The Speech Code and Learning to Read

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Good and poor readers among second-grade school children can be distinguished by the extent to which their recall of random letter strings is affected by the phonetic characteristics (rhyming or not rhyming) of the items. The recall performance of mildly backward (marginal) readers was less penalized by phonetic confusability than that of superior readers, and severely backward (inferior) readers showed a still weaker effect of confusability. These results were obtained not only for visual presentation of the letter strings (Experiments 1 and 2) but also for auditory presentation (Experiment 3). Taken together, the findings support the hypothesis that good and poor readers differ in their use of phonetic coding in working memory, whatever the sensory route of access, and they suggest that individual variation in coding efficiency may be a relevant factor in learning to read. It is suggested that a number of memory-related problems typical of poor readers may be manifestations of deficiencies in phonetic coding.

In the research presented here, we explore the possibility that children who learn to read with facility differ from those who learn to read with difficulty in the extent to which they rely on speech-related

processes in short-term memory. We have supposed that a major function of speech coding in reading is its use in comprehension of stretches of text longer than the word. Thus, our concern is directed toward the role of the phonetic representation as a medium for linguistic storage.

It is obvious that perception of language, whether written or spoken, requires that a reader or listener hold a sufficient number of individual words and their order of arrival long enough to permit interpretation of each sentence. There is a wealth of evidence (Baddeley, 1966; Conrad, 1964, 1972; Conrad & Hull, 1964; Hintzman, 1969) that for this purpose, the working memory, in both reading and listening, may rely on phonetic coding of the information to be retained. Whether the information is letters, words, or syllables, it is con-

sistently found that confusions in recall are greater when the items are phonetically similar than when the similarity is either visual or semantic. This suggests that perceivers have so strong a tendency to store the information in phonetic form that they persist in using this form of coding even when it penalizes recall. Strikingly parallel results have been obtained when words are presented logographically as Japanese kanji characters (Erickson, Mattingly, & Turvey, 1977) or as Chinese characters (Tzeng, Hung, & Wang, 1977), suggesting that phonetic coding may generally occur regardless of whether the reader uses an alphabet or a logographic writing system. Moreover, even when the stimuli are not linguistic items at all, but pictured objects, there is evidence that the information may nevertheless be recoded phonetically in memory (Conrad, 1972). Together, all these findings underscore the general use of phonetic coding as a widely applicable strategy for temporarily storing any information that can be linguistically processed.

We must consider, of course, the possibility that some readers may employ different kinds of working memory representations than listeners do. In principle, the possibility certainly exists that a nonphonetic representation of a visual or semantic kind might be used. Indeed, there is evidence that nonphonetic strategies are employed by some congenitally deaf readers (Frumkin & Anisfeld, 1977; Locke, 1978). But the well-attested difficulties of congenitally deaf children in learning to read (Swisher, 1976) also suggest that nonphonetic strategies may not work well.

Although it may be inferred that nonphonetic strategies are less common than phonetic ones for the normal adult, there is little information on children at the point of learning to read. We assume that successful beginning readers (of English) who have learned to relate the structure of the printed word to the phonological and phonetic structure of the spoken word,[1] have the phonetic form of the word available for use in working memory. Poor readers, on the other hand, have difficulty in employing

this analytic strategy, as the nature of their reading errors shows (Fowler, Liberman, & Shankweiler, 1977; Shankweiler & Liberman, 1972). Consequently, like some of the congenitally deaf, poor readers may tend to rely more on nonphonetic strategies in working memory.

The possibility that differences in children's use of phonetic coding may be related to success or failure in learning to read has only recently begun to be explored[2] (Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Shankweiler & Liberman, 1976). In consideration of the use of phonetic coding in the working memory (Baddeley, 1978; Baddeley & Hitch, 1974; Crowder, 1978; Kleiman, 1975; Levy, 1977), and in recognition of differences in the characteristic strategies of word recognition employed by successful and unsuccessful beginning readers, it seemed worthwhile to ask whether beginning readers who are progressing well can be distinguished from those who are doing poorly by the degree to which they rely

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[1] In considering the role of phonetic short-term memory in reading, we make no assumptions about the possible role that speech-related processes might play in word recognition. We would mention, however, that the reader of an alphabetically written language must derive a phonological representation from the orthography if he or she is to gain a major advantage of alphabetic writing: namely, the possibility of decoding new words never before seen in print. The mode(s) of lexical access, in the case of familiar words, is, of course, a separate question, and one that is not relevant to our concerns in this article. The need to distinguish the possible role of speech coding in lexical access from its role in working memory for stretches of text longer than the word is underscored by the findings, to which we referred, on readers of Chinese and Japanese. Users of these logographic orthographies might or might not enter the internal lexicon via a phonological representation; that is an open question. What is clear, however, from the findings of Tzeng, Hung and Wang (1977) and Erickson, Mattingly, and Turvey (1977) is that these logographic readers, like most adult readers of English, make predominantly phonetic confusions when they attempt to hold strings of logograms in short-term memory.

[2] Preliminary and incomplete accounts of portions of the findings presented here were included in Liberman, Shankweiler, Fowler, and Fischer (1977) and in Shankweiler and Liberman (1976).

on phonetic coding in a task designed to stress working memory.

A task was selected in which the effects of phonetic coding are readily detected. We borrowed a procedure devised by Conrad (1972) for adult subjects in which performance is compared on recall of phonetically similar (rhyming) and phonetically dissimilar (nonrhyming) sequences of letters. It was expected that the phonetically similar items would generate confusion and thus penalize recall in subjects who use a phonetic code. If poor readers were deficient in the use of a phonetic code, they might be expected to be less affected by the phonetic similarity of the items than good readers, whether or not the groups differ in recall of phonetically dissimilar items.

Experiment 1

Method

Subjects. The subjects were school children who were nearing completion of the second school year at the time the experiment was conducted. Reading teachers were asked to select the best and the poorest readers in their respective classes. These children were then given the word recognition subtest (Jastak, Bijou, & Jastak, 1965) of the Wide Range Achievement Test (WRAT) and a test of intelligence (Dunn, 1965), the Peabody Picture Vocabulary Test (PPVT). On the basis of scores obtained on the WRAT, three groups were selected that were nonoverlapping in reading level. Table 1 gives the particulars for each group.

As may be seen from the table, the first group, designated as the superior readers, was composed of 17 children who were reading well ahead of grade placement, having obtained a mean grade equivalent of 4.9 on the WRAT. The second group (the marginal readers) included 16 children who averaged slightly less than ½ yr. of retardation in reading (having obtained a mean WRAT equivalent of 2.5). The third group, containing 13 children whom we called the poor readers, obtained a mean WRAT equivalent of 2.0, indicating nearly a full year of retardation in reading.

The three groups did not differ significantly in mean age. In each, the mean IQ level as assessed by the PPVT was above 100. The means were closely matched for the two extreme groups. The marginal readers averaged about 10 score points below the others, a fact that, in view of the results obtained, could not be of great importance.

Stimuli: Simultaneously presented letter strings. Sixteen strings of five uppercase letters were devised for presentation by projector tachistoscope. Eight

Table 1
Means For Second-Grade Children Grouped According to Reading Attainment

Group	n	Age	IQ[a]	Reading grade[b]
Superior	17	8.0	113.9	4.9
Marginal	16	8.1	101.7	2.5
Poor	13	8.2	111.6	2.0

[a] Peabody Picture Vocabulary Test.
[b] Reading grade equivalent score on reading subtest of the Wide Range Achievement Test.

of the five-letter strings were composed of rhyming consonants (drawn from the set B C D G P T V Z), and 8 were composed of nonrhyming consonants (drawn from the set H K L Q R S W Y). In generating the test sequences, each letter was allowed to appear only once in a given sequence and all letters appeared equally often in each serial position. The rhyming and nonrhyming sets were interleaved, and all 16 sequences were randomized. The test sequences were preceded by an identification test in which each of the 16 consonant letters was presented individually, centered on the screen, twice each in randomized order.

A 2 × 2 in. (5 × 5 cm) slide was constructed for each of the 16 test sequences. Each typed letter string was centered on the slide, the group of five letters subtending a visual angle of 4.8° horizontally when projected on the viewing screen for a viewing distance of 11 ft. (3.3 m). The slides were displayed using a slide projector equipped with a projector tachistoscope, which was controlled by a bank of three 100-sec timers.

Procedure. The subjects were tested in groups of approximately 15 children. First, the identification pretest was given. Each pretest trial was preceded by an alerting stimulus, an asterisk, centered in the display field and shown for 1 sec. The stimulus followed 1 sec after the asterisk was turned off. Each letter was then displayed for 1 sec, after which the children were allowed as much time as needed to write the letter on the answer sheet. After completion of the pretest, the children were told that they were about to see groups of letters, and that their task was to write the letters in the order given when the experimenter said "write." The procedure for the test trials was the same as in the pretest except that each five-letter stimulus item was displayed for 3 sec.

The test was given twice, once with immediate recall and once with delayed recall. Three practice trials introduced each condition. In the first condition, the children were requested to write their responses immediately following each exposure. In the delay condition, 15 sec elapsed between tachistoscope presentation and the signal to respond. The children were requested to sit quietly during the delay interval; no intervening task was imposed. Half of the subjects began the test session with the

immediate recall condition; the remainder started with the delayed recall. The children recorded their responses on an answer sheet containing rows of five underlined blank spaces.

Results and Discussion

Few errors occurred in identification of single letters on the identification pretest, and there were no significant differences among the reading groups. We assumed, therefore, that any differences between the groups in their performance on the experiment proper are not attributable to differential accuracy in letter identification.

Serial recall of the five-item sequences was scored in two ways. The first, more stringent, procedure counted a response as an error if it was an incorrect item identification or if it was a correct identification assigned to the wrong serial position. The second procedure counted a response as an error only if it was not a member of the stimulus string. In either case, the dependent measure for each subject was the total number of errors summed over serial positions.

We first consider the analysis based on the more stringent scoring procedure. The error data for this analysis in Experiment 1

and in the subsequent experiments are summarized in Table 2. To show the overall effect of phonetic confusability most clearly, Figure 1 displays the results averaged across the delay and nondelay conditions. It is apparent from inspection of Figure 1 (top graph) that phonetic similarity exerts an effect, but that the effect is much stronger for superior readers than for poor ones, with marginal readers falling in between.

These effects were substantiated by a three-way factorial analysis of variance, in which the between-groups factor was reading achievement and the within-groups factors included item type (i.e., rhyming or nonrhyming letter names) and delay or nondelay of response. The overall effect of reading group was significant, $F(2, 43) = 22.7$, $p < .001$, in the expected direction: Superior readers made fewer errors than the others. We see at once that the main differences were between the superior readers and the other groups; marginal and poor readers did not differ significantly from each other.

In accord with many past findings on adults, the phonetic characteristics of the items markedly influenced the rate of cor-

Table 2

Mean Errors Summed Over Serial Positions[a] for Simultaneous Presentation of Visual Sequences (V1) in Experiment 1 and for Successive Presentation of Visual (V2) and Auditory (A) Sequences in Experiments 2 and 3

| | | Immediate recall | | | | | | Delayed recall | | | | | |
| | | Confusable | | | Nonconfusable | | | Confusable | | | Nonconfusable | | |
Statistic		V1	V2	A	V1	V2	A	V1	V2	A	V1	V2	A
							Superior readers						
M		20.1	20.9	22.4	10.8	10.0	6.3	29.1	27.7	26.9	10.8	11.6	8.4
SD		5.8	6.4	6.2	7.0	7.9	5.7	5.1	5.6	4.4	6.5	7.7	7.0
							Marginal readers						
M		25.1	26.8	25.9	19.9	22.2	18.0	31.1	31.3	31.7	25.1	24.4	23.2
SD		4.4	6.8	7.0	5.2	9.0	9.7	5.1	4.5	4.0	8.5	10.7	9.2
							Poor readers						
M		28.4	31.4	31.7	24.2	24.2	21.4	30.5	35.1	34.7	25.8	24.2	25.2
SD		1.9	4.8	3.4	6.0	8.2	7.0	4.6	3.0	2.6	5.9	8.8	6.2

[a] Maximum = 40.
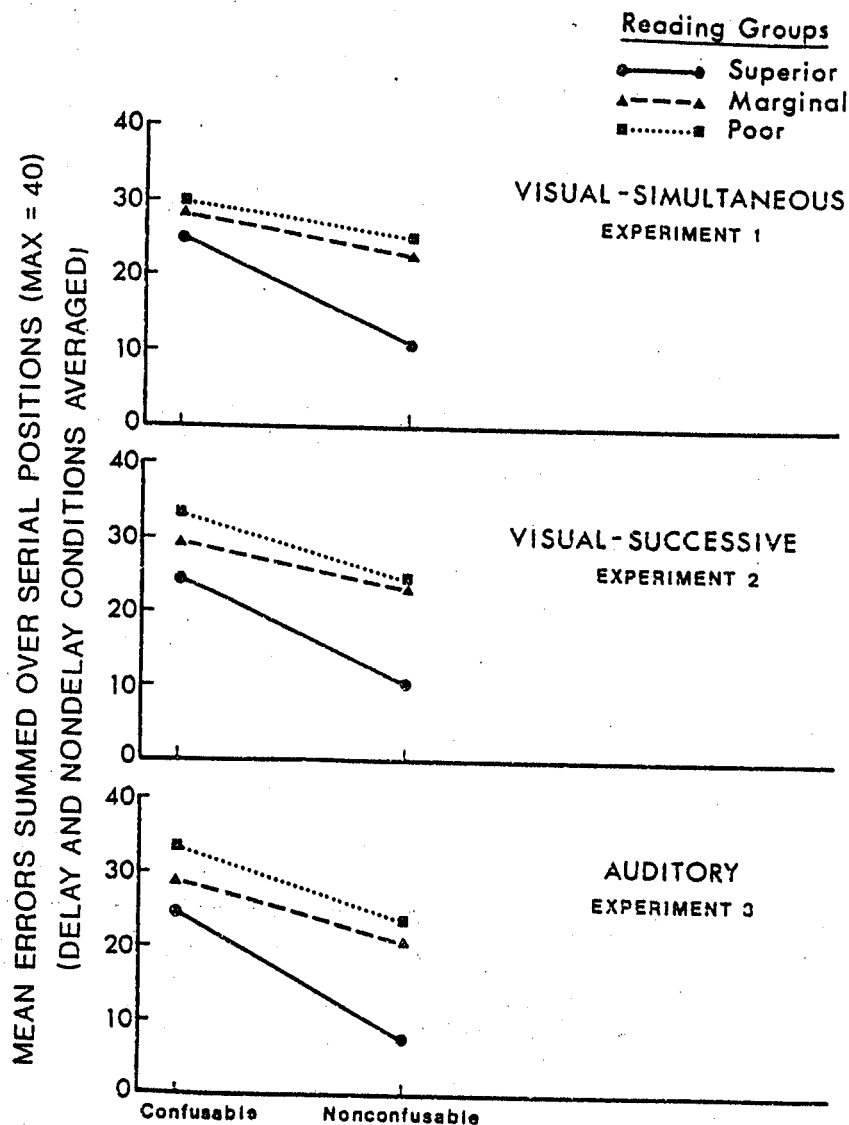
Figure 1. Mean recall errors summed over serial positions. (Means from delay and nondelay conditions are averaged.)

rect recall of the children as a whole; that is, there was a significant main effect of item type, $F(1, 43) = 73.0$, $p < .001$. But of particular interest from our standpoint is the fact that there were notable differences in the effects of phonetic similarity on the recall of children who differed in reading level. Thus we find a significant interaction between reading group and item type, $F(2, 43) = 9.9$, $p < .001$. It is apparent from the figure that the superior readers were more adversely affected by item confusability than the other groups.

Thus far we have examined the gross aspects of the response pattern, having considered errors summed over serial positions and averaged over the delay and nondelay conditions. Figure 2 displays errors for each serial position separately for nondelay (top) and delay (bottom) conditions. Two facts stand out on inspection of the figure. First, a strong effect of serial position is present in the data of all three reading groups. Second, Figure 2 makes readily visible a fact already mentioned in discussion of the top graph of Figure 1—namely,
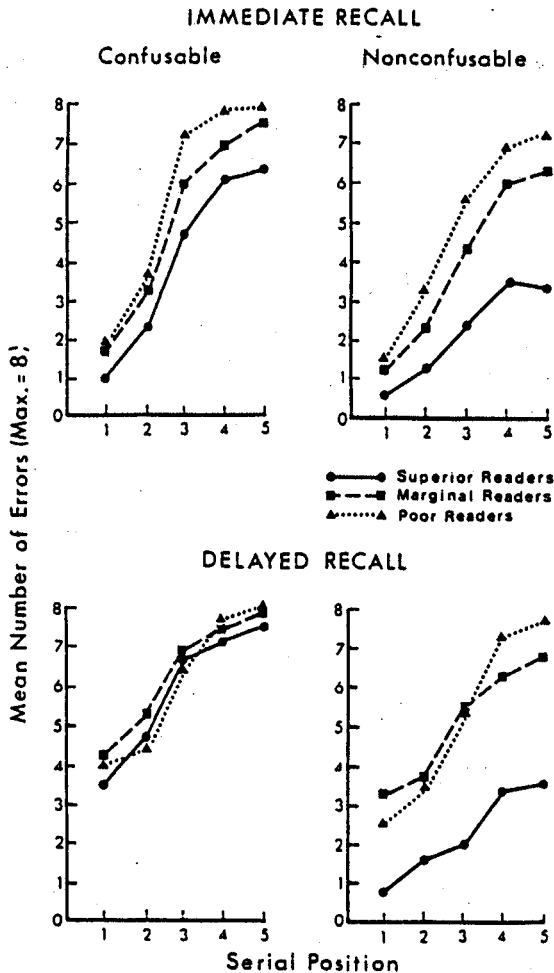
Figure 2. Mean recall errors for the visual-simultaneous condition (Experiment 1) replotted as a function of serial position.

that the superior readers were more strongly penalized than the inferior readers by phonetic confusability among the stimulus items.

We now see that the penal effect of phonetic confusability on the good readers was magnified by delay of recall. Delay led to an overall increase in errors, $F(1, 43) = 29.8$, $p < .001$, but its effect is marked only in superior readers. The interaction between group and delay was not significant, $F(2, 43) = 2.3$, $p = .113$, but when we take into consideration the additional factor of item type, the three-way interaction was significant, $F(2, 43) = 8.2$, $p < .001$. It is apparent from inspection of the figure that the interaction was due

to the departure of the superior group's performance from the performance of the poor and the marginal readers. It may be seen in the lower portion of Figure 2 that the superior readers were sharply distinguished from the others in recall of phonetically nonconfusable items, and nearly indistinguishable in their recall of confusable items.

In view of speculation that a function of the phonetic representation in working memory is to preserve information about serial order, it is of interest to ask to what extent this pattern of results reflects errors of serial order alone, and to what extent it reflects forgetting of the items. The data obtained from the less stringent scoring procedure (in which responses were scored without regard for serial order) were subjected to an analysis of variance parallel to that previously described. The results can be stated briefly. All of the main effects and interactions that were significant in the analysis of the data in which serial order was taken into account were also significant when the order in which the subject wrote down the responses was ignored. We interpret this to mean that the pattern of results reflects the forgetting of items, not merely errors of serial order.

To summarize the findings of Experiment 1, we have seen that superior readers were clearly better at recall of phonetically nonconfusable items than were the poor readers while failing to show a clear advantage on the confusable items. We regard this as an interesting result. It is a relatively easy matter to demonstrate that poor readers do less well than good readers on a variety of language-dependent tasks. But here, by manipulation of the phonetic characteristics of the test items, we have virtually eliminated the advantage of the superior readers.

It might be supposed, following a line of thought adopted by Bakker (1972) and Corkin (1975), that poor readers suffer specifically from a difficulty in reproducing the *order* of the items in the memory set. Although this idea may have some merit, our results suggest that the difference between our groups of good and poor readers

cannot be attributed solely to differences in susceptibility to order confusions, since the pattern of the results was much the same when the scoring credited the correctly recalled items regardless of whether they were recalled in the correct serial position.

The results of Experiment 1 bear out our expectation in demonstrating significant differences in susceptibility to phonetic confusions in working memory among children who differed in reading ability. It may be, as the strongest form of our hypothesis would suppose, that poor readers attempt to hold the items in memory in some nonphonetic form. If they were attempting to use a nonphonetic strategy, they could not wholly have succeeded, since they did show some effect of confusability. Speculation is, in any case, premature until we know the result of presenting the sequences to be recalled to the ear instead of to the eye.

Experiments 2 and 3: An Auditory Analogue and Its Visual Counterpart

From the results of Experiment 1, it could be argued that the problem of the poor readers lies in recoding visual symbolic material into phonetic form. If this is the case, then phonetic confusability of auditorily presented items should affect them neither more nor less than the superior readers. Moreover, even if there were quantitative differences in memory capacity between the two groups, we might still expect that the interaction between reading level and item type (demonstrated in Experiment 1) would disappear. If, on the other hand, the interaction remained, then it would follow that the difference between good and poor readers in their use of a phonetic representation is not specifically linked to the visual information channel.

In Experiment 1, it will be recalled, the five-letter sequences were presented in a single exposure. Since auditory presentation requires temporally successive presentation of the items comprising each trial, a parallel visual experiment was required with successive exposure of the items in each letter

sequence. The new experiments—the auditory recall task (Experiment 3) and its visual counterpart (Experiment 2)—were made to be as nearly identical as possible except for modality of input. We were fortunate in being able to carry out the new experiments on the same subjects who participated in Experiment 1. The children who served as subjects in Experiment 1 were used in Experiments 2 and 3, which were carried out 4–5 mo. after the original investigation. Two of the poor readers from the original sample had moved away from the area, leaving 11 poor readers. The loss of these subjects did not significantly alter the mean chronological age (CA), IQ, or WRAT reading grade of the poor readers (CA = 8.3; IQ = 111.6; WRAT grade equivalent = 2.0).

Method

Visual Successive Task (Experiment 2)

Stimuli. The sequences of letters used in this experiment were the same as those of Experiment 1. However, in the present experiment the letters in a trial were presented successively rather than simultaneously as in Experiment 1. One letter was centered on each slide; thus, five slides were required to form the entire sequence. An additional slide containing an asterisk was inserted at the beginning of the letter slides as a preparatory signal. An identification pretest employed the same slides as were used in Experiment 1.

Procedure. The subjects were tested in groups of no more than six. The instructions and test procedure for the visual identification test were identical to those given in Experiment 1 with the exception of the exposure duration, which was, in this case, 500 msec per letter, with an interstimulus interval of 1 sec. Following the identification test, directions for the letter sequences were given. The children were told that on each trial an asterisk would be displayed to signal that a letter sequence was about to appear. At the same time the experimenter operating the tachistoscope would say "ready." Five letters would then be displayed one by one. The children were instructed to write down the letters in the order in which they were presented. They were instructed to begin writing at the sound of a "clicker," which had been demonstrated previously. In the immediate recall condition, the clicker was sounded just as the last letter disappeared from the screen. On the delayed recall task, the experimenter waited for a timed interval of 15 sec before sounding the clicker. Three practice trials were given before each recall condition.

The children wrote their responses in booklets,

on each page of which was a single line of five dashes corresponding to the five items in a sequence. A separate page in the booklet was used for each sequence. Page colors were alternated so that it could easily be determined that the children were all writing their responses on the appropriate sheet.

Auditory Task (Experiment 3)

The auditory version of the serial recall task was presented to the children on a different day. In most cases a week or more elapsed between the two test sessions. The order of the visual and auditory presentations was counterbalanced.

Stimuli. The stimuli consisted of recorded utterances of the names of the same set of 16 letters that were employed in the two preceding visual experiments. One token of each was recorded on magnetic tape by a male speaker. The recorded utterances were subsequently digitized and edited using the pulse-code modulation (PCM) system at Haskins Laboratories (Cooper & Mattingly, 1968). The purpose of editing was to equate the duration of the tokens and to adjust the peak amplitudes, making them as equal as possible. The items for an identification pretest were prepared in the same manner.

The stimulus sequences were also constructed with the aid of the PCM system and a timing program designed to output timed sequences of stimuli (Cooper & Mattingly, 1968). A recorded utterance of "ready" preceded the first item of each sequence. The first stimulus token followed 1 sec after the offset of the preparatory stimulus. The interstimulus interval within each sequence of five tokens was also 1 sec. A sequence was terminated by a brief 1000-Hz tone that sounded 250 msec after the offset of the final item in the immediate recall condition, and 15 sec after in the delayed recall condition. The tone served to signal the subjects to begin writing the preceding sequence. An intertrial interval of 15 sec was programmed to allow ample time for the subjects to record their responses. In the rare instances in which a child required more time, the experimenter stopped the tape between trials. The silent period was broken by the signal "ready," which marked the beginning of the next sequence.

Procedure. The instructions and procedure for the auditory task (Experiment 3) were identical to those employed in the visual sequential task (Experiment 2) with the exception that a tone programmed on the test tape was used to initiate the written responses instead of the sound of a clicker controlled by the experimenter. The children were tested in groups of six or less. Two experimenters were present at each session. One was responsible for reading the instructions to the children and monitoring their behavior during the test; the other operated the tachistoscope or magnetic tape playback. As in the visual experiments, the auditory test sequences were preceded by an identification pretest.

Results and Discussion

Data from Experiments 2 and 3 were analyzed in a fashion parallel to Experiment 1. Two three-way factorial analyses of variance were performed, one on each set of scores, to evaluate the effects of reading group, item type, immediate versus delayed recall, and the interactions among these variables. A third analysis of variance was carried out to permit direct comparison of the visual and auditory modes of presentation on recall performance. This was a four-way factorial analysis in which modality, item type, immediate versus delayed recall, and reading group were the variables.

The data of Experiments 2 and 3 are summarized in Table 2 in the columns headed V_2 (visual-successive condition) and A (auditory condition). Each cell in this table gives the mean error score, with its standard deviation averaged across subjects within each group and summed over serial positions. The table permits us to compare the results of the two visual conditions and the auditory condition side by side. These results are remarkable for their similarity across conditions. The visual-successive condition (of Experiment 2) yielded a similar pattern of results to those of the visual-simultaneous condition of Experiment 1. This was expected. What was unexpected is that auditory presentation resulted in many of the same differences between the performances of good and poor readers as were obtained in the visual conditions.

Visually Presented Sequences (Experiment 2)

Because this was essentially a control experiment for the auditory–successive condition (Experiment 3), we can be brief in our description of the results. They are of interest chiefly in that they replicate so completely the results of Experiment 1, which differed from the present experiment in only one major methodological particular: The group of items to be recalled was presented in a simultaneous display instead of successively one by one.

As in the earlier experiment, each of the main effects of the analysis of variance was significant ($p < .001$). They were as follows: reading groups, $F(2, 41) = 11.9$; item type, $F(1, 41) = 115.3$; and immediate versus delayed recall, $F(1, 41) = 16.4$. We now examine the interactions of interest. Superior readers, as in Experiment 1, were more affected by the phonetic characteristics of the items than the other groups. This is manifested by a significant interaction between reading group and item confusability, $F(2, 41) = 6.5$, $p < .005$. A comparison of the top panel of Figure 1 (the comparable interaction under simultaneous presentation) with the middle panel shows that each interaction effect occurred because the superior readers made fewer errors than the inferior groups on the phonetically dissimilar sequences, whereas the three groups were more nearly at the same performance level on the rhyming sequences.

The analysis does reveal one difference between the two experiments. A feature of Experiment 1 was a significant three-way interaction between reading group, item type, and immediate versus delayed recall, reflecting the fact that delay magnified the differences between the groups, but only on nonrhyming items. This interaction was not obtained in the present experiment, $F(2, 41) < 1$.

Auditorily Presented Sequences (Experiment 3)

It is apparent from inspection of Table 2 that the results of the auditory condition closely paralleled those of the two visual conditions. As in the visual conditions, the factor of the phonetic similarity of the items is a potent one. Each main effect of the analysis of variance was significant at $p < .001$. They are as follows: reading group, $F(2, 41) = 18.7$; item type, $F(1, 41) = 192.2$; immediate versus delayed recall, $F(1, 41) = 39.2$.

Whether, as with visually presented stimuli, the phonetic characteristics of the items to be recalled affect good and poor readers differently is the major focus in this experiment.[3] The analysis shows that this is indeed the case, as revealed by a significant interaction between reading group and item type, $F(2, 41) = 10.7$, $p < .001$. A comparison of the graph of this interaction effect (Fig. 1, bottom panel) with the comparable ones from the visual conditions (top and middle panels) shows that the interaction was significant for the same reason as before; the superior readers were more affected by the confusable sequences than were the inferior reading groups. As in Experiment 2, but not in Experiment 1, there was no significant three-way interaction between reading group, item type, and immediate versus delayed recall, $F(2, 41) < 1$.

We will be aided in making a detailed comparison between Experiment 2 and Experiment 3 by examination of Figure 3. This figure (directly comparable to Figure 2) gives mean recall errors for each serial position on each experimental condition. Comparing the graphs in the first column of the figure with those in the second, we see that although the marginal and poor readers did show a degree of phonetic interference, it is clearly of lesser magnitude than that displayed by the superior readers. If we compare the plots in these columns of the figure with the graphs in columns 3 and 4, we see that the pattern is re-

[3] The question arises whether the phonetic and visual characteristics of the letter strings might have been confounded, with the effect of obscuring the interpretation of the results. To assess phonetic confusability independent of any confounding effects of visual similarity, we carried out an additional analysis of the data of Experiments 2 and 3, examining only the errors in which phonetic confusion, but not visual confusion, could be implicated (e.g., "B" occurred as the response at the position in which Z occurred in the stimulus string). Thus, this analysis excluded from consideration errors that are ambiguous (e.g., the response "B" for P). Classification of the errors was based on the results of visual and phonetic similarity scaling by Wolford and his colleagues (Wolford & Hollingsworth, 1974; Wolford & Porter, Note 2). The results of the analysis of unambiguous cases showed that good readers still uniformly made a significantly higher proportion of phonetic confusions than the poor readers. Details of this analysis will be made available to the reader on request.
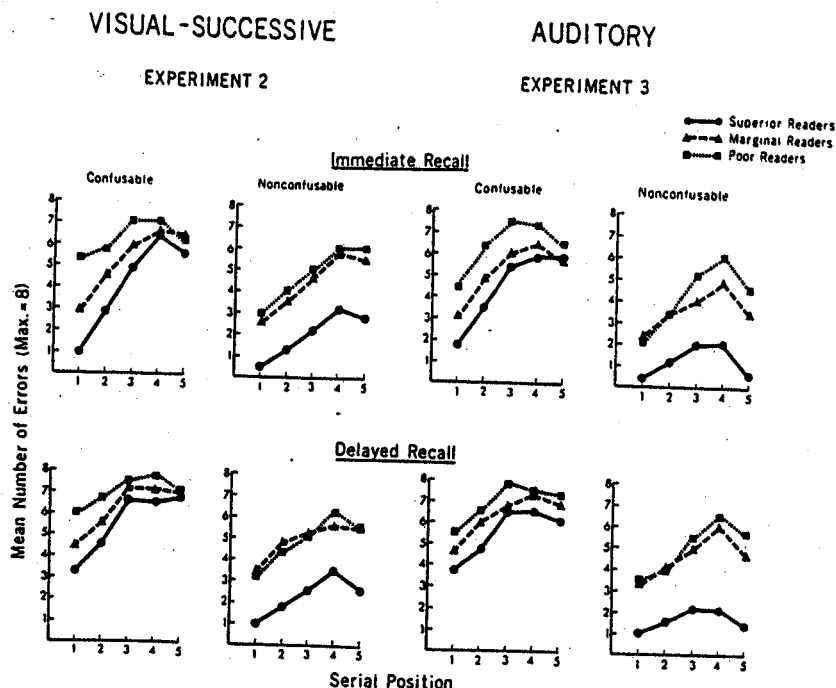
Figure 3. Mean recall errors for the visual-successive condition (Experiment 2) and the auditory condition (Experiment 3) replotted as a function of serial position.

markably similar to that obtained in the visual counterpart to this experiment. This point is demonstrated statistically by the analysis of variance in which the factor of immediate versus delayed recall was collapsed giving a four-factor design in which the factors were modality (visual vs. auditory), reading group, serial position, and item type. In this analysis the Modality ✕ Reading Group ✕ Item Type interaction failed to approach significance, $F(2, 41)$ = 1.4. Thus the factor of phonetic similarity was no less potent in its effect on auditory presentation than on visual.

As in Experiment 1, a set of parallel analyses of variance was carried out on scores derived from an alternative method of scoring in which serial order was disregarded in tallying the items correctly recalled. The outcome is basically the same as that reported for Experiment 1. The significant main effects and the interactions that we have considered above all yielded significant effects in both the auditory and visual conditions.

The principal thing we learn from Experiments 2 and 3, as plainly revealed in Figure

3, is that phonetic similarity produces a differential effect on the recall by good and poor readers whether the items are presented auditorily or visually. This leads us to a different interpretation of the phenomenon than the one we favored when we had done Experiment 1 but before we had completed Experiments 2 and 3. Our original supposition was that the poor readers' difficulty had to do with *recoding* from alphabetic characters to a phonetic representation of the linguistic message. Experiments 2 and 3, on the other hand, tell us that poor readers have difficulty accessing or using a phonetic representation whether its origin is print or speech. Hence, the problem could not be limited to recoding.

A difference may be noted between the outcome of Experiment 1 and Experiments 2 and 3 in the effects of immediate and delayed recall on the error score. In Experiment 1, we noted that delay magnifies the differences between the reading groups in susceptibility to phonetic confusion in recall. This is manifested in a significant triple interaction in the analysis of vari-

ance. However, no interaction was present under either the visual or the auditory conditions of Experiments 2 and 3, respectively. Thus we may be sure that this discrepancy has nothing to do with modality of input. As we shall see, it can plausibly be attributed, instead, to the manner in which the stimuli were presented—that is, successively or simultaneously, since Experiments 2 and 3 share the characteristic of successive presentation in contrast to Experiment 1 in which the group of letters was presented simultaneously.

General Discussion

Possible Consequences of a Deficiency in Phonetic Coding

Each of the three experiments answers yes to the question that motivated our investigation: Can good and poor readers be distinguished by the extent to which their performance on a serial recall task is affected by the phonetic characteristics of the items? Although superior readers made considerably fewer errors than poorer readers on the nonrhyming letter strings, the groups were less distinguishable on the rhyming strings. The recall performance of both the mildly backward ("marginal") readers and the severely backward ("inferior") readers was less penalized by phonetic confusability than that of the superior readers in simultaneous visual presentation of the letter strings (Experiment 1), in successive visual presentation (Experiment 2), and in auditory presentation (Experiment 3).

The findings of the three experiments, taken together, support the hypothesis that good and poor readers differ in their use of speech coding, whatever the route of access, and they suggest that individual variation in coding efficiency places limits on reading acquisition. Since differential effects of phonetic confusability on good and poor readers occurred regardless of whether input was to the eye or to the ear, we suspect that difficulties of poor readers are not limited to the act of recoding from script, but that they are of a more general nature. A benefit of this hypothesis is that it

permits us to bring together a number of previously unrelated findings regarding the cognitive characteristics of poor readers and permits us to view the findings as related manifestations of a unitary underlying deficit. It remains for us to examine the expected consequences of a general phonetic coding deficit both within the confines of our experimental task and in the reading process generally.

Rehearsal. A possible manifestation of a general deficiency in the poor readers' use of a phonetic code is slow, ineffective rehearsal of phonetically coded items. Given that the three experiments demanded retention and recall of arbitrary strings of items, it may be said that the situation encouraged rehearsal. Phonetically confusable items could reasonably be expected to generate more interference for good readers than for poor readers if the good readers rehearse confusable items at a more rapid rate.

An interpretation that emphasizes the relevance of rehearsal is compatible with the results of Experiment 1 (visual simultaneous stimulus presentation), in which it was found that imposing a 15-sec delay between stimulus presentation and recall adversely affected the good readers' performance on rhyming items and the poor readers' performance hardly at all. However, these differential effects of delay of recall were absent in Experiments 2 and 3. In these experiments, both groups were adversely affected by delay. The relevant difference is presumably the successive presentation of items that permits opportunity for rehearsal during delivery of the string. It is possible that successive presentation may tend to evoke an active rehearsal strategy in both good and poor readers.

In any case, the experiment of Mark, Shankweiler, Liberman, and Fowler (1977) leads us to believe that differences in efficiency of rehearsal cannot alone account for the differences we obtained between good and poor readers. The subjects in the study of Mark et al., selected in the same manner as those in the present experiments, were tested on rhyming and nonrhyming words using a recognition memory task

that minimized the opportunity for rehearsal. As in the present study, the good readers were adversely affected by phonetic similarity among the items to a much greater extent than the poor readers, though rehearsal strategy or its effectiveness could not plausibly have been a distinguishing factor.

However, none of the findings we have mentioned is incompatible with the possibility that a short-term rehearsal loop plays an important part in reading and in learning to read, as Baddeley (1978) has suggested. It would be of interest to discover whether good readers are more susceptible to suppression of rehearsal than poor readers. In this connection, Bauer (1977) has studied matched groups of children with and without "learning disabilities" on recall of word strings in which a delay interval was either unfilled or occupied by a task designed to block rehearsal. Differences between the groups were greater with the unfilled interval, suggesting that the subjects with learning problems did rehearse, but not as effectively as the controls. At any rate, with respect to the proposal that poor readers have a rehearsal problem, we wish to maintain that underlying the slower (or otherwise less effective) rehearsal of the poor readers may be their poorer access to a phonetic code or their access to a degraded phonetic representation. Thus, from our perspective, the primary problem is the availability of a phonetic representation, not rehearsal per se.

Span length. Another expected manifestation of inefficient coding would be a reduced memory span. It is possible that poor readers exhaust relatively more of their central processing capacity on the task of coding the items and have a reduced recall span as a consequence (see Perfetti & Lesgold, in press). It was indeed the case that in each of the present experiments, the reading groups differed in overall accuracy of recall. Our results are in agreement in this respect with earlier work by Naidoo (1970) and Miles and Miles (1977) in finding that reading ability is related to memory span in ordered recall.

We interpret the relative brief memory span of poor readers as the result of some deficiency in the use of phonetic coding. An alternative interpretation would treat the difference in memory span as the fundamental difference between good and poor readers, and would attribute the statistical interaction between reading group and phonetic confusability–nonconfusability to the greater difficulty of both the rhyming and nonrhyming tasks for the poor readers. The poor readers' limited span places them at or near chance level in the later serial positions on the more difficult task of recalling the rhyming items (see Figures 2 and 3) and therefore gives them less room to show an effect of phonetic confusability. There is no way to choose between these interpretations within the confines of the serial recall experiment. However, the investigation by Mark et al. (1977), to which we referred, demonstrated an unequivocal interaction between phonetic confusability and level of reading ability on a recognition memory task lacking the methodological difficulties inherent in the serial recall type of experiment.

Also relevant to the interpretation of our findings is the fact that poor readers, though impaired on tasks involving verbal material, may perform at the same level as good readers on nonlinguistic memory tasks (Vellutino, Pruzek, Steger, & Meshoulam, 1973; Vellutino, Steger, & Kandel, 1972). Two studies that find deficits in poor readers in recall of abstract figural patterns (Morrison, Giordani, & Nagy, 1977) and in recall of spatiotemporal patterns (Corkin, 1975) cannot properly be regarded as contradictory, since in both cases the tasks lend themselves to verbal labeling. Evidence from our own laboratory shows no significant differences between good and poor readers on a memory task employing highly abstract nonsense figures and faces (Liberman, Mark, & Shankweiler, 1978).[4] The existing data are consistent with the hypothesis that the deficiency of poor readers on memory

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[4] A full account of this study, which includes M. Werfelman as a coauthor, is in preparation.

tasks is limited to situations in which speech coding can readily occur.

New Directions

The preceding discussion suggests that the hypothesis of differences in the use of speech coding in working memory by good and poor readers may bring a unifying perspective to other often cited difficulties of poor readers: limited span in verbal recall and inefficient rehearsal. It remains to consider the consequences of the temporal order requirement of the task and to probe the origins of the phonetic coding deficit.

In view of suggestions in the literature (Crowder, 1978) that a major function of phonetic coding in working memory is to preserve information about temporal order, it is appropriate to consider whether difficulty specific to recalling the order of items is a manifestation of a faulty phonetic representation. With this possibility in mind, we rescored the subjects' responses in each experiment ignoring order and giving credit for any correctly recalled item regardless of the order in which it was written down. The change in scoring procedure did not significantly alter the differences among the reading groups with regard to susceptibility to phonetic confusion. The present study, however, was not designed to distinguish order memory from item memory and therefore does not permit us to draw any definite conclusions as to whether good and poor readers differ in this respect. We are currently investigating the possibility that difficulties in ordered recall and recognition in poor readers are limited to situations in which speech coding is likely to occur. The question is the more interesting in view of Bakker's (1972) claim that in tests of perception and retention of information about order of items, the verbal or nonverbal nature of the task requirements is crucial.

It remains to be explored whether the problem that poor readers have in dealing with the phonetic representation stems from faulty establishment of phonetic encoding or reflects a difficulty of access to it. If the problem is chiefly of the latter kind, it will be important to discover what it is that limits access to the phonetic representation in poor readers. As for the hypothesis that the quality of the phonetic representation is the distinguishing factor, the possibility needs examination that subtle deficits might be demonstrated by children with reading disabilities in their perception of the acoustic cues for speech. Initially, this possibility seemed unlikely. There were no apparent difficulties in speech production or speech understanding in the poor reading groups. Indeed, these children were apparently indistinguishable from the superior readers. However, it is conceivable that although there were no clinically apparent deficits in spoken language, suitably subtle analytic techniques, such as those used in the study of the acoustic cues for speech perception (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967), might reveal differences between the good and poor readers.

Whether the origin of the language deficits in poor readers is in phonetic perception or whether it is specific to the memorial aspects of language, we may appropriately ask whether good and poor readers differ in susceptibility to phonetic confusions in memory for materials that are more like text designed for normal reading than are random letter strings. If poor readers typically have a genuine problem in phonetic coding, the effects should be demonstrable in sentence processing. At present we are investigating differences between good and poor readers in recall of semantically meaningful and nonmeaningful sentences and random word strings in which, for each type of material, a parallel comparison can be made between items that do and those that do not offer the opportunity for phonetic confusions to occur (Mann, Liberman, & Shankweiler, Note 1).

Up to this point we have not considered possible alternatives to phonetic coding in working memory and their use in reading. The obvious possibility is that children with reading disability have a tendency to code memory representations of print into

some visual or semantic form, and for that reason show relatively little susceptibility to phonetic interference. Conrad (1972) found that children younger than about 6 yr. typically employ a nonphonetic strategy in recall of pictured objects. He suggested that phonetic coding may not be available as a memory strategy for visual material in younger children since, at about 6 yr. the normal children in his sample (but not the congenitally deaf taught by the manual method) spontaneously abandoned pictorial coding in favor of phonetic coding. The problem exposed by Conrad of the development of working memory codes merits further study. In view of the present findings that show closely parallel effects of phonetic similarity on recall of material presented visually and auditorily, it would be of interest to find out whether a comparable developmental shift in coding strategy occurs in normal children for recall of material presented by ear. We would expect, in any case, that individual differences in the age at which memory coding changes to a phonetically based strategy would have a bearing on readiness to read.

The findings showed that poor readers make less effective use than good readers of a phonetic recall strategy in memory for letter strings. This result lends support to the hypothesis that differences in the use of phonetically organized representations in working memory are a relevant factor in learning to read. The poor readers' low susceptibility to phonetic interference in recall of rhyming letter strings may be due either to the unavailability of the phonetic representation to ready access or to the degraded quality of such representations. Failure to make effective use of phonetic coding in memory was not limited to situations in which the materials were presented visually, but was manifested on auditory presentation as well. The poor readers' problem can therefore not be understood solely as a deficit in recoding from print, but as a more general deficiency in coding strategy that may be expected to have consequences that extend beyond reading.

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