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# Phonetic coding and order memory in relation to reading proficiency: A comparison of short-term memory for temporal and spatial order information

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ABSTRACT
Since children with reading disability are known to have problems using a phonetic memory strategy, it was expected that their recall of order would be inferior to that of good readers in situations where a phonetic strategy is optimal, i.e., when temporal order recall, but not necessarily spatial order recall, is required. On separate tests for retention of temporal sequence and spatial location, the good readers were better than the poor readers on the temporal order task as expected, but contrary to expectation, they maintained their superiority on the spatial task as well. Nevertheless, differences in the error patterns of the good and the poor readers are supportive of earlier evidence that links poor readers' short-term memory deficiencies to reduced effectiveness of phonetic representation.

Indications in the research literature suggest that reading problems in young children tend to be associated with poor memory for the order of items in a series (Bakker, 1972; Benton, 1975; Corkin, 1974; Mason, Katz, & Wicklund, 1975; Noelker & Schumsky, 1973; Stanley, Kaplan, & Poole, 1975). Shankweiler, Liberman, Mark, Fowler, and Fischer (1979) have supposed that difficulties with order recall may reflect a deficiency in the working memory system that supports comprehension of sentences both in speech and in reading. It has been argued that the working memory system used in processing connected discourse relies on phonetic coding for its operation (Liberman, Mattingly, & Turvey, 1972), and moreover, that the retention of item order is facilitated by the use of a phonetic memory strategy (Baddeley, 1978; Crowder, 1978). One of the mechanisms responsible for this facilitating effect of phonetic coding may be the

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rehearsal loop proposed by Baddeley (1979). Since it has been shown that poor beginning readers tend to depend less on phonetic coding than good readers on some laboratory memory tasks (Byrne & Shea, 1979; Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Mann, Liberman, & Shankweiler, 1980; Mark, Shankweiler, Liberman, & Fowler, 1977; Shankweiler et al., 1979), we may ask whether poor readers' difficulties in remembering order may be attributed to their failure to make appropriate use of phonetic codes in working memory.

If retention of order is indeed dependent on the use of phonetic codes, we might expect matched groups of good and poor beginning readers to differ in memory for item order only when the items to be remembered can easily be named, thereby allowing them to be held in phonetically based working memory. When the items to be held in memory cannot easily be named, there is no clear basis for expecting good and poor beginning readers to differ. A recent study by Katz, Shankweiler, and Liberman (1981) supports this possibility, finding good and poor beginning readers not significantly different in their ability to reproduce the order of an array of figures that are difficult to label (Kimura's, 1963, nonsense drawings). When these subjects were tested for retention of the order of line drawings of common objects, however, the poor readers were deficient. Thus, it is clear that the poor readers' difficulty with memory for order applied specifically to remembering the order of items that could easily be coded linguistically and held in phonetic working memory. Comparable results were obtained by Holmes and McKeever (1979) in tests of memory for the order of photographed faces and printed words with adolescent good and poor readers. Neither study, however, provided direct evidence of the memory strategy the subjects actually used. Although it has been assumed that the subjects retained the easily named items by using phonetic codes, other aspects of the stimuli could have been used, e.g., semantic aspects or visual imagery. Moreover, ordering items with readily available names by memory has been found to be easier than ordering items that are difficult to name (Katz et al., 1981), making a direct comparison of the two tasks difficult. It is therefore important to address the question raised by Katz et al. by means of an experimental paradigm which avoids these difficulties, but in which, as before, the level of success in retaining item order could be expected to depend on the use of phonetic coding. Such a paradigm has been used by Healy (1975, 1977) for testing memory for order.

Healy (1975, 1977) has shown that two aspects of memory for order can usefully be distinguished: memory for temporal sequence and memory for spatial location. In most situations outside the laboratory, the two aspects of order memory are confounded, since they vary simultaneously. Healy has devised a technique for experimentally dissociating temporal and spatial order in a way that also allows us to infer the coding strategy used in the retention of each. (See Berch, 1979, for a discussion of this and related techniques.) Moreover, to the point of our present interest, her work with adult subjects has shown that memory for temporal sequence ordinarily depends strongly on the use of phonetic coding whereas retention of spatial location does not. Instead, spatial order recall depends on the retention of the temporal-spatial pattern of the stimulus display (Healy, 1975, 1977, 1978, 1982).

If by using this method we were able to dissociate the two aspects of order memory in children, we should be well placed to infer the memory strategies actually adopted by good and poor readers and to compare directly the strategies favored by each group. Thus, we would be in a position to pinpoint more definitely than heretofore the poor readers' difficulty in retaining each type of order information by showing whether it is tied to the use of phonetic coding.

The technique used by Healy (1975, 1977) involves successive visual presentations of a set of stimulus items whose order is to be remembered. On each trial, the same set of items, which is known to the subjects beforehand, is always used. Therefore, there is essentially no requirement for remembering the items themselves, but only their order of presentation. In the temporal order recall condition, the spatial order of the items is kept constant, whereas in the spatial order recall condition, temporal order does not vary. By using conditions that are completely parallel, this methodology separately assesses the two aspects of order memory in a comparable manner. Inasmuch as the original technique had been designed for adult subjects, it was necessary to modify it to make it suitable for use with children. The memory load on each trial was reduced from four to three items and the rate of stimulus presentation was slowed. These changes were introduced in order to ensure that the least successful subjects would perform above chance, allowing us to assess their preferred memory strategy.

We expected to find evidence that the good readers would use a phonetic strategy more than the poor readers in those situations where phonetic coding is feasible. Furthermore, we expected the good readers' memory for order to be better than that of the poor readers whenever a phonetic strategy is optimal for the task. It would follow, then, that the good readers should have an advantage over the poor readers in recall of temporal order. Moreover, it ought to be possible to demonstrate greater use of phonetic coding by the good readers than by the poor readers when temporal order recall is tested. Possibly, the poor readers would prefer to use an alternative memory strategy, such as temporal-spatial pattern coding, on this task. (See Healy, 1975, for evidence that adult subjects use this strategy when phonetic coding is hampered.) For spatial order recall, on the other hand, we had no clear basis for expecting performance to vary with reading ability, because Healy has shown that phonetic coding is not the preferred strategy when this aspect of order memory is tested. On this task, we expected to find evidence that all subjects retained the temporal-spatial pattern of the stimulus display.

## METHOD

### *Task*

Both the Temporal Order and the Spatial Order Recall conditions required successive presentations of items. A trial consisted of a presentation of three letters followed by a list of digits, to be used as a distractor task. In the Temporal Order Recall condition, the subjects retained the temporal sequence of the three letters; the spatial locations of the letters, known to the subjects in advance, were kept constant. Likewise, in the Spatial Order Recall condition, the subjects retained the spatial locations of the letters; the subjects were aware of the constant temporal letter sequence. During the presentation of the digits, the subjects were required to perform one of two distractor tasks. In the Digit Name task, they read the names of the digits aloud; in the Digit Position task, the subjects indicated each digit's spatial location by raising their fingers.

### *Subjects*

The subjects were selected from four second-grade classes in the East Hartford, Connecticut, public school system. The children were of middle-class socioeconomic status and attended a neighborhood school. Candidates for the poor reader group were selected for screening if they were so designated by their teachers or if they scored below grade level on either the vocabulary or comprehension subtest of the *Gates-MacGinitie Reading Tests* (1978), which had been administered in the eighth and ninth months of the second grade. Candidates for the good reader group either received a superior evaluation or scored more than one year above grade level on one of the subtests.

The subjects selected for screening were administered the *Peabody Picture Vocabulary Test* (Dunn, 1959) and the word identification and word attack subtests of the *Woodcock Reading Mastery Tests* (Woodcock, 1973) in the ninth month of the school year. The subjects with extreme IQ scores (below 90 or above 135) were ineligible for further testing. The final good reader group consisted of the 16 subjects (8 females, 8 males) who attained the highest combined raw scores on the two Woodcock subtests, whereas the poor reader group included the 16 subjects (9 females, 7 males) with the lowest combined scores. All of the poor readers were achieving below local norms, and all of them lagged substantially behind their peers. The good readers had a mean age of 7 years, 11 months compared with the poor readers' mean age of 8 years, $t(30) = 0.3$, $p > .5$ (two-tailed). The good readers had a mean IQ of 109.1, whereas the poor readers had a mean IQ of 102.2, $t(30) = 2.1$, $p = .044$ (two-tailed). The mean combined raw score on the Woodcock was 144.4 for the good readers (range: 134 to 161) and 80.3 for the poor readers (range: 64 to 104), $t(30) = 18.3$, $p < .001$ (two-tailed).

### *Stimuli and apparatus*

A memory drum was used for presentation of the stimuli, which were typed onto a paper tape. The stimuli were successively presented in the display window of the memory drum. The duration of each display was ½ sec and the interdisplay interval was ½ sec.

Four different 24-trial sequences were devised. A trial consisted of a 3-letter stimulus followed by a retention interval of 3 or 12 intervening digits. The letters and digits were presented successively, each in a different one of three spatial positions that formed a horizontal array. The remaining two positions were occupied by dashes.

The letters presented were permutations of the set F, P, and V typed in capitals. These letters were chosen because F and P are visually, but not phonetically, confusable, whereas P and V have phonetically confusable names, but are not visually confusable. For the two sequences in the Temporal Order Recall condition, each of the six permutations of the three letters appeared twice at each of the two retention intervals as the temporal order of the letters, the spatial order being held constant over all 24 trials. In one of the sequences, the constant spatial order was FPV; in the other, it was VPF. For the Spatial Order Recall condition, each permutation occurred twice at each retention interval as the spatial order of the letters, while the temporal order was held constant. In one of the sequences, the constant temporal order was FPV, and in the other, it was VPF. For example, in the Temporal Order Recall condition when the constant spatial order was FPV, F would always be presented in the left position of the memory drum display, P in the middle, and V in the right position. Only the temporal order of the letters would vary. Likewise, in the Spatial Order Recall condition when the constant temporal order was FPV, F was always shown first, followed by P, then V. Only the spatial order of the letters varied across trials. Within a sequence, the presentation order of the trials was random with these three constraints: Each of the six permutations of the three letters must appear twice in every block of 12 trials, once at each of the two retention intervals; in every subset of six trials each retention interval must occur three times; a given permutation must not appear on two successive trials.

The intervening digits were selected from the set: 4, 6, 8. Selection was random with the constraints that no digit occur on two successive displays and that each digit occur equally often in every group of 15 digits. By using a mapping of the three digits to the three spatial positions, the digits that were selected for the retention intervals of the first 12 trials determined the positions, in reverse order, of the digits in the final 12 trials; the digits of the final 12 trials determined the positions in reverse order of the digits of the first 12 trials. A practice sequence of 15 digits was devised by the same method.

Response cards were prepared by typing the three letters F, P, and V in the center of white, 3 × 5-inch cards, one letter per card.

### *Procedure*

The subjects were tested individually in two 20-min sessions. Each session was devoted to one recall condition. The order of the two conditions was counterbalanced so that half the members of each reading group participated in the Temporal Order Recall condition in the first session and in Spatial Order Recall in the second. The order of the conditions was reversed for the other subjects. Half the members of each group were tested on the sequence in which the constant temporal order was FPV and the sequence in which the constant spatial order was FPV. The remaining subjects were tested on the two sequences in which the constant order was VPF.

At the beginning of each session, the subjects were informed of the condition in which they were participating and were explained the task. For the Temporal Order Recall condition, the subjects were told the constant spatial order. Thus, the subjects had to remember only the temporal order, since they were aware of the stimulus items and their spatial locations. For the Spatial Order Recall condition, the subjects were told the constant temporal order and had to remember only the spatial order. As letters were displayed, the subjects read them aloud. As digits were presented, the subjects were required to perform one of two interpolated tasks for the first 12-trial block and the other task for the final 12-trial block. In the Digit Name task, the subjects read the digits aloud as they appeared. In the Digit Position task, the subjects raised their fingers as digits appeared, with the number of fingers raised indicating the spatial location of the presented digit. When the digit appeared in the left position, one finger was raised; two were raised for the middle position; either three or five fingers were raised for the right position, depending on which was more comfortable for the individual subject. The order of the distractor tasks was the same for each subject within both sessions, but was counterbalanced within reading groups. Before each block of 12 trials, the subjects were given practice on the appropriate distractor task using the practice sequences. During these trials, the presentation rate of the digits was manually controlled by the experimenter so that it could be increased as the subjects became more proficient at the task.

The end of a trial was signaled by the appearance of three dashes in the memory drum display window. The subjects in the Spatial Order Recall condition then attempted to reproduce the spatial order of the letters as seen in that trial by arranging the response cards into a horizontal array. The subjects in the Temporal Order Recall condition arranged the cards into a vertical array such that the top card had typed on it the letter first seen and the bottom card depicted the letter last seen.

## RESULTS

The number of stimulus items incorrectly ordered by each subject for each condition was tallied. An item was considered incorrect if it was not placed in the serial position that corresponded to its position in the memory drum display. For the Temporal Order Recall condition, the serial positions refer to the temporal sequence of the items from first seen to last seen. For the Spatial Order Recall condition, the serial positions correspond to the spatial locations from left to right. Preliminary to examining the experimental predictions, we tested whether there were sex differences associated with order memory. For this test, the total number of errors was calculated for each child. These data were subjected to an analysis of variance (unweighted means analysis) with two between-groups measures (sex of child and reading ability). The results indicated that reading ability was a significant factor in order memory, $F(1,28) = 8.9, p = .006$, whereas sex was not, $F < 1$. The interaction of reading ability and sex was nonsignificant, $F(1,28) = 1.2, p > .05$. Since sex differences were not found, this factor was not included in the principal analysis of the data.

Subsequently, the data were subjected to an analysis of variance with one between-groups measure (reading ability) and four within-groups measures (recall type, distractor type, retention interval, and serial position). Significant effects involving the serial position factor were verified using a procedure by

Box (1954). This procedure ensured that the obtained effects were not artifacts of inhomogeneous variances and covariances. The full data set, converted to percentages, is presented in Table 1. Each percentage is based on a maximum of six errors per subject. A summary of the results of the analysis of variance is presented in Table 2 under the column labeled "Absolute errors."

### *Good vs. poor readers*

The expectation of an interaction between reading ability and recall type was based on past evidence of good and poor readers' differential proficiency for using phonetic codes. Temporal order recall has been found to depend usually on the retention of phonetic memory codes, with which poor readers are known to be deficient. Thus, the good readers should perform better than the poor readers on temporal order recall. No such expectation can be made for spatial order recall, however. Since retention of spatial order has not been shown to depend on phonetic coding, the performances of the good and poor readers were not expected to differ.

The percentage of incorrect placements on the two recall tasks by each reading

Table 1. *Percentage of incorrect placements (standard deviations are in parentheses)*

| | 3 Digits | | | 12 Digits | | |
|---|---|---|---|---|---|---|
| | Pos 1 | Pos 2 | Pos 3 | Pos 1 | Pos 2 | Pos 3 |
| *Good readers* | | | | | | |
| Temporal Order Recall | | | | | | |
| Digit Name | 20 (20) | 34 (14) | 32 (18) | 40 (18) | 41 (23) | 39 (21) |
| Digit Position | 19 (15) | 30 (21) | 29 (20) | 29 (21) | 33 (19) | 34 (16) |
| Spatial Order Recall | | | | | | |
| Digit Name | 43 (17) | 48 (18) | 48 (18) | 43 (29) | 44 (28) | 43 (26) |
| Digit Position | 49 (23) | 52 (25) | 53 (20) | 53 (23) | 50 (20) | 49 (26) |
| *Poor readers* | | | | | | |
| Temporal Order Recall | | | | | | |
| Digit Name | 31 (22) | 43 (27) | 38 (24) | 36 (20) | 48 (20) | 51 (19) |
| Digit Position | 30 (21) | 38 (17) | 40 (19) | 39 (20) | 54 (22) | 52 (14) |
| Spatial Order Recall | | | | | | |
| Digit Name | 46 (24) | 54 (20) | 55 (26) | 56 (20) | 48 (23) | 54 (16) |
| Digit Position | 52 (18) | 51 (16) | 59 (17) | 59 (24) | 68 (21) | 60 (23) |

Table 2. *Summary of analyses of variance*

| | | Absolute errors | Conditional phonetic errors | Conditional visual errors |
|---|---|---|---|---|
| Factor | *df* | *F* | *F* | *F* |
| Reading | 1,30 | 8.3[b] | 4.0 | 1.0 |
| Recall | 1,30 | 31.7[c] | 0.5 | 2.3 |
| Distractor | 1,30 | 1.3 | 1.9 | 0. |
| Retention interval | 1,30 | 6.1[a] | 0.7 | 0. |
| Serial position | 2,60 | 12.9[c] | 0.1 | 1.3 |
| Reading × recall | 1,30 | 0.2 | 1.1 | 2.7 |
| Reading × distractor | 1,30 | 0.6 | 1.0 | 19.4[c] |
| Reading × retention interval | 1,30 | 0.9 | 0.1 | 3.3 |
| Reading × serial position | 2,60 | 0.9 | 0.7 | 0.7 |
| Recall × distractor | 1,30 | 4.4[a] | 0.2 | 0.2 |
| Recall × retention interval | 1,30 | 3.2 | 7.4[a] | 6.0[a] |
| Recall × serial position | 2,60 | 7.3[b] | 1.1 | 0.8 |
| Distractor × retention interval | 1,30 | 0.4 | 1.4 | 1.6 |
| Distractor × serial position | 2,60 | 0. | 1.3 | 0.2 |
| Retention interval × serial position | 2,60 | 1.3 | 1.2 | 0.1 |
| Recall × retention interval × serial position[d] | 2,60 | 0.6 | 1.5 | 4.6[a] |

[a]$p < .05$ Considering the number of factors involved in these analyses, it is conceivable that the true risk of a Type I error is greater than .05.
[b]$p < .01$
[c]$p < .001$
[d]All other three-way interactions and all higher-order interactions were nonsignificant.

group is shown in Table 3. It is clear that the good readers made fewer errors than the poor readers in both conditions. The analysis of variance indicated that the good readers' performance was significantly better than that of the poor readers. To control for IQ differences between the members of the two reading groups, an analysis of covariance was conducted using IQ as the covariate. (See Crowder, in press, for a discussion of the rationale for this procedure.) With IQ controlled, the two reading groups were again distinguished, $F(1,29) = 11.8, p = .002$. The superiority of the good readers' order memory extended both to temporal order recall and to spatial order recall; the interaction between reading ability and recall type did not approach significance.

Thus, the anticipated interaction between type of recall task and reading ability did not occur. It is important to ask, therefore, whether this outcome may nevertheless reflect a tendency for the good and poor readers to use different coding strategies. An examination of confusion errors was carried out in order to investigate this possibility. As in the previous studies with adults (e.g., Healy, 1982), we examined the relative percentages with which phonetic confusions and visual confusions occurred (i.e., the conditional percentages of each type of

Table 3. *Error percentages for each reading group by recall condition*

| Reading ability | Recall condition: Temporal order | Spatial order |
|---|---|---|
| Good readers | 32 | 48 |
| Poor readers | 42 | 55 |

confusion error given that an error was made), rather than the absolute percentages of confusion errors. We took as evidence for phonetic coding an indication that the conditional percentages of phonetic confusion errors were greater than would be expected on the basis of chance alone. The conditional percentage of phonetic errors was found by determining the ratio of the number of confusions of the letters P and V to the total number of errors for each subject for each condition. The full set of conditional percentages is shown in Table 4. The mean conditional percentage of phonetic errors for each recall type is shown in the left

Table 4. *Conditional percentage of phonetic errors (standard deviations are in parentheses)*

| | 3 Digits | | | 12 Digits | | |
|---|---|---|---|---|---|---|
| | Pos 1 | Pos 2 | Pos 3 | Pos 1 | Pos 2 | Pos 3 |
| *Good Readers* | | | | | | |
| Temporal order recall | | | | | | |
| Digit name | 48 (31) | 51 (42) | 60 (35) | 30 (26) | 33 (23) | 51 (31) |
| Digit position | 47 (36) | 48 (32) | 37 (37) | 48 (39) | 33 (33) | 31 (42) |
| Spatial order recall | | | | | | |
| Digit name | 38 (31) | 45 (27) | 34 (28) | 40 (28) | 40 (32) | 57 (33) |
| Digit position | 24 (24) | 32 (24) | 30 (24) | 36 (27) | 36 (32) | 44 (30) |
| *Poor Readers* | | | | | | |
| Temporal order recall | | | | | | |
| Digit name | 22 (36) | 42 (28) | 44 (31) | 35 (41) | 48 (21) | 25 (19) |
| Digit position | 33 (33) | 27 (28) | 33 (35) | 29 (30) | 35 (24) | 28 (26) |
| Spatial order recall | | | | | | |
| Digit name | 35 (39) | 30 (32) | 24 (19) | 31 (25) | 36 (34) | 38 (29) |
| Digit position | 38 (33) | 41 (28) | 30 (23) | 29 (20) | 42 (27) | 37 (28) |

half of Table 5. Although the good readers made fewer errors than the poor readers overall (see Table 3), when they made an error, it can be seen that the good readers were more likely than the poor readers to confuse the phonetically similar letters. The mean conditional percentage expected by chance alone is 33%, since there were three possible types of confusion – F with P, F with V, and P with V – only one of which was a phonetic confusion. The mean conditional percentage of phonetic confusion errors tended to be greater than the chance level for the good readers on temporal order recall, $t(15) = 2.2, p < .05$ (two-tailed), but not on spatial order recall, $t(15) = 2.0, p = .07$ (two-tailed). In contrast, for the poor readers, the conditional percentages were essentially equal to the chance level, $0 < t < 1$ in both cases.

The phonetic error data were subjected to an analysis of variance with one between-groups measure (reading ability) and four within-groups measures (recall type, distractor type, retention interval, and serial position). The results of this analysis are summarized in Table 2 under the heading "Conditional phonetic errors." This analysis indicated that the main effect of reading ability was marginally significant. With IQ controlled in an analysis of covariance, the reading groups were distinguished, $F(1,29) = 4.8, p = .038$. When an error was made, it was more likely to be a phonetic error for the good readers than for the poor readers on both temporal order recall and spatial order recall, as the interaction between reading ability and recall type was not significant. Thus, it would seem that on both tasks the good readers, more often than the poor readers, were coding in a phonetic manner.

Because of the constraints on proportions, we carried out an additional analysis of the phonetic error data after subjecting them to an arcsine transformation. This analysis fully corroborated the results of the initial one: All effects that were significant in the analysis of untransformed proportions remained significant; all other effects remained nonsignificant.

Finding that the conditional percentage of phonetic confusions was as large in spatial order recall as in temporal order recall is contrary to the expectation generated by Healy's (1975, 1977) research with adult subjects. Why phonetic coding was used in spatial order recall in this experiment might have the following explanation: In Healy's experiments, four items were presented at a rate of one per 400 msec. In contrast, we presented three stimulus items at a rate of one per sec. It is likely that in modifying Healy's paradigm for use with children, the presentation rate was kept slow enough to permit the subjects to recode phonet-

Table 5. *Mean conditional percentage of phonetic (P-V) errors and visual (P-F) errors, given that an error was made for each reading group*

| | Phonetic errors | | | Visual errors | | |
|---|---|---|---|---|---|---|
| Reading ability | Temp. | Spat. | Avg. | Temp. | Spat. | Avg. |
| Good readers | 43 | 38 | 40 | 28 | 36 | 32 |
| Poor readers | 33 | 34 | 34 | 36 | 35 | 36 |

ically in the spatial order recall condition as well as the temporal order recall condition. Apparently, good readers were better able to take advantage of this opportunity. Good readers, then, seem to adopt a phonetic memory strategy more often than poor readers. Though contrary to our original expectation, this strategy was apparently used for spatial order, as well as for temporal order, recall.

To ascertain directly whether the poor readers made greater use than the good readers of a visual coding strategy based on the shapes of the stimulus items, we computed the conditional percentage of visual errors (i.e., confusions of F and P) given that an error was made. The full set of conditional percentages is shown in Table 6. The mean percentage for each recall type is shown in the right half of Table 5. Again, the mean conditional percentage expected by chance alone is 33%, since there were three possible types of confusions, only one of which was a visual confusion. These mean percentages did not significantly differ from chance for either the good readers or the poor readers. An analysis of variance, analogous to that conducted on the conditional percentages of phonetic errors, was performed on the conditional percentages of visual errors and is summarized in Table 2 under the heading "Conditional visual errors." The procedure of Box

Table 6. *Conditional percentage of visual errors (standard deviations are in parentheses)*

| | 3 Digits | | | 12 Digits | | |
|---|---|---|---|---|---|---|
| | Pos 1 | Pos 2 | Pos 3 | Pos 1 | Pos 2 | Pos 3 |
| *Good readers* | | | | | | |
| Temporal order recall | | | | | | |
| Digit name | 17 (18) | 28 (34) | 13 (22) | 31 (30) | 28 (23) | 24 (18) |
| Digit position | 40 (32) | 31 (26) | 28 (35) | 23 (34) | 41 (39) | 37 (38) |
| Spatial order recall | | | | | | |
| Digit name | 38 (24) | 32 (30) | 34 (33) | 28 (26) | 32 (32) | 17 (22) |
| Digit position | 54 (20) | 47 (30) | 49 (28) | 41 (29) | 32 (30) | 31 (32) |
| *Poor readers* | | | | | | |
| Temporal order recall | | | | | | |
| Digit name | 36 (34) | 37 (30) | 35 (26) | 48 (34) | 45 (33) | 48 (29) |
| Digit position | 40 (35) | 25 (24) | 19 (21) | 24 (35) | 34 (26) | 37 (18) |
| Spatial order recall | | | | | | |
| Digit name | 40 (29) | 38 (30) | 40 (33) | 54 (29) | 31 (29) | 38 (22) |
| Digit position | 25 (29) | 34 (26) | 32 (27) | 36 (24) | 26 (20) | 31 (23) |

(1954) was used to ensure that the triple interaction involving serial position was not an artifact of inhomogeneity of variances and covariances. Again, applying an arcsine transform to the data and redoing the analysis of variance did not change the results.

The mean conditional percentage of visual errors did not differ with reading ability. However, there was a highly significant interaction between reading ability and distractor type. This interaction is evidence for different coding strategies in the two reading groups. If a subject is retaining visual codes, a high percentage of visual confusion errors would be expected unless the distractor task disrupts the visual mode of processing through interference. In fact, for the poor readers the conditional percentage of visual errors was large, and significantly different from chance, $t(15) = 2.2$, $p < .05$ (two-tailed), with the Digit Name distractor task which demanded phonetic processing (41%), but was reduced considerably, and was essentially at chance, $t(15) = -1.2$, $p > .05$ (two-tailed), with the Digit Position distractor task which demanded the processing of spatial location information (30%). This difference between the two distractor types proved significant in a post hoc analysis using Fisher's protected $t$-test (Cohen & Cohen, 1975), $t(15) = 2.8$, $p = .013$ (two-tailed). (The protected $t$-test, also known as the LSD test, is an ordinary $t$-test performed on group means that significantly vary according to an overall $F$ value. This test preserves the power of the $t$-test, while efficiently protecting against an inflated Type I error rate.) Thus, the pattern of visual errors for the poor readers suggests that they do code the to-be-remembered letters in terms of their visual features but that this coding is disrupted by the requirement to monitor the spatial positions of the interpolated digits. In contrast, for the good readers, the conditional percentage of visual errors was actually smaller with the Digit Name task (27%) than with the Digit Position task (38%), protected $t(15) = -3.5$, $p = .004$ (two-tailed). The error percentage on the Digit Name task was significantly below chance, $t(15) = -2.6$, $p < .02$ (two-tailed), whereas the percentage on the Digit Position task was essentially at chance, $t(15) = 1.5$, $p > .05$ (two-tailed).

In summary, the good readers made a greater proportion of phonetic errors than visual errors, but the poor readers actually showed a small difference in the opposite direction. Moreover, for the poor readers, the proportion of visual errors was particularly large when they were not forced to attend to the spatial locations of the digits. These analyses of confusion errors suggest that the good readers adopt consistently a phonetic coding strategy whereas the poor readers at times code information about the visual properties of the letters.

In addition to coding the forms of the individual letters, there is another nonphonetic strategy that might be adopted as an aid to recall: retention of the temporal-spatial pattern in which items were presented and using the remembered pattern to reconstruct the order. The six patterns are illustrated in Figure 1. The experiment was designed so that each pattern occurred twice at each retention interval in each condition. On any given trial, if the subject retains the pattern and the constant order, the to-be-remembered order can be inferred. For example, in the Temporal Order Recall condition, if the subject knows that the stimulus items were presented according to pattern 2 and that the constant spatial order is FPV, then the temporal order FVP can be determined. Likewise, in the

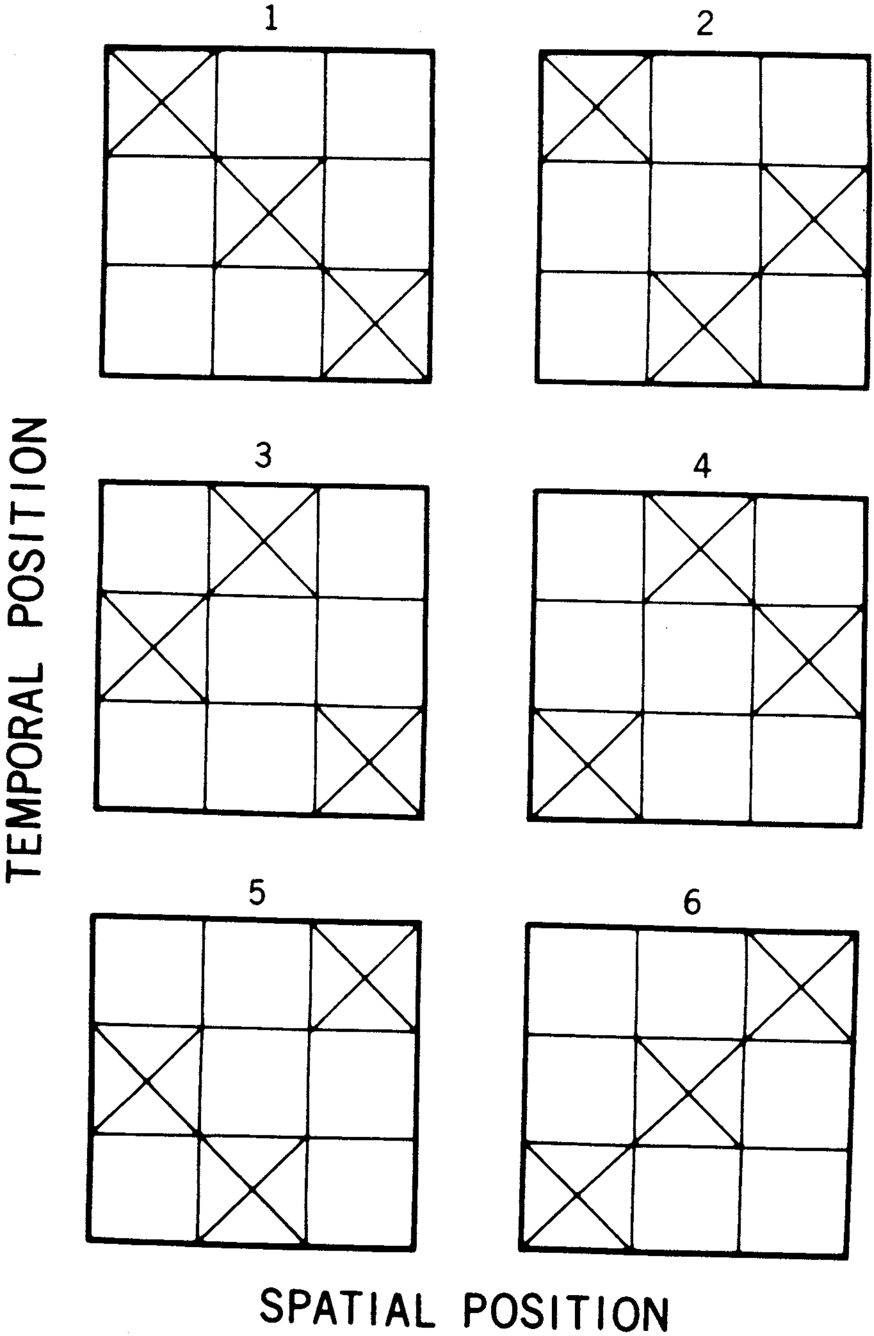


Figure 1. Temporal-spatial patterns of letter presentations. The spatial positions are shown horizontally and the temporal positions are shown vertically. For example, in pattern 4, the subject first sees a letter in the second spatial position, then a letter in the third position, and then a letter in the first position.

Spatial Order Recall condition, if the pattern and constant temporal order are known, then the spatial order can be reconstructed.

To examine the extent to which pattern coding was used, we looked for a consistent effect of pattern over the two recall conditions, which were subdivided by distractor type. For each of these four blocks of trials, the number of incorrect trials was tallied for each of the six patterns, scoring each trial as either completely correct or as incorrect. Pattern scores were obtained by averaging the number incorrect for each pattern over the subjects in each reading group. The percentage of errors for each pattern is shown in Table 7. Inspection of the table shows that a lower percentage of errors occurred on the more regular patterns (such as patterns 1 and 6) than on the others. Also, it can be seen that the consistency of these percentages over the six patterns is, apparently, relatively large for the poor readers. To discover whether this is a statistically significant trend, the six pattern scores for each block of trials were correlated with the six scores in each of the other blocks. The use of pattern coding in any two blocks of trials should be reflected by a high correlation, since patterns that are difficult to code should result in an increase in errors in each block, whereas patterns that are

Table 7. *Error percentages committed on each temporal-spatial pattern as a function of reading ability, recall condition, and distractor type (standard deviations are in parentheses)*

| | Pattern | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| *Good readers* | | | | | | |
| Temporal order recall | | | | | | |
| Digit name | 38 | 47 | 62 | 38 | 53 | 41 |
| | (41) | (37) | (33) | (33) | (33) | (32) |
| Digit position | 19 | 50 | 47 | 44 | 34 | 38 |
| | (24) | (40) | (37) | (39) | (34) | (38) |
| Spatial order recall | | | | | | |
| Digit name | 28 | 72 | 66 | 53 | 72 | 59 |
| | (35) | (30) | (38) | (33) | (39) | (36) |
| Digit position | 47 | 62 | 69 | 66 | 88 | 59 |
| | (37) | (38) | (35) | (34) | (22) | (36) |
| *Poor readers* | | | | | | |
| Temporal order recall | | | | | | |
| Digit name | 31 | 59 | 69 | 56 | 69 | 44 |
| | (35) | (40) | (35) | (30) | (35) | (35) |
| Digit position | 38 | 50 | 66 | 53 | 78 | 47 |
| | (33) | (31) | (34) | (41) | (30) | (37) |
| Spatial order recall | | | | | | |
| Digit name | 44 | 75 | 78 | 72 | 66 | 72 |
| | (39) | (31) | (35) | (30) | (38) | (35) |
| Digit position | 56 | 75 | 75 | 78 | 81 | 66 |
| | (30) | (35) | (31) | (35) | (24) | (34) |

easy to code will result in fewer errors. In previous research with adults (Healy, 1975, 1977), high correlations were found between pattern scores for spatial order recall conditions, implicating the use of pattern coding, but low correlations were found between scores on temporal order recall conditions. The Pearson Product-Moment correlations for each reading group are listed in Table 8. The correlations for the good readers range from .37 to .78. None is statistically significant, although all are positive. The correlations for the poor readers range from .44 to .93, and two of these are significant. Moreover, one of the significant correlations for the poor readers reflects the relationship between pattern scores on the two temporal order recall conditions. The significant correlations for the poor readers suggest that they tended to use pattern coding for both temporal order recall and spatial order recall whereas the good readers may not have adopted this strategy.

The pattern correlations are particularly interesting because the poor readers showed a great degree of regularity on this measure, despite the fact that by several other measures their performance was less regular than that of the good readers and more nearly random: The overall performance level of the poor readers was lower than that of the good readers (see Table 3), and the conditional percentages of phonetic confusion errors were closer to the chance level for the poor readers than for the good readers (see Table 5).

### *Temporal order vs. spatial order recall*

Whereas a comparison of the recall levels of good and poor readers was the major aim of the present experiment, an ancillary goal was to attempt to re-

Table 8. *Pearson Product-Moment correlations for good and poor readers among error scores on the temporal-spatial patterns as a function of recall type (temporal order or spatial order) and distractor type (digit name or digit position)*

| | Temp. name | Temp. pos. | Spat. name | Spat. pos. |
|---|---|---|---|---|
| *Good readers* | | | | |
| Temp.–Name | — | .39 | .62 | .57 |
| Temp.–Pos. | | — | .78 | .37 |
| Spat.–Name | | | — | .76 |
| Spat.–Pos. | | | | — |
| *Poor readers* | | | | |
| Temp.–Name | — | .89[a] | .73 | .93[b] |
| Temp.–Pos. | | — | .44 | .81 |
| Spat.–Name | | | — | .71 |
| Spat.–Pos. | | | | — |

[a] $p < .05$ (two-tailed)
[b] $p < .01$ (two-tailed).

produce with children the effects previously found in tests of adults' memory for order (Healy, 1975, 1977). The analysis of variance examining incorrect placements (Absolute errors, Table 2) indicated that the present experiment using children's data did indeed reproduce several of the effects found by Healy (1975, 1977) but failed to reproduce one. Examining the main effects, we note first a significant effect for retention interval. Not surprisingly, performance declined with the long interval of 12 digits compared with the short interval of 3 digits. Second, serial position proved significant, as performance was better on the first position than on either the second position, protected $t(31) = 4.5$, $p < .001$ (two-tailed), or the third position, protected $t(31) = 4.5$, $p < .001$ (two-tailed). Third, we found that performance on temporal order recall was generally better than on spatial order recall. Healy (1977), on the contrary, found that temporal order recall was superior only with certain interpolated distractor tasks or at certain retention intervals. Under some conditions, spatial order recall was as good as, or better than, temporal order recall.

Turning to the interactions that were reproduced with child subjects, we note a significant interaction between recall type and distractor type. As shown in Table 9, for the Temporal Order Recall condition, the Digit Name distractor, a phonetic task, resulted in a nonsignificant decrement in performance compared with the effect of the Digit Position distractor, a spatial task, $0 <$ protected $t < 1$. This pattern of results differed in the Spatial Order Recall condition where it was found that performance was worse with the Digit Position distractor task, protected $t(31) = 2.2$, $p < .04$ (two-tailed). Second, it may be noted that different serial position curves for the two recall tasks are reflected in the interaction between recall type and serial position. As is evident in Table 10, for spatial order recall, the serial position curve is relatively flat; the differences between the means for any two positions are nonsignificant. In contrast, the curve for temporal order recall shows a marked superiority in performance at the first serial position compared with either the second position, protected $t(31) = 5.6$, $p < .001$ (two-tailed), or the third position, protected $t(31) = 7.8$, $p < .001$ (two-tailed).

The major departure from Healy's previous findings with adults was our finding of the use of phonetic coding for spatial order recall. (In the present experiment, the conditional percentage of phonetic errors did not differ for temporal and spatial order recall.) As explained earlier, we attribute this dif-

Table 9. *Error percentages in each recall condition by distractor type*

| | Distractor type | |
|---|---|---|
| Recall type | Digit name | Digit position |
| Temporal order | 38 | 36 |
| Spatial order | 48 | 55 |

Table 10. *Error percentages in each recall condition by serial position*[a]

| | Position | | |
|---|---|---|---|
| Recall type | 1 | 2 | 3 |
| Temporal order | 30 | 40 | 39 |
| Spatial order | 50 | 52 | 53 |

[a]For temporal order recall, the serial positions refer to the temporal sequence of the items from first seen to last seen; for spatial order recall, the serial positions correspond to the spatial locations from left to right.

ference to a slow stimulus presentation rate that allowed the subjects enough time to recode the spatial positions into phonetic form. This explanation receives additional support upon examining the results of the analysis of variance for the conditional percentage of phonetic errors. Here we found an interaction between recall type and retention interval. At the short retention interval, the results were as expected: When an error was made, it was more likely to be a phonetic error for temporal order recall (43%) than for spatial order recall (33%), protected $t(31) = 2.1, p < .05$ (two-tailed). At the long retention interval, the percentage of phonetic errors was nonsignificantly greater for spatial order recall (39%) than for temporal order recall (33%), protected $t(31) = -1.8, p < .09$ (two-tailed). The comparable percentages for spatial order recall and temporal order recall at the long retention interval suggest that the long interval allowed enough time for the subjects to recode the spatial positions linguistically.

The opposite interaction was found upon examining the conditional percentage of visual errors. In this case, the conditional percentage of errors was greater for spatial order recall (39%) than for temporal order recall (29%) at the short retention interval, protected $t(31) = 2.2, p < .04$ (two-tailed). At the long interval, the percentage of visual errors for temporal order recall (35%) and for spatial order recall (33%) were not significantly different, $0 <$ protected $t < 1$. Since visual and phonetic errors are complementary to some extent (as the conditional percentages of phonetic, visual, and other errors must sum to 100%), this pattern for visual errors may possibly be explained solely in terms of the pattern for phonetic errors.

The triple interaction of recall type, retention interval, and serial position for the conditional percentage of visual errors indicates that the increase in the percentage of visual errors on temporal order recall on the long retention interval compared with the short interval was significant on only the third serial position: in two-tailed tests, first position, $0 <$ protected $t < 1$; second position, protected $t(31) = -1.5, p < .05$; third position, protected $t(31) = -2.3, p = .008$. On spatial order recall, in contrast, there was a decrease in the percentage of errors on the long interval at the third serial position: in two-tailed tests, first position, $-1 <$ protected $t < 0$; second position, protected $t(31) = 1.6, p < .05$; third position, protected $t(31) = 2.1, p < .05$. This triple interaction was unexpected and is not readily interpretable.

## DISCUSSION

The impetus for this study arose from a question originally addressed by Katz et al. (1981): Can we understand poor beginning readers' characteristic difficulties in remembering order as a consequence of deficient use of a phonetic memory strategy? This issue was previously approached by comparing good and poor readers' memory for the order of items in an array. In one condition, the items had readily available names that could easily be coded phonetically, whereas in a second condition, this was not the case, since the items were nonrepresentational designs. The failure to find a difference between good and poor readers in remembering the nonsense designs encouraged us to press the issue by undertaking a more analytic study of memory for order. To investigate whether, in some circumstances, good and poor beginning readers preferred to use different memory strategies, we adopted a new approach that would allow us to infer the strategy that subjects actually used.

We were able to infer the memory strategies adopted by good and poor readers in an experimental task that allowed us to assess separately memory for temporal order and memory for spatial order. Previous research using this experimental procedure (Healy, 1975, 1977) with adult subjects indicated that purely temporal order recall normally relies on phonetic coding, whereas purely spatial order recall does not. Since poor beginning readers have known deficiencies in their use of phonetic codes, we expected that their performance relative to that of good readers on temporal order recall might be impaired. However, no such impairment was predicted for spatial order recall, on which a nonphonetic strategy is presumably used. Moreover, we expected to find evidence for greater use of phonetic codes among good readers than poor readers whenever a phonetic strategy was possible. Therefore, basing our prediction on Healy's previous research, we expected the phonetic strategy to be evident only on temporal order recall.

The results confirmed our expectation that the good readers would use a phonetic strategy more often and more effectively than the poor readers even though the expected dissociation in memory coding for temporal and spatial order was not obtained. The data suggested that in adapting Healy's paradigm for use with children, the modifications (lengthening the stimulus presentation times and reducing the number of stimulus items per trial) had the effect of permitting phonetic coding to occur for spatial order recall as well as for temporal order recall. Thus, the procedure did not force the use of divergent strategies for the two tasks as we had intended. But in spite of this limitation, the findings supported our expectation that the good readers would use phonetic codes whenever it was possible to do so and that poor readers would attempt to use other strategies. The results indicate that the good readers preferred to use phonetic codes more than the poor readers even in spatial order recall. The poor readers, on the other hand, tended to make greater use of an alternative to the phonetic coding strategy, presumably in order to evade the difficulties they have in using phonetic codes. Thus, the poor readers, in contrast to the good readers of the present study and Healy's normal adult subjects, coded information about the visual features of the letters and elected to retain temporal-spatial patterns for the temporal order recall condition. Furthermore, they persisted in using this memory strategy for the spatial order recall condition even though a phonetic strategy was both feasible and efficient for the task, as indicated by the good readers' performance. Thus, it was found in the present study, as in the experiment of Katz et al. (1981), that in those task situations in which phonetic coding is possible, the good readers' performance was superior to that of the poor readers.

By using a paradigm that varied the task (temporal order or spatial order recall) while always using the same stimulus material, the present study provides independent support for the view that poor beginning readers' problems remembering order are linked to deficient use of phonetic coding in working memory. The present results are also consistent with the results of previous studies that found that good readers make greater use than poor readers of phonetic codes on tasks requiring recall of both item identity and item order (Liberman et al., 1977; Mann et al., 1980; Shankweiler et al., 1979). In those studies, which compared good and poor readers' ordered recall of rhyming and nonrhyming linguistic material, it was found that only the good readers' performance was detrimentally affected by the rhyming (phonetically confusable) items. Furthermore, Shankweiler et al. (1979) conducted an analysis (unpublished) of the actual substitutions committed by their subjects. This indicated that good readers made a significantly higher proportion of phonetic errors than poor readers. The present experiment permitted us to examine short-term retention of item order with no requirement for retaining item identity. At the same time, it allowed the subjects the opportunity to make either phonetic or visual errors. Again, we found that the good readers' errors were more likely to be phonetic than were those of the poor readers.

The literature points to a high degree of consensus on the failure of poor beginning readers to use phonetic strategies effectively. (The tests that distinguish good and poor readers in the early school years may not serve to differentiate older children and adults who differ in reading ability; see, for example, Johnston, 1982; Olson, Davidson, Kliegl, & Davies, in press; and Siegel & Linder, in press.) On the other hand, there is no agreement regarding the comparative levels of spatial abilities characteristic of good and poor readers. In one recent study (Symmes & Rapoport, 1972), poor readers were found to be actually better than good readers on certain spatial tasks. Thus, on one view, the poor readers of the present study would have been expected to do better on spatial order recall than the good readers and, possibly, to retain temporal-spatial patterns more often in both recall conditions. The opposite expectations, however, can be generated on the basis of the finding that poor readers are less sensitive than good readers to letter position frequencies (Mason & Katz, 1976; Mason et al., 1975). Our findings do not unequivocally support either position. Although we did find that the poor readers tended to adopt a strategy of retaining temporal-spatial patterns, they were, nevertheless, not able to perform at levels comparable to the good readers on spatial order recall. Perhaps, a better test of these conflicting hypotheses, and of our expectation of equal performances for good and poor readers on spatial order recall, would require the elimination of the opportunity for phonetic coding for spatial order recall. At all events, our expectation that poor readers would tend to use an alternative strategy, in preference to the phonetic memory strategy with which they have difficulty, draws support from the findings.

Evidence that poor beginning readers tend to prefer nonphonetic memory strategies in some situations has been previously noted. Byrne and Shea (1979), for example, reported that poor readers tended to code words semantically for retention in memory, whereas good readers tended to rely on phonetic codes. However, when the task required subjects to remember pseudowords, poor readers resorted to phonetic strategies, since those stimuli offered no option of semantic coding. Even in this case, it should be noted, the poor readers' performance was deficient. Thus, poor readers can use phonetic codes when the task requires it, but even then, they do so less efficiently than good readers. Under the particular conditions of the present experiment, neither the spatial order recall task nor the temporal order recall task logically required the use of phonetic codes. As explained earlier, it was possible to do either task by retaining temporal-spatial patterns. However, the requirement that the subjects read stimulus items aloud may have been expected to dispose them toward a phonetic memory strategy (Torgesen & Goldman, 1977). It should be remarked that in spite of this possibly biasing factor the poor readers in the present study tended to adopt the nonphonetic strategy, as did those of Byrne and Shea (1979).

In sum, the present findings, like those of Katz et al. (1981), support the view that the poor reader's problem in retaining order is linked to deficient use of phonetic codes in working memory. Thus, poor readers' inferior memory for order should not be viewed as an independent disorder. Rather, it may be considered as one manifestation of a deficiency in the domain of language, involving the use of phonetic coding in working memory.

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