to allow Ss an opportunity to rehearse the series of syllables, since previous research (Cole et al, 1969) has implicated the importance of rehearsal for the phonetic interference effect. Two master tapes were made: one consisting of 108 sequences of CV syllables, the other consisting of 108 VC syllables. The tapes were identical, except that the order of phonemes in a syllable was reversed for the two tapes.

Procedure

Each S was randomly assigned to the CV or VC group. Ss were seated in a small sound-attenuated room with E. Ss were first presented with the 36 possible CV (or VC) combinations and were instructed to repeat each syllable after hearing it spoken on the tape recorder. They were then instructed that they would hear sequences of four syllables which they were to repeat in order after hearing the click. If a syllable was forgotten, Ss were instructed to either guess or say "blank." The experiment was begun after 10 practice trials. All responses were transcribed by E and recorded on a second tape recorder.

Scoring

An error was scored whenever a particular phoneme was not recalled in its original serial position. Thus, an error occurred whether S made an error of omission (S say "blank") or an intrusion (e.g., /bu/ for /du/).

RESULTS

Consonants

Figure 2 displays the accuracy of recall of the nine consonant sounds in the CV and VC group for the control sequences, in which any effects due to distinctive feature similarity should be minimized. Analysis of variance revealed that the observed differences in recall of consonant phonemes are statistically significant ($F = 19.2$, $df = 8/384$, $p < .001$). Consonant phonemes were recalled more accurately in CV than VC sequences ($F = 7.0$, $df = 1/48$, $p < .01$) and the interaction between phonemes and sequence type was significant ($F = 5.4$, $df = 8/384$, $p < .001$).

Analysis of variance for the CV group revealed significant differences in recall performance for the three sequence types (place, manner, control; $F = 9.1$, $df = 2/48$, $p < .001$), a main effect of serial position ($F = 25.7$, $df = 2/48$, $p < .001$), and a significant interaction between sequence type and serial position ($F = 7.7$, $df = 4/96$, $p < .001$). Analysis of variance for the VC group also revealed main effects of sequence type ($F = 4.9$, $df = 2/48$, $p < .025$), serial position ($F = 6.7$, $df = 2/48$, $p < .005$), and a significant interaction between sequence type and serial position ($F = 5.0$, $df = 4/96$, $p < .001$).

In order to examine the effects of distinctive feature similarity on recall performance, error scores were tabulated for each phoneme in Serial Positions 2, 3, and 4 in the manner, place, and control sequences. Then, for each serial position, the error score for each consonant phoneme in the control sequences was subtracted from the error score for the same phoneme in the same serial position in the manner and place of articulation sequences. The results of this analysis are presented in Fig. 3 for the CV and VC groups. The data at each point in Fig. 3 are combined at each serial position for the three manner of articulation sequences and the three place of articulation sequences in each group. It can be seen that phonetic interference occurs at Position 3 for both manner and place of articulation sequences for both CV and VC groups. Moreover, the magnitude of the phonetic interference effect is identical to that found in previous experiments for manner of articulation sequences, as shown in Fig. 1. Individual correlated means t tests indicated that neither place nor manner sequences differed from control sequences in Position 2 for either group; only the place of articulation sequences

Fig. 2. Percentage of correct recall responses for each of the nine consonant phonemes in the control sequences for consonant-vowel and vowel-consonant groups. Each point is summed over 25 Ss and, for each S, is summed over all serial positions.

in the CV group differed from the control in Position 4 ($t = 3.7$, $df = 24$, $p < .005$), while both place and manner sequences differed from the control sequences in both CV and VC groups in Position 3 ($p < .001$ in all cases).

The effect of distinctive feature similarity on recall performance is displayed for the individual manner and place of articulation sequences for the two groups in

Fig. 3. Percentage differences between manner and place of articulation sequences and comparable phonemes appearing in the control sequences for the consonant-vowel and vowel-consonant groups as a function of position. Data at each point are summed over the three sequence types defining manner of articulation and place of articulation sequences.

Fig. 4. Percentage differences between each place and manner of articulation sequence and the comparable phonemes in the control sequences for the consonant-vowel and vowel-consonant groups as a function of position.

Fig. 4. For manner of articulation sequences, correlated means *t* tests revealed that, at Serial Position 3, significantly more errors occurred in voiced and unvoiced sequences than in control sequences for both groups ($p < .02$ in all cases), while nasal sequences did not differ from controls. For place of articulation sequences, significantly more errors occurred in Position 3 for front and back sequences ($p < .02$ in all cases) but not for middle (alveopalatal) sequences. For Positions 2 and 4 no consistent differences were observed across the two groups for place or manner of articulation sequences.

Vowels

Figure 5 displays the percent correct recall performance for the different vowel phonemes in control sequences for the CV and VC groups. Analysis of variance revealed significant differences in recall of the different vowels ($F = 14.4$, $df = 3/144$, $p < .01$), a significant advantage for vowel recall in the VC group ($F = 13.2$, $df = 1/48$, $p < .001$), and a significant interaction between vowel recall and sequence type ($F = 8.8$, $df = 3/144$, $p < .001$). Note that, while consonants are recalled more accurately in sequences of CV syllables (see Fig. 2), vowels are recalled more accurately in sequences of VC syllables.

Analyses were also performed to determine the effect of consonant distinctive feature similarity within a sequence on recall of vowel phonemes. Analysis of variance for the CV group revealed significant differences in recall of vowels as a function of sequence type ($F = 5.5$, $df = 2/48$, $p < .01$) and a significant effect of serial position on recall of vowel phonemes ($F = 12.3$, $df = 2/48$, $p < .01$). However, no interaction was

observed between sequence type and serial position. This is shown in Fig. 6, which compares recall performance for vowel phonemes in manner and place of articulation sequences with recall performance for the same vowel phonemes in control sequences. It can be seen that there is a small (less than 5%) increase in errors for vowel phonemes in the CV group in manner and place of articulation sequences, and this effect is distributed equally across Serial Positions 2, 3, and 4. Analysis of

Fig. 5. Percentage of correct recall responses for the four vowel phonemes in the control sequences for the consonant-vowel and vowel-consonant groups. Each point is summed over 25 Ss and, for each S, overall serial positions.

variance revealed no significant effect of sequence type on a vowel recall for the VC group.

DISCUSSION

The present experiment demonstrates that phonetic interference occurs in short-term memory when consonant phonemes in a sequence of CV or VC syllables share the same place of articulation (front or back) or manner of articulation (voiced or unvoiced). As in previous experiments (Cole et al, 1968, 1969), the interference effect is restricted to the consonant phoneme in Serial Position 3; it is only in this serial position that consonant phonemes in *both* adjacent syllables in the sequence share the same place or manner of articulation.

An interesting result of the present experiment is that phonetic interference occurred in similar place of articulation sequences. In previous experiments, interference was consistently observed in manner of articulation sequences, but errors in place of articulation sequences were never significantly different from errors in control sequences. The reason for this effect appears to be that in previous experiments consonant phonemes were always paired with the vowel /a/, whereas in the present experiment the vowel was varied from one syllable to the next within a sequence. Thus, it appears that changing the vowel phoneme between adjacent syllables caused place of articulation to become a salient feature for discriminating among consonant phonemes in short-term memory.

It is likely that this context-conditioned effect is caused by the relative importance of place of articulation for encoding vowels in memory. Whereas consonant phonemes require several distinctive features for their description, of which manner features are perceptually more salient (Peters, 1963), vowels may be described solely in terms of their place of articulation. For example, in a classic set of experiments, Wickelgren (1965, 1966) showed that intrusion errors for consonants were best described by a distinctive feature system employing voicing, nasality, place of articulation, and openness of the vocal tract, whereas intrusion errors for vowels were perfectly predicted by the relative height and front-backness of the tongue required to produce the vowel. Thus, place of articulation is an essential feature for discriminating among vowels in short-term memory. In view of the evidence for the importance of place of articulation as an encoding variable for vowels, it is not surprising that place of articulation is indicated as an encoding variable for consonant phonemes when they are presented for recall in a sequence with different vowels.

This interpretation is consistent with Wickelgren's (1969) context-sensitive associative theory of sound encoding, which concludes that sounds presented in a serial order are encoded allophonically and not phonemically, since the encoding of each item is sensitive to the neighboring items. Several results in this

Fig. 6. Percentage differences for vowel phonemes in manner and place of articulation sequences and comparable vowel phonemes in the control sequences for consonant-vowel and vowel-consonant groups as a function of position. Data at each point are summed over the individual manner and place of articulation sequence.

study support this conclusion: (1) The observed consonant encoding differed from the data collected in prior research; place of articulation became an important variable here, in addition to the manner of articulation, and this appears to be due to the fact that both phonemes in the syllable were constantly changing. (2) The consonantal distinctive features most affected in the CV sequences differed from those most affected in the VC sequences. (3) More errors were made on consonants when the consonant was presented second rather than first. The same result occurred for vowels. (4) There was a significant difference in the recall of vowels as a function of the type of consonantal sequence it was embedded within.

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