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Linguistic Coding by Deaf Children in Relation to Beginning Reading Success

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The coding of printed letters in a task of consonant recall was examined in relation to the level of success of prelingually and profoundly deaf children (median age 8.75 years) in beginning reading. As determined by recall errors, the deaf children who were classified as good readers appeared to use both speech and fingerspelling (manual) codes in short-term retention of printed letters. In contrast, deaf children classified as poor readers did not show influence of either of these linguistically based codes in recall. Thus, the success of deaf children in beginning reading, like that of hearing children, appears to be related to the ability to establish and make use of linguistically recoded representations of the language. Neither group showed evidence of dependence on visual cues for recall.

To be able to comprehend text, a reader must hold several words in short-term memory, and their order, long enough for sentence interpretation. The nature of this short-term memory store is a matter of considerable interest. For hearing children, research evidence suggests that success in beginning reading is related to ability to make efficient use

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of a speech-based code.[1] In tests of short-term memory, hearing second graders who are good readers have been found to be more sensitive to this information than those who are poor readers. For example, in a test of the recall of printed consonant strings, the performance of second grade good readers was found to differ significantly for rhyming and nonrhyming strings (Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977). For the poor readers, in contrast, performance was similar in the two cases. The difference in error pattern was attributed to the good readers' greater or more efficient use of a speech-based code. This result has been obtained not only with printed letter presentation, but also when the letter names were spoken (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). Similar results have been obtained also in tasks of recognition memory for words. Good readers are more likely than poor readers to make errors in recognizing words that rhyme with earlier-occurring words, whether the words are heard (Byrne & Shea, 1979) or read (Mark, Shankweiler, Liberman, & Fowler, 1977). These findings have suggested that for hearing children in the process of acquiring reading skills, the poor readers may be deficient in the use of a speech-based code.

The present research examines short-term memory coding as it relates to the beginning reading success of prelingually, profoundly deaf children. The most comprehensive work that has been done to date on reading in deaf populations is an extensive study by Conrad (1979) of older hearing impaired students (ages 15–16.5) in England and Wales. In that study, three factors were found to be determinants of reading success: degree of hearing loss, level of intelligence, and use of a speech-based code. Of these factors, the latter is of particular relevance here.

The use of a speech-based code was assessed by Conrad by means of a short-term memory task in which the students were presented short lists of rhyming words (e.g., *do, blue,* and *through*) and nonrhyming words (e.g., *bean, door,* and *farm*). Students were considered to be using a speech-based code if they made more errors on rhyming lists than on nonrhyming lists. Degree of hearing loss was found to be related to reading achievement (those persons having a loss of 85 dB or greater showing a marked deficiency in reading achievement), but success in reading for a given degree of hearing loss was largely determined by the use of a speech-based code. Individuals who made use of this code tended to be better readers than those who did not. Although the ability to use a speech-based code was correlated with degree of hearing loss and intelligence, use of a speech-based code was also an independent determiner of reading success.

[1] The use of the term "speech-based code" here is not meant to imply that the code need be based on auditory or articulatory concomitants of speech, but rather may be an abstract representation of the phonetic or phonological features of the language.

It is of further interest to note that the majority of the profoundly deaf students in Conrad's study had not acquired the use of a speech-based code and, moreover, that those profoundly deaf students who had acquired it were using it less efficiently than their hearing counterparts. This latter finding accords well with results obtained with deaf college students (Hanson, 1982). The question therefore arises as to whether alternative coding strategies might be in use by deaf readers. The most obvious available alternative strategy is a manually based code. Its use could not be assessed in Conrad's study since the schools from which he drew his subjects were strictly oral in their educational approach.

Research with deaf subjects has indicated that internal representations based on manual language systems can be used in short-term memory. Studies using American Sign Language (ASL) have shown that when sign stimuli are presented to skilled users, short-term recall is mediated by a sign-based code. It has been demonstrated that, for deaf adults, intrusion errors in sign recall tend to be formationally related to sign parameters (Bellugi, Klima, & Siple, 1975). Thus, for example, an error in the recall of the sign NOON might be the word *tree*. The ASL sign for TREE is similar to the sign NOON in handshape and place of articulation and differs only in movement. Deaf subjects have also been found to have more difficulty in recalling lists of signs that are formationally similar than lists of unrelated signs (Hanson, 1982; Poizner, Bellugi, & Tweney, 1981; Shand, 1982). Similarly, deaf children tested with a continuous recognition memory procedure tended to falsely recognize formationally similar signs (Frumkin & Anisfeld, 1977).

However, the important question of how a manual short-term memory code might relate to the acquisition of reading in young children has remained largely unexplored. Research with deaf teenage and adult signers has examined short-term memory coding of written letters and words, but these studies have not examined how coding strategy relates to reading success. The results have been somewhat inconsistent in their indications; some finding evidence for speech-based coding (Hanson, 1982; Locke & Locke, 1971; Novikova, 1966; Wallace & Corballis, 1973) and others finding evidence of manually based coding (Conlin & Paivio, 1975; Locke & Locke, 1971; Moulton & Beasley, 1975; Odom, Blanton, & McIntyre, 1970; Shand, 1982). Such variety in outcome is understandable given the differences in subject background characteristics (e.g., degree of hearing loss, educational achievement, and age) and the varied methodologies employed.

Short-term memory coding has been examined in deaf children (Frumkin & Anisfeld, 1977; Liben & Drury, 1977), but once again not in relation to reading success. Deaf children receiving oral education, tested in a task of recognition memory for printed words, have been found to make semantic errors in a task of recognition memory for printed words, as well as making visual/phonetic errors (Frumkin & Anisfeld, 1977). Since visual and phonetic similarity were confounded in the study (as in their stimuli TOY–BOY, MAKE–TAKE), it is impossible to know whether it was phonetic similarity or visual similarity, or both, that led to the errors. Deaf children educated with the Rochester method, which uses simultaneous speech and fingerspelling, have been observed using simultaneous speech and dactylic rehearsal in a task of short-term memory for printed letters (Liben & Drury, 1977).

The present research examines short-term memory for written material by young children just beginning to acquire reading skills. Though it derives its motivation from Conrad's (1979) seminal work, it departs from that work in two major respects. First, the children under study are beginning readers whereas Conrad tested students about to graduate from high school. Second, the children have been instructed with simultaneous speech and manual communication whereas Conrad's subjects had received only oral instruction.

The procedure follows the format of previous studies of short-term memory in which printed strings of letters, varying in their phonetic similarity (rhyming or nonrhyming), are presented for recall by good and poor beginning readers (Liberman et al., 1977; Shankweiler et al., 1979). The task here is expanded by also including stimuli varying in their manual and visual similarity. In selecting items for the manually similar strings of letters, it was, of course, necessary to base similarity on the handshapes of fingerspelling, not on the signs of ASL. That is because the signs of ASL correspond, not to letters, but very roughly to English at the whole-word level (see Klima & Bellugi, 1979). Fingerspelling, as its name implies, is a dactylic system based on a manual alphabet. In the American manual alphabet there is a one-handed configuration for each of the 26 letters of the English alphabet. Words are manually spelled out in fingerspelling by the sequential production of each letter of the word. Fingerspelling thus provides a manual system for representing the orthography of English.

In the present research, the recall of strings of consonants that are phonetically, manually (dactylically), or visually similar was compared to recall of unrelated (control) strings. Differential ability to recall a given experimental set will be presumed to reflect coding strategies in short-term memory. Typically, in short-term memory studies similarity produces performance decrements compared with a control condition in which the stimulus items are dissimilar (e.g., Conrad & Hull, 1964; Baddeley, 1966). To anticipate our results, we should note that the procedure of the present experiment differs from the typical short-term memory task in one respect: Each experimental set of letters was limited to only four consonants; moreover, all four consonants of a set were presented on each trial of testing with a set. It might be expected that such a procedure would influence the pattern of results. As will be seen, this was indeed the case. With this repeated presentation of the same sets of consonants, similarity produced improvement in performance relative to the control set, instead of a decrement in performance.

METHOD

Subjects

Background information necessary for subject selection was obtained from the detailed records kept by the school for the deaf where the subjects were enrolled as students. To be accepted as subjects, the children had to meet several stringent selection criteria. The criteria required that a child be both prelingually and profoundly deaf (hearing loss of 85 dB or greater in the better ear) and of average or above average intelligence. Children with handicapping conditions other than hearing loss were excluded. The number of children meeting these criteria even at a school for the deaf was limited. A further limiting factor was that only children returning parent permission forms could be included in the study. The experimental subject group finally included 17 children. One was dropped from the study due to unwillingness to complete the task. The remaining 16 subjects were distributed as follows: 4 children were in a preparatory class, 3 in first grade, 3 in second grade, and 6 in third grade. The school attended by the subjects uses a total communication approach to instruction.

An additional prerequisite for subject selection was that the child know the names of letters of the printed alphabet and know the correspondence between each printed letter and its dactylic representation. The students' teachers were consulted in this regard.

The ratings by the school's reading diagnostician were used to differentiate groups of good and poor readers. These ratings were based on the children's measured reading achievement in relation to their ages. The reading achievement results were from the Woodcock Reading Mastery Test for the four youngest children and from the Stanford Achievement Test—Hearing Impaired for all other children. By these criteria, 10 of the children were classified as good readers, 6 as poor readers. Although averaging over results from two different tests is not strictly legal, for purposes of providing a description of the reading abilities of these children, such averaging was undertaken. For the good readers, the mean reading achievement was grade 2.2; for the poor readers, grade 1.8. By an analysis of covariance with age as the covariate, this difference in reading ability between the two groups was significant, $F(1, 13) = 12.12$, $p < .005$.

Additional background information was obtained regarding each subject's age, speech production skills, and parents' hearing status. The speech intelligibility of each child was based on the ratings of a speech pathologist at the school on a scale of 1 to 5 in which 5 represents speech that is completely intelligible and 1 represents speech that is completely *un*intelligible. The subjects in the good and poor reader groups did not differ significantly in their rated speech intelligibility, $t(14) = .36$, $p > .20$.

A summary of these background characteristics of the subject groups is given in Table 1. For the children in the preparatory class and in first grade, the IQ score was a combined measure based on the Hiskey–Nebraska Test of Learning Aptitude and the child's chronological age. For the children in the second and third grades, the IQ score was a combined measure based on the performance section of the Wechsler Intelligence Scale for Children—Revised and the child's chronological age. Since scores for age and IQ were markedly skewed, median scores are presented. Median levels of hearing loss are presented since mean averages of such scores would be nonsensical.

Four of the subjects had deaf parents—all four were classified as good readers. One subject, classified as a poor reader, had an older deaf sibling.

Stimuli

The stimuli were individual letters of the alphabet. To examine the possible effects of phonetic, dactylic, and visual similarity, sets of consonants related along each of these dimensions were constructed. In constructing sets that vary in similarity along three dimensions, it is to be expected that the degree of similarity between dimensions may vary. Thus, it may be argued, for example, that the visually similar items are not *as* similar as the phonetically similar items. Such potential disparity in relative similarity would be difficult to assess reliably and, for now, will not be considered.

Due to the limitations of a 26-letter alphabet and a need to manipulate phonetic, dactylic, and visual similarity independently, it was necessary to modify the procedure of earlier studies somewhat (Conrad, 1972; Liberman et al., 1977; Shankweiler et al., 1979). The major modifications

TABLE 1
CHARACTERISTICS OF GOOD AND POOR READERS

	Hearing loss (dB)[a]	Age[a]	IQ[a]	Speech intelligibility[b]
Good readers				
Score	101	8.5	105	2.3
Range	87–110+	6.25–11.0	88–143	1–4
Poor readers				
Score	103.5	9.3	97	2.1
Range	85–107	7.5–11.33	87–111	1–4

[a] Median score.
[b] Mean score.

were that sets were limited to only four consonants each and that the same four consonants were presented on each trial using each set.

The phonetically similar set consisted of four rhyming consonants, *B C P V*, which have been rated as phonetically similar (Wolford & Hollingsworth, 1974) and which are a subset of the stimuli used by others to investigate the use of a phonetic code (e.g., Liberman et al., 1977). The dactylically similar set consisted of the four letters, *M N S T*. The manual handshapes for these letters, which are pictured in Fig. 1, have been found to be dactylically similar as rated by adult native signers of ASL (Richards & Hanson, 1982). The visually similar set consisted of the letters, *K W X Z*, which have been rated as visually similar (Wolford & Hollingsworth, 1974) and are a subset of letters previously used to measure visual coding (Conrad, 1972). In addition, a control set of four

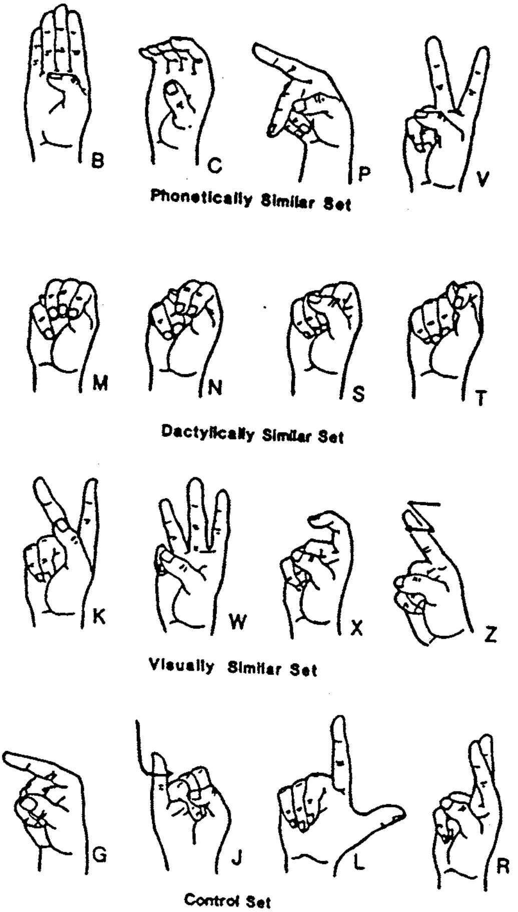

FIG. 1. The handshapes of the letters in the four experimental sets.

letters, *G J R L*, was constructed. The letters of this set are dissimilar along all three dimensions studied here.

As much as possible, letters of each set were selected to be similar only along the relevant dimension. That is, for example, the letters of the visually similar set were selected to be dactylically and phonetically dissimilar. There were unavoidably some confoundings, however, if sets truly high in phonetic and dactylic similarity were to be used. The alphabet does not permit a complete independence of phonetic, dactylic, and visual similarity. As a result, in the phonetically similar set the letters *B* and *P* are also visually similar (Wolford & Hollingsworth, 1974), and in the dactylically similar set the letters *N* and *M* are also phonetically and visually similar (Wolford & Hollingsworth, 1974).

While these stimuli were chosen on the basis of judged similarity in sorting tasks (Wolford & Hollingsworth, 1974; Richards & Hanson, 1982), their similarity can be evaluated on the basis of confusability scores from other studies on auditory, dactylic, and visual perception. As shown in Table 2, the measured auditory confusability is highest for the phonetically similar set, the measured dactylic confusability is highest for the dactylically similar set, and the measured visual confusability is highest for the visually similar set. The confounding of phonetic similarity and dactylic similarity on the letters *M* and *N* is apparent in these confusability ratings. The similarity of *M* and *N* account for 86% of the auditory confusability of the dactylically similar set. Thus, the relatively high auditory confusability of the dactylically similar set results from the confusability of these two letters. The auditory confusability of these two letters with the other letters of the dactylically similar set, however, is low.

TABLE 2
AUDITORY, DACTYLIC, AND VISUAL CONFUSIONS OF THE FOUR STIMULUS SETS BASED ON PREVIOUS STUDIES

	Auditory[a] confusions	Dactylic[b] confusions	Visual[c] confusions
Phonetically similar set			
BCPV	1321 (45.2%)	2 (1.4%)	8 (18.6%)
Dactylically similar set			
MNST	989 (33.8%)	121 (86.4%)	8 (18.6%)
MN	*846 (28.9%)*		
Visually similar set			
KWXZ	294 (10.0%)	16 (11.4%)	21 (48.8%)
Control set			
GJLR	321 (11.0%)	1 (.7%)	6 (14.0%)
Total	2925 (100%)	140 (100%)	43 (100%)

[a] From Conrad (1964).
[b] From Weyer (1973).
[c] From Fisher, Monty, and Glucksberg (1969), 400-msec presentation.

The test consisted of 16 trials—four presentations of each of the four sets of stimuli. Each letter of a set appeared once in each of the four possible serial positions. Trials were randomized with the constraint that the same stimulus set was not tested on consecutive trials.

Each letter was typed in upper case and slides of the individual letters were made.

Procedure

Stimuli were presented at the rate of one consonant every 2 sec. That is, each slide was displayed for 1 sec with a 1-sec blank interval following.

The children, who were tested individually, were instructed that on each trial they would see four letters, one after the other. They were to watch carefully as each of the four letters was presented and try to remember the letters in order. Following presentation of the items, they were to write them in correct order in their answer booklets. The answer booklets were prepared so that answers to each trial could be written on a separate page. On each page, four lines were drawn to indicate that four letters were to be recalled. Two practice trials were presented, using letters not appearing in the four stimulus sets. Instructions were simultaneously signed and spoken by the experimenter.

RESULTS

Responses were scored in two ways: *order-strict* scoring, in which a response was considered correct only if the correct letter appeared in the correct serial position; and *order-free* scoring, in which a response was considered correct if a correct letter for that trial was written, regardless of serial position. The mean number of errors for the two reader groups in each condition for both scoring procedures is shown in Table 3. The two scoring procedures produced a similar pattern of results; an analysis of variance performed on the number of errors for the between subjects factor of group (good or poor readers) × the within subjects

TABLE 3
MEAN NUMBER OF ERRORS (OUT OF 16 POSSIBLE) FOR GOOD AND POOR READERS

	Phonetically similar lists	Dactylically similar lists	Visually similar lists	Control lists
Good readers				
Order-free	3.5 (3.1)	3.6 (3.1)	5.8 (3.8)	5.8 (3.8)
Order-strict	5.7 (4.1)	6.0 (4.4)	8.2 (3.4)	7.5 (5.7)
Poor readers				
Order-free	7.5 (4.6)	6.7 (4.2)	6.5 (3.6)	7.3 (3.7)
Order-strict	10.0 (7.5)	9.3 (5.2)	9.2 (4.2)	11.0 (5.1)

Note. Standard deviations are given in parentheses.

factors of stimulus set (phonetic, dactylic, visual, or control sets) and scoring procedure (order-strict or order-free scoring) produced no significant interactions involving scoring procedure ($p > .25$). There was, however, a main effect of scoring procedure, $F(1, 14) = 55.40$, $p < .001$, with significantly more errors occurring in the order-strict than in the order-free scoring.

Good and poor readers were found to be differentially affected by the four stimulus sets as evidenced by a significant interaction of group × stimulus set, $F(3, 42) = 3.57$, $p < .025$. Post hoc tests were conducted to determine the basis of this interaction. An analysis on the simple effects indicated a significant effect of stimulus set for the good readers, $F(3, 42) = 7.71$, $p < .001$, but no significant effect of stimulus set for the poor readers, $F(3, 42) = 1.20$, $p > .25$. Thus, performance of the poor readers did not significantly vary as a function of stimulus set. For the good readers, in contrast, accuracy for the phonetically and dactylically similar sets was significantly greater than accuracy on the control set (Dunnett's t statistic, $p < .05$, two tailed). Performance of the good readers on the visually similar set was not significantly different from the control (Dunnett's t statistic, $p > .05$, two tailed).

An analysis was also undertaken of the *types* of errors made by good and poor readers. For the responses on the phonetically similar trials, the number of responses that rhymed with the target set was tabulated. These responses were the five letters *D*, *E*, *G*, *T*, and *Z*. Using the order-free scoring procedure, 55% of the errors made by the good readers on the phonetically similar set were responses that rhymed with the target set. For the poor readers, only 22% of such errors rhymed with the target set. Since a chance response with one of the 22 letters not from the phonetically similar set would produce rhymes for 5 of the letters (22.7% of the responses), it is apparent that the poor readers were responding randomly when they made an error, while the good readers tended to respond with a letter related to the target set. The dactylically similar set is less suitable than the phonetically similar set for such an analysis because the only two letters that are manually very similar are *A* and *E*, both vowels (Richards & Hanson, 1982; Weyer, 1973). Since vowels never occurred in the experiment, it might be expected that subjects would have a reluctance to respond with vowels. The pattern of results with the dactylically similar set was, however, consistent with the results of the phonetically similar set: With chance at 9.1%, the errors of the good readers were dactylically related to the target set 22.2% of the time, while the errors of the poor readers were, again, exactly at chance, with a related letter only 9.1% of the time. Thus, the error analysis on the phonetically and dactylically similar sets indicates that only the good readers made errors based on the linguistic similarity of the target sets.

An analysis of the individual responses of good readers is relevant to the question of whether the improved performance of the good readers on the dactylically similar set can be attributed primarily to the phonetic similarity of the letters *M* and *N* in that set. This analysis revealed that the improvement was not due solely to better recall of only these two letters. Using the order-free scoring procedure, it was found that the good readers recalled an *M* on 80% of the dactylically similar test trials, an *N* on 65% of these trials, an *S* on 85% of these trials, and a *T* on 87.5% of these trials. Thus, it is clearly not the case that the *M* and *N* are solely responsible for the improved performance.

Since the good readers vary in age from 6.25 to 11.0 years, it is of interest to determine whether the tendency to use speech-based and manually based codes changes with age. For hearing children, use of a speech-based code has been shown to increase throughout this age span (Conrad, 1971). For each of the good readers, an index of speech-based and dactylically-based encoding was obtained as the ratio of number of errors with the phonetically or dactylically similar set to the number of errors on the control set. Thus, for example, if a subject made three errors on the phonetically similar sets and four errors on the control sets, the speech encoding index for the subject would be .75. By this measure, the lower the index, the greater the indication of speech encoding. A correlation of $-.47$ was obtained between age and the speech encoding index, and a correlation of $-.56$ was obtained between age and the dactylic encoding index. Both of these correlations are in the expected direction in finding that the older the child, the greater the evidence for both speech and dactylic encoding.

Analysis of recall accuracy indicated that use of linguistic coding strategies affected the ability of subjects to recall information about the order in which items were presented. Because a valid comparison of recall accuracy between the two reader groups can only be made on the control sets, these analyses of accuracy were confined to the control sets. It was found that the poor readers were relatively more penalized by order-strict scoring than were the good readers, as demonstrated by a significant interaction of scoring procedure × group in an analysis of the errors, $F(1, 14) = 5.02$, $p < .05$. To determine the basis of this interaction, additional analyses were undertaken of the accuracy of the two reader groups for the control lists. Since the poor readers were somewhat older than the good readers, an analysis of covariance was performed with age as the covariate. The analysis indicated a significant difference between the groups for order-strict scoring, $F(1, 13) = 5.08$, $p < .05$, but not for the order-free scoring, $F(1, 13) = 2.17$, $p > .15$. These results suggest that poor readers have relatively more difficulty than good readers in the recall of order information.

DISCUSSION

These results indicate that the good readers differed from the poor readers in their use of linguistically based recall strategies. This was shown by the good readers' improved performance on the phonetically and dactylically similar lists as compared with the control lists. In contrast, the performance of poor readers did not vary as a function of stimulus set. Thus, in keeping with results obtained with hearing beginning readers (Byrne & Shea, 1979; Liberman et al., 1977; Mark et al., 1977; Shankweiler et al., 1979), deaf children who are good beginning readers are able to make greater or more efficient use of linguistically based codes in short-term recall than are deaf children having difficulties in acquiring reading. It should be noted that the better performance of the good readers on the phonetically similar set could not be simply a reflection of differences in speech production capabilities of the good and poor readers. The speech production skills of the two reader groups were not significantly different. This suggests that it is not differences in speech ability, per se, that differentiate good and poor readers, but rather the good readers' more effective use of a short-term memory code based on linguistic features.

The lack of significant influence of linguistic similarity for the poor readers was not due to individual differences among the poor readers obscuring group tendencies. Inspection of the recall errors of the poor readers indicated a consistent pattern—for each of the poor readers, the recall accuracy across the four stimulus sets was comparable. The failure of the accuracy of the poor readers to vary as a function of stimulus set is in marked contrast to the performance of the good readers. The recall accuracy for each of the good readers consistently showed an improvement in *both* the phonetically and dactylically similar sets as compared with the control.

In the present experiment, phonetic and dactylic similarity were manipulated to investigate potential differences between good and poor readers in linguistic coding. It must be borne in mind that linguistic similarity will facilitate or hinder recall ability depending on task demands. In poetry, for example, as in certain short-term memory tasks (see Watkins, Watkins, & Crowder, 1974), phonetic similarity aids recall. The recall accuracy of the good readers in the present study benefited by the rhyming set, whereas in earlier studies with hearing children the performance of the good readers was penalized by the rhyming set (Liberman et al., 1977; Shankweiler et al., 1979). Since other investigations with deaf subjects have found decrements in serial order recall when sets of words are phonetically similar (Conrad, 1972, 1979; Hanson, 1982; Locke & Locke, 1971; Wallace & Corballis, 1973), it cannot be the case that phonetic similarity affects deaf and hearing subjects differentially. The explanation for the discrepancy between the present results and earlier studies would seem to be due to differences in procedure. On any given trial in a typical short-term memory experiment, the subject is shown only a subset of the set of stimuli. In the present experiment, however, the constraints imposed by the need to manipulate independently the phonetic, dactylic, and visual similarity of the consonant sets limited the available stimuli for each set; on any given trial an entire set of confusable stimuli was presented. If subjects in this situation could determine the similarity principle used in stimulus selection, they could use that principle to aid recall. The finding that good readers, but not poor readers, made errors that were consistent with the target set in the phonetic and dactylic similarity conditions provides strong evidence that the good readers did abstract the linguistic similarity principle used in stimulus list construction and that they then used this principle to aid recall. It is just this ability to establish and make use of linguistically based codes in the recall of letter strings that distinguishes the two groups.

The phonetically similar set consisted of letters whose names were auditorily confusing, but not dactylically or visually confusing. In the construction of the dactylically similar set, however, some confounding was unavoidable. The two letters *M* and *N* were also high in auditory confusability. The data nonetheless suggest that this phonetic similarity was not the sole reason for the improvement of the good readers on the dactylically similar set: Though this phonetic similarity applied to only two of the four letters of the dactylically similar set, analyses showed that the improved recall applied to all four letters.

Some comment should be made about the failure to find evidence of the use of visual coding strategies that have so often been considered to be the preferred strategies for deaf individuals (see, for example, Conrad, 1972; Frumkin & Anisfeld, 1977; MacDougall, 1979; Wallace & Corballis, 1973). Caution must always be used in cases of failure to find that the experimental manipulation produces an effect. It is possible that the present experimental situation was inappropriate for detecting a visual strategy, and that such strategies may have been present but were not detected. Although we cannot rule out this possibility altogether, such a possibility does not diminish the major finding of the present study that the good readers differed from the poor readers in their use of linguistically based codes.

The fact that no evidence was obtained for the poor readers' use of phonetic, dactylic, or visual codes in the present study is consistent with recent findings for hearing children who are poor readers. Although these poor readers are able to recall the letters with better than chance accuracy, when they make an error their error pattern is random. These findings with poor readers have been interpreted as indicating that poor readers have linguistic codes available to them, but that they make less efficient use of these codes than do good readers (Wolford & Fowler, in press).

In line with such an interpretation, two features of the present study should be noted. First, as indicated earlier, one criterion for subject selection in the present study was that the subjects know the names and handshapes of the letters of the alphabet. Thus, all subjects in this experiment had this linguistic information available to them. Second, the experimenter here observed that nearly all the subjects, whether good readers or poor readers, simultaneously produced the spoken names and the handshapes of the printed letters as each stimulus item was presented. Only the good readers, however, appeared by their performance to have abstracted the system underlying these linguistic performances and to make use of this information in recall. The failure of the deaf poor readers to make effective use of a linguistic representation after deriving the letter names is closely paralleled in research with hearing children. This was demonstrated with hearing beginning readers in a consonant recall task similar to the one used here, in which the children spoke aloud the letter name for each printed letter as it was presented (Wolford & Fowler, in press). In that study, as in the present one, good readers, but not poor readers, displayed errors related to linguistic recall strategies.

The difference between good and poor readers in the use of short-term memory codes was also associated with differences in serial recall ability. The analysis of the control sets demonstrated that the poor readers were relatively more penalized than the good readers by the order-strict scoring procedure. Thus, the poor readers were less able than the good readers to retain information about the order in which items were presented. These results are in accord with research with hearing children in finding that poor readers exhibit specific difficulty in the retention of order information (Katz, Shankweiler, & Liberman, 1981). This difficulty may be understood in terms of the deficient use of a linguistically based code. It has been hypothesized that a speech-based code is particularly well suited for carrying information about item order (Baddeley, 1978; Crowder, 1978; Healy, 1975). Indeed, the ability of deaf persons to recall information about order has been found to vary as a function of use of a speech-based code (Conrad, 1979; Hanson, 1982). As the good readers in the present study were found to use both speech-based and manually based codes, it is not possible here to determine whether it was the speech code alone that was related to ability to recall order information or whether the manual code contributed also. It must remain for future research to determine whether a manually based code can retain this information as well as a speech-based code.

In summary, the present findings are important in the indications they provide that deaf children need not be limited to reading strategies that involve visual retention; instead they are able to make use of linguistic strategies—derived, it appears, from both spoken and manual language—that could mediate comprehension. Although the language system is accessed via different modalities in the speech-based and manually based codes used by the good readers, both provide the reader with a means of representing the internal structure of words (see also Hirsh-Pasek, 1981) and, specifically, in terms of the present study, provide a linguistic basis for holding information in short-term memory. These results argue that successful deaf beginning readers differ from their poorly reading deaf counterparts in the use of these linguistic recall strategies. This suggestion is consistent with research on hearing children in indicating that differences in the use of linguistically based representations in working memory are a relevant factor in learning to read.

REFERENCES

Baddeley, A. D. (1966). Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. *Quarterly Journal of Experimental Psychology*, **18**, 362–365.

Baddeley, A. D. (1978). The trouble with levels: A reexamination of Craik and Lockhart's framework for memory research. *Psychological Review*, **85**, 139–152.

Bellugi, U., Klima, E. S., & Siple, P. (1975). Remembering in signs. *Cognition*, **3**, 93–125.

Byrne, B., & Shea, P. (1979). Semantic and phonetic memory codes in beginning readers. *Memory & Cognition*, **7**, 333–338.

Conlin, D., & Paivio, A. (1975). The associative learning of the deaf: The effects of word imagery and signability. *Memory & Cognition*, **3**, 335–340.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology*, **55**, 75–84.

Conrad, R. (1971). The chronology of the development of covert speech in children. *Developmental Psychology*, **5**, 398–405.

Conrad, R. (1972). Short-term memory in the deaf: A test for speech coding. *British Journal of Psychology*, **63**, 173–180.

Conrad, R. (1979). *The deaf school child*. London: Harper & Row.

Conrad, R., & Hull, A. J. (1964). Information, acoustic confusion, and memory span. *British Journal of Psychology*, **55**, 429–432.

Crowder, R. G. (1978). Language and memory. In J. F. Kavanagh & W. Strange (Eds.), *Speech and language in the laboratory, school, and clinic*. Cambridge, MA: MIT Press.

Fisher, D. F., Monty, R. A., & Glucksberg, S. (1969). Visual confusion matrices: Fact or artifact? *Journal of Psychology*, **71**, 111–125.

Frumkin, B., & Anisfeld, M. (1977). Semantic and surface codes in the memory of deaf children. *Cognitive Psychology*, **9**, 475–493.

Hanson, V. L. (1982). Short-term recall by deaf signers of American Sign Language: Implications of encoding strategy for order recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **8**, 572–583.

Healy, A. F. (1975). Coding of temporal–spatial patterns in short-term memory. *Journal of Verbal Learning and Verbal Behavior*, **14**, 481–498.

Hirsh-Pasek, K. A. (1981). *Phonics without sound: Reading acquisition in the congenitally deaf*. Unpublished doctoral dissertation, University of Pennsylvania.

Katz, R. B., Shankweiler, D., & Liberman, I. Y. (1981). Memory for item order and phonetic recoding in the beginning reader. *Journal of Experimental Child Psychology*, **32**, 474–484.

Klima, E., & Bellugi, U. (1979). *The signs of language*. Cambridge, MA: Harvard Univ. Press.

Liben, L. S., & Drury, A. M. (1977). Short-term memory in deaf and hearing children in relation to stimulus characteristics. *Journal of Experimental Child Psychology*, **24**, 60–73.

Liberman, I. Y., Shankweiler, D., Liberman, A. M., Fowler, C., & Fischer, F. W. (1977). Phonetic segmentation and recoding in the beginning reader. In A. S. Reber & D. L. Scarborough (Eds.), *Toward a theory of reading: The proceedings of the CUNY conference*. Hillsdale, NJ: Erlbaum.

Locke, J. L., & Locke, V. L. (1971). Deaf children's phonetic, visual, and dactylic coding in a grapheme recall task. *Journal of Experimental Psychology*, **89**, 142–146.

MacDougall, J. C. (1979). The development of visual processing and short-term memory in deaf and hearing children. *American Annals of the Deaf*, **124**, 16–22.

Mark, L. S., Shankweiler, D., Liberman, I. Y., & Fowler, C. A. (1977). Phonetic recoding and reading difficulty in beginning readers. *Memory & Cognition*, **5**, 623–629.

Moulton, R. D., & Beasley, D. S. (1975). Verbal coding strategies used by hearing-impaired individuals. *Journal of Speech and Hearing Research*, **18**, 559–570.

Novikova, L. A. (1966). Electrophysiological investigation of speech. In F. J. McGuigan (Ed.), *Thinking: Studies in covert language processes*. New York: Appleton–Century–Croft.

Odom, P. B., Blanton, R. L., & McIntyre, C. K. (1970). Coding medium and word recall by deaf and hearing subjects. *Journal of Speech and Hearing Research*, **13**, 54–58.

Poizner, H., Bellugi, U., & Tweney, R. D. (1981). Processing of formational, semantic, and iconic information in American Sign Language. *Journal of Experimental Psychology: Human Perception and Performance*, **7**, 1146–1159.

Richards, J. T., & Hanson, V. L. (1982). *Handshape similarity for the 26 letters of the American manual alphabet*. Unpublished data.

Shand, M. A. (1982). Sign-based short-term coding of American Sign Language signs and printed English words by congenitally deaf signers. *Cognitive Psychology*, **14**, 1–12.

Shankweiler, D., Liberman, I. Y., Mark, L. S., Fowler, C. A., & Fischer, F. W. (1979). The speech code and learning to read. *Journal of Experimental Psychology: Human Learning and Memory*, **5**, 531–545.

Wallace, G., & Corballis, M. C. (1973). Short-term memory and coding strategies in the deaf. *Journal of Experimental Psychology*, **99**, 334–348.

Watkins, M. J., Watkins, O. C., & Crowder, R. G. (1974). The modality effect in free and serial recall as a function of phonological similarity. *Journal of Verbal Learning and Verbal Behavior*, **13**, 430–447.

Weyer, S. A. (1973). *Fingerspelling by computer* (Tech. Rep. 212). Stanford, CA: Institute for Mathematical Studies in the Social Sciences, Stanford University.

Wolford, G., & Fowler, C. A. (in press). Differential use of partial information by good and poor readers. *Developmental Review*.

Wolford, G., & Hollingsworth, S. (1974). Evidence that short-term memory is not the limiting factor in the tachistoscopic full-report procedure. *Memory & Cognition*, **2**, 796–800.

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