Journal of Experimental Psychology:
Learning, Memory, and Cognition
1986, Vol. 12, No. 3, 402–412

0278-7393/86/$00.75

Echoic Memory Processes in Good and Poor Readers

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Four experiments were conducted to determine whether echoic memory plays a role in differences between good and poor readers. The first two experiments used a suffix procedure in which the subject is read a list of digits with either a tone control or the word *go* appended to the list. For lists that exceeded the length of the subjects memory span by one digit (i.e., that avoided ceiling effects), the poor readers showed a larger decrement in the suffix condition than did the good readers. The third experiment was directed at the question of whether the duration of echoic memory is different for good and poor readers. Children shadowed words presented to one ear at a rate determined to give 75–85% shadowing accuracy. The items presented to the nonattended ear were words and an occasional digit. At various intervals after the presentation of the digit, a light signaled that the subject was to cease shadowing and attempt to recall any digit that had occurred in the nonattended ear recently. Whereas good and poor readers recalled the digit equally if tested immediately after presentation, the poor readers showed a faster decline in recall of the digit as retention interval increased. A fourth experiment was conducted to determine whether the differences in echoic memory were specific to speech stimuli or occurred at a more basic level of aural persistence. Bursts of white noise were separated by 9–400 ms of silence and the subject was to say whether there were one or two sounds presented. There were no differences in detectability functions for good and poor readers.

It has been well established that children who are deficient in reading skills but comparable to their normal reading level peers on standardized tests of intelligence also show deficits on many remembering tasks (Allen, 1975; Bakker, 1972; Corkin, 1974; Guthrie & Goldberg, 1972; Mason, Katz, & Wicklund, 1975; Spring, 1976; Torgesen, 1977). The finding that poor readers have memory deficits on both auditory and visual tasks suggests that their cognitive functioning is different from good or normal readers along some basic dimensions other than the simple activation of long-term memory representations of visual patterns.

Even though it would seem to make sense from an ecological validity standpoint to use visual presentation of verbal material in such studies, differences in memory tasks using visual presentation are suspect because the poor readers were chosen precisely because of their deficits in this realm. That makes it difficult to assess whether the differences found between good and poor readers are the result of a basic deficit in the cognitive processes of poor readers or the result of their not having learned to read properly (Morrison & Manis, 1982). It is necessary that both good and poor readers have an equal opportunity to perceive the stimuli in order to test for memory differences. Additionally, it is important that differences between good and poor readers in cognitive functioning can be observed using auditory presentation because it further belies the old view that poor readers suffer from a disturbance of the visual nervous system (Cruickshank, 1972). This view is disputed by present conceptualizations that view the reading process as a linguistic activity dependent on both auditory and visual processing (Morrison & Manis, 1982; Vellutino, 1977, 1979; Vellutino & Scanlon, 1982).

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It has been demonstrated that at least part of the memory deficit in poor readers may result from unsophisticated rehearsal and central processing strategies (Bauer, 1979; Torgesen, 1977; Torgesen & Goldman, 1977). These researchers have argued that this deficiency leads to poor readers demonstrating a reduced-capacity working memory that would in turn hamper their ability to develop efficient skills in reading. However, in an experiment where the ability to use rehearsal strategies was minimized because of task difficulty and speeded presentation, recall differences between good and poor readers were still found (Watson & Engle, 1982).

This raises the possibility that good and poor readers differ in their echoic memory abilities. Echoic memory, at least as portrayed by Crowder and Morton (1969) and Crowder (1972), is a rather primitive representation of auditory input that persists long enough (probably 3–5 s) to be of use in the recall of auditorily presented information. Although data reported by Engle, Fidler, and Reynolds (1981) argues that normal children show no developmental differences in echoic memory, the possibility remains that poor readers differ either in their echoic memory abilities or in their use of this ancillary source of information.

There are other lines of research suggesting that poor readers show deficits in some rather basic auditory, and specifically speech-related, processes. For example, phonetic recoding of verbal material is a behavior first observed in normal children beginning at age 5 and increasingly so, at least until age 9 (Conrad, 1971). Phonetic recoding appears to facilitate retention in working memory that has been shown to play an important role in reading comprehension (Daneman & Carpenter, 1980). The work of Shankweiler and Liberman (1972) and others at Haskins Lab (Mark, Shankweiler, Liberman, & Fowler, 1977) suggested that poor readers do not phonetically recode material presented visually or auditorily. This was based on the finding that, whereas the short-term recall of normal readers is hurt by phonetically confusable material, the recall of poor readers is relatively unhindered. Although Hall, Wilson, Humphreys, Tinzmann, & Bowyer (1983) were not able to replicate these findings if floor and ceiling effects were eliminated, the Haskins Lab work has been influential in theorizing about differences between good and disabled readers, and the possibility remains that tasks that are difficult and require substantial resource allocation on the part of the subject do lead to the poor reader failing to recode phonetically.

Godfrey, Syrdal-Lasky, Millay, and Knox (1981) tested good and poor readers in the identification and discrimination of series of synthesized voiced-stop consonants differing in place of articulation. These were stimuli similar to the type used in the study of categorical perception in adults. For example, a series might gradually change from *ba* to *da* in small increments. Godfrey et al. found that the poor readers were generally worse at discriminating stimuli in the series, even at the boundary of the two categories where the good readers, like normal adults, show the best discrimination. They concluded that this resulted from an inconsistency in the phonetic classification of auditory cues by the poor readers which could lead to the formation of inadequate phonetic representations in long-term memory.

The findings of Shankweiler and Liberman (1972) and Godfrey et al. (1981) would seem to be irrelevant to earlier theories of echoic memory (Crowder & Morton, 1969), which saw it as a repository of auditory sensory information. But a recent reformulation of the theory (Crowder, 1983; Greene & Crowder, 1984) views echoic memory as the result of the activation of auditory or phonetic features "prior to consultation of the lexicon, or logogen system" (Greene & Crowder, 1984, p. 380). Presumably, echoic memory is limited to how many features can be activated at a given time, and the activation persists for 3–5 s.

It is clear that echoic traces can be activated by speech-related visual stimuli like the sight of moving lips. And, whereas there is no evidence that echoic traces can be activated by silent reading, there still seems to be an obvious parallel between the mechanisms used in the newer theories to explain echoic memory and the mechanisms described above to explain deficits in poor readers. It was our purpose in the studies reported here to investigate whether good and poor readers differ in either echoic memory capacity or duration.

A variety of techniques have been used to study echoic memory but none of them alone gives a totally unambiguous picture. By far the procedure most commonly used is the stimulus suffix technique in which the subject hears a list of verbal items to remember (typically in the correct order) and half the lists are followed by a redundant, nonrecalled speech suffix and the other half are followed either by nothing or a nonspeech signal such as a tone. The nonsuffix condition typically leads to very good recall for those items at the end of the list but the suffix condition leads to a decrement in recall over those positions. Recall is presumed to be better in the nonsuffix condition (cf., Crowder, 1972) because the subject can make use of the lingering echoic trace for the last few items to aid recall while the suffix presumably disrupts or displaces the echoic trace for those items. In the first two experiments, we look for differences in the magnitude of the stimulus suffix effect for good and poor readers as one way of looking for echoic memory differences.

We also were interested in making some inferences about whether any group differences in the task could be caused by differing propensities or abilities for rehearsal. We assumed that a slow rate of presentation would be more likely to allow any differences in rehearsal to appear and that we might see reading group differences in primacy effects and possibly in suffix effects as well because subjects who rehearse the last items would not suffer if the echoic trace for those items were lost. We are well aware that the effects of varying rate of presentation are not unambiguous, particularly as it may interact with the amount of material stored in echoic memory. Regardless, however, a faster rate of presentation should give a more pure estimate of echoic memory differences with the contaminating effects of differential rehearsal minimized. This assumption was based on our earlier findings that any differences in suffix effects between younger and older normal children were eliminated with a fast rate of presentation (Engle et al., 1981).

An inherent problem in comparing different developmental groups on any two conditions (and the suffix procedure is no exception) is assuring that the two conditions are of relatively equal difficulty for all subjects. For example, the results of several developmental investigations of echoic memory using the suffix technique have been clouded by floor and ceiling effects (Engle, 1977). The magnitude of the suffix effect was masked for older children at short list lengths and overall recall was impaired for younger subjects at longer list lengths. This makes comparisons of the magnitude of the suffix effect for different groups difficult. We attempted to circumvent this problem by using the same procedure used in Engle et al., (1981). Subjects were pretested to determine their basal memory span, then list length was varied with respect to that span. This allows one to estimate the effect of the suffix at varying levels of list length difficulty with the difficulty roughly equal across subjects.

In the first experiment, two list-length conditions were used; span length, as determined for each subject on the basal memory span pretest (the span condition), and span plus one item (span + 1 condition). Because performance on the span-length lists might be at or near perfect in the nonsuffix condition, the span + 1 condition was included to assess the effect of the suffix without ceiling effects.

Experiment 1

Method

Subjects. Nine poor readers and nine good readers were chosen from the same public school to serve as subjects. The sample of poor readers had a mean chronological age of 11.05 years ($SD = 0.88$) with a mean IQ of 102.00 ($SD = 7.22$). Reading scores on the reading section of the Wide Range Achievement Test ($M = 2.8$, $SD = 1.51$) and the Woodcock Reading Mastery Test ($M = 2.9$, $SD = 1.42$) indicated that the subjects in this group were all at least 1 year below their grade level on both tests of reading placement. All of these subjects were diagnosed by a school psychologist as reading disabled and were placed in a special resource-room class. In addition, none of the subjects in this group displayed any hard or soft neurological signs, hearing impairment, or hyperactivity, nor were they receiving any medication. Subjects in the normal-reader control group had a mean chronological age of 10.90 years ($SD = 0.74$) with a mean IQ of 101.55 ($SD = 5.48$). All IQ scores referred to were determined from the Wechsler Intelligence Scale for Children—Revised administered by a school psychologist.

All subjects were first pretested to determine their digit memory span. Subjects heard 50 lists, over earphones, varying from four to nine digits in length and presented at a two digit per second rate. The lists were grouped into 10 blocks ascending in length and 10 blocks descending in length. The digit span was determined by rounding off to the nearest integer the mean of the lengths of the longest list recalled perfectly in each block. Of the poor readers, five subjects had digit spans of four and the remaining four subjects had digit spans of five. Of the good readers, six had digit spans of five, two subjects had digit spans of six, and one had a span of seven.

Design. There were three within-subjects variables in this experiment: suffix condition (speech suffix or tone control), list length (span, i.e., the same length as the child's measured digit span, or span plus one item), and rate of presentation (one digit per second or four digits per second). The between-subjects variable was reading level (good or poor readers). Order of list length and presentation rate were blocked and counterbalanced. Suffix and nonsuffix lists were randomly ordered within blocks of a given list length and presentation rate. Subjects received 10 trials in each of the eight conditions with the first trial in each condition being a nonscored practice trial giving a total of 72 trials for analysis.

Apparatus. The digit lists were composed from a random numbers table with the restriction that no digit occurred more than once per list. The digits were recorded on tape by a female experimenter who read all the digits in a monotone voice, attempting to produce digits of the same duration independent of presentation rate.

Procedure. Each child was tested individually in a room at the school and heard the lists through stereo headphones. Subjects were required to write the digits on response sheets prepared with the same number of lines as there were digits for each list. A 20-s period was allowed for recall and the subject was instructed to write the digits in a left-to-right fashion only, guessing when uncertain. This proved to be more than enough time for all subjects. Responding was closely monitored to ensure that all subjects followed the instructions.

Results and Discussion

Scoring consisted of awarding a score of 1 for each position that had a digit correctly placed in it and a 0 if the digit was not in the correct serial position. It is customary in reports of studies measuring the retention of short lists to present the results as a function of serial position. This presents a problem in this study because subjects in the same condition received lists of different length. As a way around the problem we present the primacy results for all subjects, that is, recall performance for the first four positions in each list, (Figure 1) and the recency results, that is, recall performance for the last four positions in each list (Figure 2). It should be understood that for some subjects the same data will be represented in both primacy and recency figures. For example, the data from a subject with a memory span of four digits would be represented in the span condition in all four positions of both primacy and recency figures.

The first thing to be noted from the top panels of both figures is obvious ceiling effects in the span condition, most noticeably for the poor readers. This precludes any meaningful conclusions

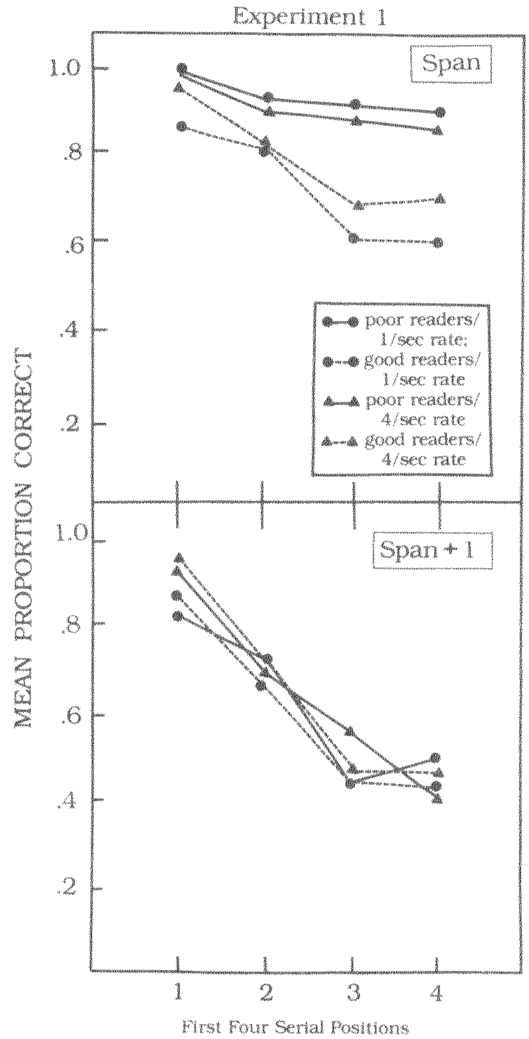

Figure 1. Mean proportion correct for the first four serial positions for the span condition (top panel) and the span + 1 condition (bottom panel) as a function of reading group, rate of presentation, and suffix condition.

from the span data. The span + 1 data do not appear to be clouded by boundary effects, with the highest level of performance around 90% correct. As we will argue below, the directions of the findings are opposite to what would be expected if a ceiling effect did exist. Thus, the conclusions reported below from this experiment will be based on the results of the analysis of the span + 1 condition.

The primacy results, shown in Figure 1, were not the focus of this study, but to the extent that differences between good and poor readers in rehearsal processes would be reflected over the primacy positions, they are relevant. It is clear from the bottom panel of Figure 1 that whereas both groups show a primacy effect, there is no difference in the extent of primacy for the two groups or for the different rates of presentation. To the extent that rehearsal is implicated in primacy effects, this suggests that good and poor readers do not differ in rehearsal.

The data of primary concern to this study are for the recency

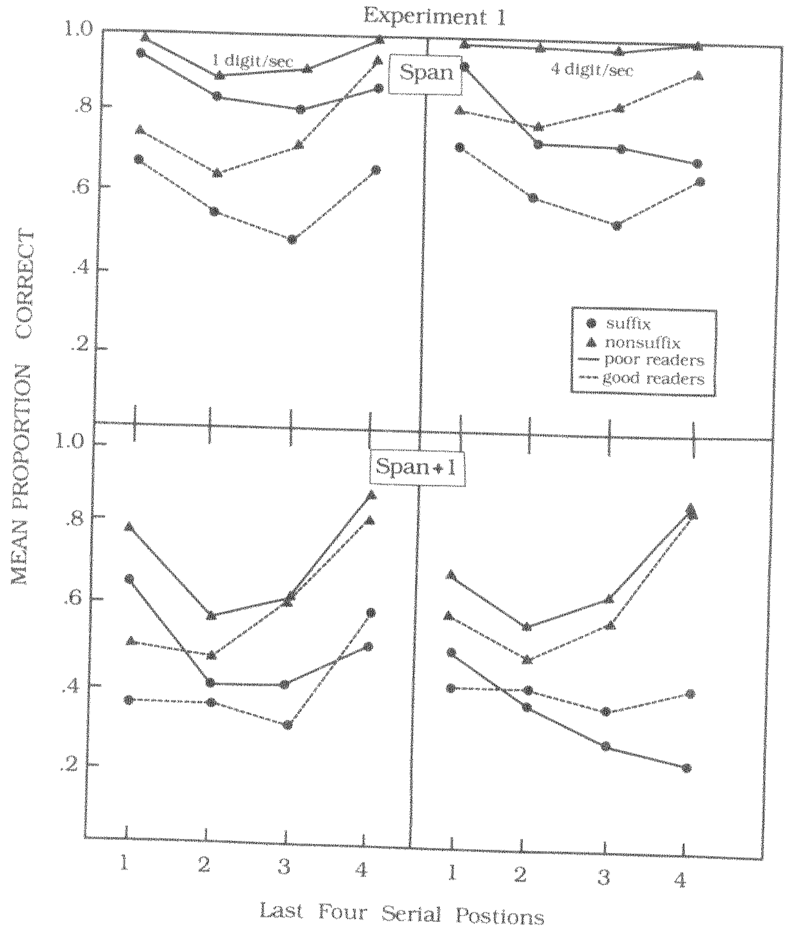

Figure 2. Mean proportion correct for the last four serial positions for the span condition (top panel) and the span + 1 condition (bottom panel) as a function of reading group, rate of presentation, and suffix condition.

positions, shown in Figure 2. The bottom panel shows the recall performance for the last four positions in the span + 1 condition as a function of reading group, rate of presentation, and suffix condition. Earlier investigations of the stimulus suffix effect have argued that only the terminal suffix effect (i.e., the difference between suffix and nonsuffix conditions for the final serial position) should be viewed as a pure reflection of echoic memory (Balota & Engle, 1981; Crowder, 1976, 1978). Because this study is concerned primarily with echoic memory differences between good and poor readers, the analyses reported below are only for the last position (i.e., Serial Position 4 in Figure 2). The proportion correct for the terminal serial position in the span + 1 condition was analyzed in a three-way mixed analysis of variance (ANOVA).

The only between-subjects variable was reading level (good or poor readers), and the within-subjects variables were nature of suffix (speech suffix or tone control) and presentation rate (one digit or four digits per second). Any two means reported below as being different reflect a difference at the .05 level on a Tukey HSD test.

The main effect of group was not significant, $F(1, 16) = .5$, but the main effect of suffix condition was, $F(1, 16) = 133.5$, $p < .01$. Whereas the main effect of rate, $F(1, 16) = 5.9$, $p < .03$, reflects the fact that performance was generally better in the slower, one digit per second rate, the interpretation of this main effect must be qualified by the significant Suffix × Rate interaction, $F(1, 16) = 10.2$, $p < .01$. Figure 2 shows that there was a larger suffix effect with the four digits per second presentation rate (54%) than with the one digit per second rate (31%). The magnitude of the difference in the suffix effect between the fast and slow rate was not significantly different for good and poor readers, reflected by the absence of a Group × Suffix × Rate interaction, $F(1, 16) = .14$.

The Group × Suffix interaction, $F(1, 16) = 5.2$, $p < .04$, is shown in Table 1. Whereas the two groups performed similarly on the last serial position in the nonsuffix condition, the suffix led to a much larger decrement in the recall of the poor readers (a 51% suffix effect) than in the recall of the good readers (a 34% suffix effect). It is not possible to totally rule out a ceiling effect for the terminal position in the span + 1 condition but several points militate against this conclusion. First, the nonsuffix results for both groups are below 90% correct (87% for the poor reader and 83% for the good readers). Second, although those two means are not significantly different, they are in the wrong

Table 1
Mean Proportion Correct Recall for the Terminal Serial Position in the Span + 1 Condition as a Function of Suffix Condition

Subjects	Condition: Nonsuffix	Condition: Suffix	Percent suffix effect
Poor readers	.87	.36	51
Good readers	.83	.49	34

direction (i.e., poor readers higher than good readers) for ceiling effects to be a problem. Third, the preterminal serial position data (from the bottom panel of Figure 2) is also in a direction that is counter to any notion that the ceiling prevents the nonsuffix results for the good readers from being higher and thus washing out any difference between the suffix effect for good and poor readers.

Experiment 2

The results of Experiment 1 were pretty clear in showing a larger suffix effect for poor readers with the span + 1 lists. But this finding was rather surprising in light of our earlier research showing no difference in echoic memory for children of different ages (Engle et al., 1981), and the sample size was rather small (nine subjects in each group). In order to increase confidence in the finding and to avoid the complication arising from the ceiling effect with the span-length lists, the span + 1 condition was replicated as Experiment 2. Whereas the Rate × Group × Suffix interaction was not significant, the bottom panel of Figure 2 shows a clear tendency for the suffix effect for the poor readers to be larger than the good readers with the four digits per second rate. Thus, this experiment used only the faster rate.

Method

Subjects. Twelve poor readers and 12 good readers were chosen from four public schools to serve as subjects. The sample of poor readers had a mean chronological age of 10.85 years ($SD = 0.72$) with a mean IQ of 103.00 ($SD = 8.13$). Reading scores on the reading section of the Wide Range Achievement Test ($M = 2.5$, $SD = 0.94$) and the Woodcock Reading Memory Test ($M = 2.7$, $SD = 1.02$) indicated that the poor readers were all at least 1 year below their grade level on both tests of reading placement. All of these subjects were diagnosed by a school psychologist as reading disabled and were selected against the same criteria as in Experiment 1. Subjects in the normal-reader control group had a mean chronological age of 10.70 years ($SD = 0.81$) with a mean IQ of 102.75 ($SD = 6.84$). All IQ scores referred to were determined from the Wechsler Intelligence Scale for Children—Revised administered by a school psychologist.

All subjects were pretested to determine their digit memory span as in Experiment 1. Two of the poor readers had digit spans of four, eight had digit spans of five, and the remaining two had digit spans of six. Nine of the good readers had digit spans of five and three had digit spans of six.

Design. The purpose of the second experiment was simply to replicate the conditions in Experiment 1 that led to the increased suffix effect shown by the poor readers at the span + 1 list length. Thus, in this experiment there was one between-subjects variable, reading level (good or poor), and one within-subjects variable, suffix condition (speech suffix or tone suffix). All subjects received lists that were the length of their digit memory span plus one item. Presentation rate was four digits per second. Ten suffix and 10 nonsuffix lists were randomly ordered over the block of 20 lists.

Procedure. The lists from the second condition of Experiment 1 were used. Subjects were tested individually in a room in the school building. The procedure in Experiment 2 was identical to that used in Experiment 1 except that the suffix effect was measured in only one condition: the span + 1 lists at four digits per second.

Results and Discussion

As in Experiment 1, only the data from the terminal serial position were analyzed in a mixed two-way ANOVA. The between-subjects variable was reading level and the within-subjects variable was suffix condition. The means for the final serial position are plotted in Figure 3 as a function of reading group and suffix condition.

As can be seen in the graph, the results were similar to those found in Experiment 1. The recall performance of the two groups of readers was not significantly different in the nonsuffix condition. However, the suffix led to a larger decrement in the recall of the poor readers, 58%, than in the recall of the good readers, who showed only a 35% suffix effect. This was roughly equivalent to the magnitude of the suffix effect in this condition in Experiment 1.

These conclusions were supported by the ANOVA with the significant main effects of reading group, $F(1, 22) = 12.3$, $p < .01$, and suffix, $F(1, 22) = 483.8$, $p < .01$, and the Group × Suffix interaction, $F(1, 22) = 76.5$, $p < .01$.

Because eight of the poor readers and nine of the good readers had the same digit span, we decided to do a separate analysis on just these subjects. This gets around the problem of comparing performance on lists of different length for different subjects and lets us look at traditional serial position functions.

The eight poor readers had a mean IQ of 103.23 ($SD = 7.63$) and a mean chronological age of 10.91 years ($SD = 0.57$). Reading scores on the reading sections of the Wide Range Achievement Test ($M = 2.6$, $SD = .82$) and the Woodcock Reading Mastery Test ($M = 2.8$, $SD = .61$) indicated that all subjects were at least 1 year below their grade. The nine good readers had a mean IQ of 101.64 ($SD = 7.14$) and a mean chronological age of 10.62 years ($SD = .92$).

The serial position functions are shown in Figure 4. The nonsuffix functions are roughly equivalent for the good and poor readers over both primacy and recency positions. Whereas the performance on the beginning two thirds of the list in the suffix condition is also similar for the two groups, the poor readers show a much greater decrement for the last position than do the good readers. The poor readers with a span of five showed a 49% suffix effect, and the good readers with a span of five showed a 29% suffix effect. An ANOVA on the data from the last serial position with group as a between-subjects factor and suffix condition as a within-subjects factor supported these conclusions. The main effect of group only approached significance, $F(1, 15) = 3.6$, $p > .10$. The main effect of suffix condition, $F(1, 15) = 298.7$, $p < .01$, and the Group × Suffix interaction, $F(1, 15) = 58.3$, $p < .01$, were both significant. The same arguments

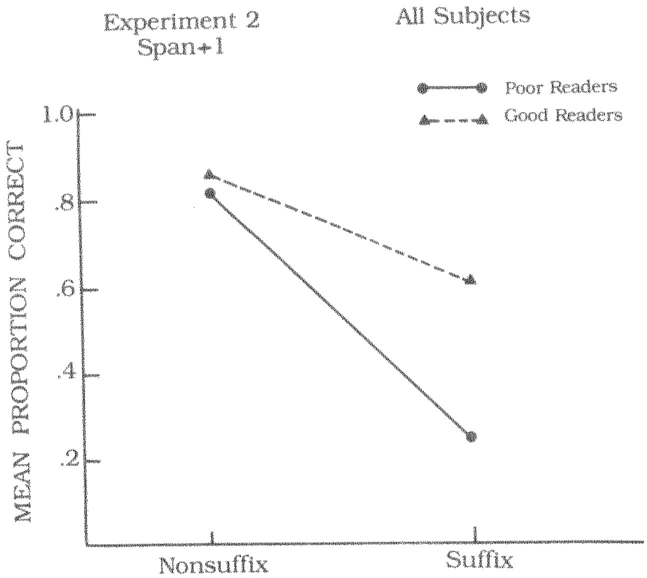

Figure 3. Mean proportion correct for the terminal serial position in the span + 1 condition as a function of suffix condition and reading group.

used above regarding ceiling effects can be used here with the additional argument that the two groups were chosen within constraints that bias against any finding of a difference between the groups and, nevertheless, a significantly larger suffix effect was demonstrated for the poor readers.

The results of these two experiments give strong evidence that good and poor readers differ in the function and/or structure of echoic memory. Two additional experiments were performed, both to extend the generality of this finding to other tasks designed to study echoic memory and to determine the specific locus of echoic memory differences between good and poor readers. As mentioned earlier, all the tasks currently being used to study echoic memory are imperfect for different reasons and all have their limitations in measuring specific characteristics of echoic memory. One possible cause of the larger suffix effect for the poor readers is that their echoic memory is of shorter duration than the echoic memory of the good readers. The suffix procedure is not very good for measuring the duration of echoic memory. If recall of the item in the last position is better with a delayed suffix than it is with a suffix occurring immediately after the item, it could be because the echoic trace has already decayed and thus, the suffix has no effect. Alternately, it could be that the echoic trace remains but the subject has coded the item into a more permanent form and the suffix, though interfering with the echoic trace, has no effect on the more permanent code of the item.

In order to measure the duration of echoic memory for the two groups, we chose a method used previously by Glucksberg and Cowen (1970). This involves the subject being presented with different auditory messages to the two ears simultaneously and shadowing, or repeating aloud one of the messages. Both messages consist of lists of letters, and the nonshadowed message also includes the periodic presentation of a digit. At some period of time after the digit is presented, a visual signal occurs and the subject is to stop shadowing and to recall a digit if one has occurred recently to the nonshadowed ear. The assumptions are (a) the nonshadowed message is being stored in echoic memory, (b) the subject is not attending to the nonshadowed message and is thus not coding the items in that message into a more permanent form, and (c) varying the delay between the presentation of the digit and the recall signal should lead to a recall function that reflects the duration of echoic memory without the contaminating effects of short-term memory coding or rehearsal. We further assumed that if good and poor readers differ in the duration of their echoic memory, this should be reflected in different recall performance for the digit as we varied the delay of the recall cue.

It should be noted here that several of these assumptions are not made without risk. For example, the venerable shadowing task has traditionally been criticized for the assumption that no attention is given to the nonshadowed message and for the assumption that different groups will not differ in how much attention they allocate to the shadowed and nonshadowed task. Both are valid criticisms and we attempt to control for these two related problems in the experiment reported below. It is also not guaranteed that differences in the Recall × Cue delay function reflect simply differences in the duration of echoic memory. That point will be discussed later.

Experiment 3

Method

Subjects. Fourteen poor readers and 14 good readers from a local public school were chosen according to the same criteria used in the first two studies. The poor readers had a mean chronological age of 10.64 (SD = .82) and mean IQ of 101.4 (SD = 4.27). These subjects were at least 1 year below grade level on the reading scores from the reading section of the Wide Range Achievement Test (M = 3.4, SD = 1.01) and the Woodcock Reading Mastery Test (M = 3.6, SD = .97). All of the poor readers were diagnosed by a school psychologist as reading disabled and were being served in a special education resource class. Further, none of the subjects displayed any hard or soft neurological signs, hearing impairment, or hyperactivity, and none were taking any medication.

The normal reading control group had a mean chronological age of 10.83 (SD = .65) with a mean IQ of 102.7 (SD = 5.79). All IQ scores were obtained from the Wechsler Intelligence Scale for Children—Revised administered by a school psychologist.

Design. The two variables in this experiment were reading group (good and poor readers) and the amount of the delay of the recall cue after the digit was presented (0, 1, 2, 4, 8, and 16 s), which was a within-subjects variable. Order of cue delay was random with the restriction that each delay interval occurred twice in each block of 12 trials.

Apparatus. A male, trained and experienced as a professional broadcaster, spoke the letters of the alphabet (excluding *w*) and the digits 1 through 9 into a microphone for digitizing on a Mountain Computer Supertalker attached to an Apple II computer. The letters and digits were recorded so that the duration ranged from 250–350 ms and were judged to be of similar volume. From this digitized "master," four-track audio tapes were constructed by recording from the computer onto tape, using a Teac four-channel recorder.

A master tape was constructed such that Track 1 contained the letters to be shadowed and Track 2 contained the message to be ignored, which included letters and digits. The shadowed message included the letters of the alphabet in random order, with the restriction that a letter occurred no more than three times consecutively. The message to be ignored was recorded on Track 2 and contained the letters of the alphabet recorded in a different random order from the shadowed message. Embedded in the message to be ignored were the digits 1 through 9 in random order, with the restriction that no digit occurred more than two times consecutively. On Track 3 of the tape was recorded a brief pure tone, which was inaudible to the subject but which followed the digit by the corresponding cue delay and which served to close an electronic switch that eventually led to a signal to the subject to recall the digit. That is, the interval between the digit on Track 2 and the tone on Track 3 represented the designated cue delay of 0, 1, 2, 4, 8, or 16 s. The tone triggered a circuit that operated a light situated in front of the subject for 1 s.

After the master tape was generated, four copies were made that were identical except that the rate of presentation of the message to be shadowed was varied. The rate of the shadowed message was either 1.85, 1.64, 1.43, 1.22, or 1.00 letters per second. The rate of the to-be-ignored message was recorded at 1.43 items per second. An additional set of tapes was generated without the tone on Track 3. Tapes were recorded at each of the presentation rates to be used as practice tapes.

Procedure: Pretesting. As we mentioned earlier, to draw any conclusions in a shadowing task, it is necessary that the experimenter be able to assume that the shadowing task is sufficiently difficult that subjects must allocate full attention to it. In addition, when groups of different developmental levels are used it is necessary that the task be equally difficult for the two groups. Therefore, our subjects were pretested to determine an appropriate rate of presentation for each subject that would yield a performance level on the shadowing task of 75–85% correct.

On Day 1 of the experiment, the children were asked to shadow the message contained on the practice tape. The messages were presented using the same four-channel Teac recorder and were presented over stereo headphones. Each subject first heard the tape recorded at 1.43 letters per second and, after 2 min of practice, their shadowing accuracy was measured for 3 min. If the subject performed above 85%, he or she was switched to the next faster rate. If the subject shadowed at less than 75% accuracy on the first tape, he or she was switched to the next slower rate. This procedure continued until accuracy of 75–85% was achieved for 5 consecutive minutes. By using this method, we were able to ensure that subjects were performing at relatively equal levels of difficulty on the shadowing task. Of the poor readers, five met criterion at 1.22 letters per second, and nine met criterion at 1.00 letters per second. Eleven of the good readers met criterion at 1.22 letters per second and three at 1.43 letters per second.

Procedure: Test trials. At the beginning of the second session, each subject was given 2 min of practice shadowing the tape that had resulted in 75–85% accuracy. This was followed by the test tape recorded at the same rate as the practice tape. The subjects were instructed to listen to the to-be-shadowed message and to shadow as accurately as possible. They were told to ignore the message in the other ear, but that occasionally the red bulb in front of them would light and when that happened to stop shadowing for a moment and try to recall whether or not they had heard a digit recently in the unattended ear. If so, they were to tell the examiner which digit. This was recorded by the examiner. The children were further informed that they would probably not be able to recall a digit each time the bulb was lit and that that was alright because they should do as well as they could on the shadowing task.

The test session consisted of 32 consecutive 1-min segments of message with two, three, or four digits recorded within each 1-min segment. A total of 96 digits were embedded in the unattended message such that each of the six cue delays occurred 16 times. Half the subjects in each group heard the to-be-shadowed message in the right ear and half heard it in the left ear.

Results and Discussion

There were no spontaneously reported digits by subjects from either group. The number of digits that each subject recalled at each of the six cue delays was analyzed in a two-factor ANOVA. Figure 5 shows that the recall functions of the two groups differed. This was supported by significant main effects of reading level, $F(1, 26) = 12.44$, $p < .01$, and cue delay, $F(5, 130) =$

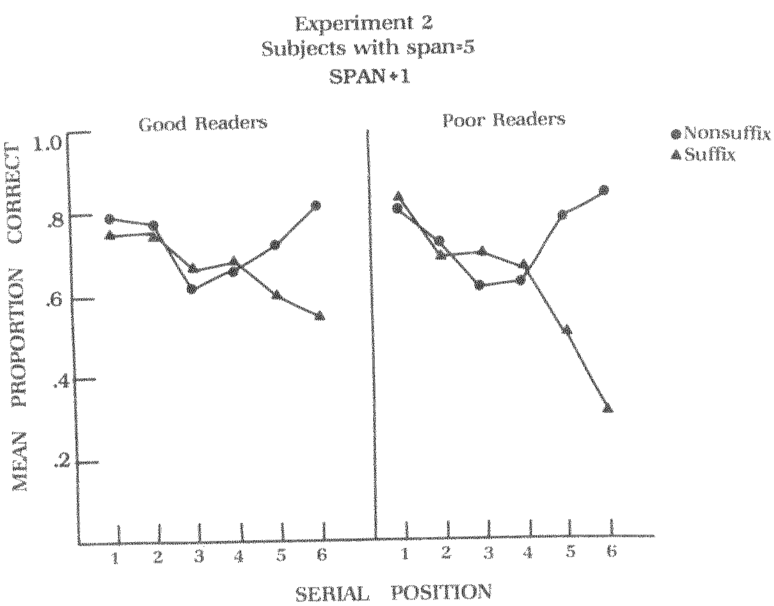

Figure 4. Mean proportion correct for the span + 1 condition for those subjects with a span of five digits as a function of serial position, reading group, and suffix condition.

53.19, $p < .01$, and the Reading Group × Cue Delay interaction, $F(5, 130) = 11.99$, $p < .01$. It is particularly important that the two groups showed equivalent recall when the cue was presented immediately after the digit was presented and that this level of performance was not so high that ceiling effects would be suspected. This suggests that our attempts to make the task of equal difficulty for the two groups were successful. The two groups performed identically when the cue was given immediately after the digit was presented, but the poor readers performed significantly worse at every cue delay after that, with the largest difference between the two groups being in the 2- to 4-s range. It should be further noted that the poor readers reached chance level after a delay of between 2 s and 8 s whereas the good readers did not reach asymptote even after a delay of 16 s.

These data would appear to support a conclusion that poor readers show a more rapid loss of information from echoic memory than do good readers. Although this is certainly the simplest explanation and may be the best and correct one, at least one other possible explanation would fit with the existing literature. We will consider it in the General Discussion section.

We next wanted to determine whether this difference between good and poor readers on tasks designed to measure echoic memory was peculiar to speech or was more general. Although early work suggested that echoic memory stored only spoken information, that was probably an artifact of the procedures most commonly performed (Foreit, 1976). Cowan (1984), however, has recently proposed that there are really two types of auditory memory. The first is a short auditory storage that lasts about 200–300 ms and is experienced by the subject as a continuation of sensation. The second type is longer lasting and not experienced as a continuation of sensation but as "an after-ringing or echo" (Cowan, 1984, p. 365). It is clear that the procedures used in the first three experiments are tapping the long-auditory storage.

The purpose of the next experiment was to test the limits of the differences due to reading group observed in the first three experiments in a task that minimizes the importance of speech and language and is designed to more directly measure what is probably best called "aural persistence."

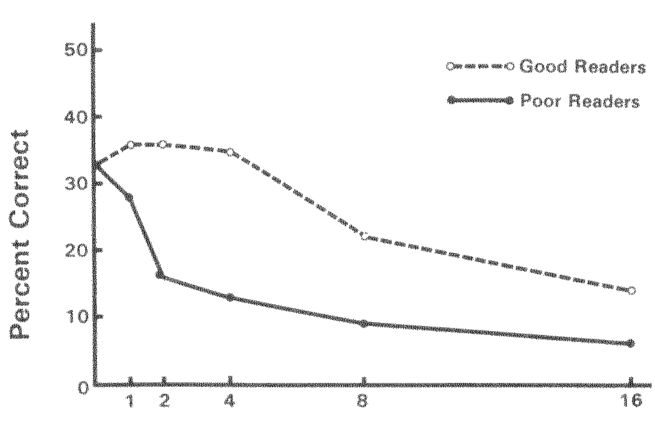

Figure 5. Percent correct recall as a function of cue delay and reading group.

Experiment 4

A gap detection procedure, similar to that designed by Plomp (1964), was used to determine whether good and poor readers differed in rate of decay from the short-auditory storage described by Cowan (1984). The subjects were presented with two bursts of white noise over earphones. The length of the silent interval between the two bursts was varied across trials. The subjects' task was to respond "yes" if they detected a silent gap between two discrete bursts of noise and "no" if they detected a single burst with no gap. Previous studies (e.g., Campbell & Meyer, 1981; Plomp, 1964) have shown that at silent intervals in the range of 10–70 ms subjects do not report a gap between the two bursts. Presumably, the trace of the first stimulus persists to fill the interval between the bursts of noise and, consequently, no silent period is perceived. Further, the minimum detectable silent interval is greater when the second burst is slightly lower in intensity than the first. Apparently the echoic trace of the first stimulus has a functional intensity more similar to the less intense second stimulus.

Because the duration of the echoic trace determines the detection threshold in this task, it was predicted that if the poor readers have a faster decaying or weaker echoic trace, they should detect the two stimuli at shorter silent intervals than the good readers. This is a rather novel situation for comparative studies with groups of different developmental level in that the lower level is predicted to do better on a task than the developmentally more sophisticated group. That is precisely what Campbell and Meyer found with mentally retarded subjects, that is, the retarded subjects were more accurate in gap detection at shorter silent intervals.

Method

Subjects. All the subjects that served in Experiment 2 also served in this experiment. The two tasks were administered on two consecutive days with half the subjects starting with the task representing Experiment 2 and half starting with the task representing this experiment.

Design. Reading group (good or poor reader) was the only between-subjects variable. The one within-subjects variable was the length of the gap or silent interval between the two bursts of white noise (0, 30, 50, 70, 100, 150, or 400 ms).

Apparatus. Each trial consisted of two bursts of white noise; the first occurred for 500 ms and was 86 dbA in intensity measured at the headphones. The second burst was 71 dbA in intensity and varied in duration. The two bursts were separated by 0, 30, 50, 70, 100, 150, or 400 ms of silence. The duration of the second burst was varied so that the duration of the silent period and the second burst equaled 500 ms. Thus, each trial lasted 1 s. Prior to each trial, a warning light occurred for 300 ms. A period of 2 s elapsed between the end of one trial and the warning light for the next. The sequencing and duration of bursts were controlled by a programmable digital timer that activated two white noise generators. The stimuli were recorded and played back to the subject over headphones from a Teac four-channel recorder.

Prior to being tested on the critical stimuli, subjects received a series of training trials. For the training stimuli, both bursts were 86 dbA in intensity with the first being 500 ms in duration. A series of 12 trials was presented first with the gap either 0 ms in duration, in which case the second burst was 500 ms long, or 400 ms, in which case the second burst was 100 ms long. The next series of 12 training trials was like the first 12 except that there were two trials each with a gap length of 0, 30, 50, 70, 100, or 150 ms and the duration of the second burst adjusted accordingly.

Procedure. Subjects were instructed to listen to each stimulus following the warning light and to circle a *Y* on the response sheet if they detected a gap between the two sounds and to circle an *N* if they did not. Immediately following the training trials, the subjects received the 70 test trials, 10 trials at each of the 7 gap lengths. The order of gap lengths was randomly ordered such that each gap length occurred twice within each block of 14 trials.

Results and Discussion

The correct gap detection percentage is shown in Figure 6 as a function of the length of the silent interval. The performance of the two groups is almost indistinguishable at every interval length. Performance of both groups is perfect by a separation of 100 ms and exceeds the 50% threshold at some point between 50 and 70 ms. These data seem to support Cowan's (1984) notion of multiple echoic memories and argue that good and poor readers do not differ in the shorter, and probably more veridical, representation we referred to previously as aural persistence.

This finding of no difference between good and poor readers on a task designed to measure sensory persistence takes on added significance given evidence that good and poor readers do differ in the persistence of visual information. Badcock and Lovegrove (1981) and Di Lollo, Hanson, and McIntyre (1983) found that poor readers had longer duration of visible persistence for nonlanguage stimuli. The interpretation was that the visual system of poor readers may take longer to recover from the aftereffects of neural activity evoked by an inducing stimulus. The present data argue for no such difference for the auditory system.

General Discussion

We have reported three findings in these studies that merit discussion and interpretation: (a) Poor readers show a larger terminal position suffix effect than good readers even when ceiling effects are controlled. The two groups appear to have equal performance for the nonsuffix conditions but the poor readers suffer a larger decrement in recall as a consequence of the suffix than do the good readers. (b) In the recall of digits to the unattended ear in a dichotic listening task, the performance of poor readers shows a faster loss over time than does that of good readers, who are superior even after 16-s delay. (c) The performance of good and poor readers is identical in a gap-detection task designed to measure the duration of aural persistence.

There are at least three possible explanations of these data. One theory is that poor readers do indeed have a deficit in echoic memory, not what Cowan (1984) calls short auditory memory or aural persistence, but a deficit in the longer lasting echoic memory. There are several possibilities for the locus of this problem. The echoic memory of poor readers could be of smaller capacity or their echoic trace could decay faster, as might be indicated by the simplest interpretation of the recall of the unattended digits.

It seems impossible to make any sound inferences about differential capacity of good and poor readers on the basis of these data. The problem is in the interpretation of the larger suffix effect for the poor readers. There is nothing in either the earlier theory (Crowder & Morton, 1969) or the newer version (Greene & Crowder, 1984) that would help us interpret differential suffix effects for two groups. The logic we presented in the introduction suggested that poor readers might have a deficit in echoic memory. But the finding of a larger suffix effect for this group makes the notion that they have a larger echoic memory even more tenable.

The faster drop in recall of the digit in Experiment 3 might lead us to suspect that poor readers have a faster decay of echoic memory. The larger suffix effect for the poor readers, however, would seem to suggest that when the suffix occurs there is more echoic information available for the poor readers, not less. Thus, a faster decay theory seems inconsistent with the data.

A second explanation that is more consistent with the data

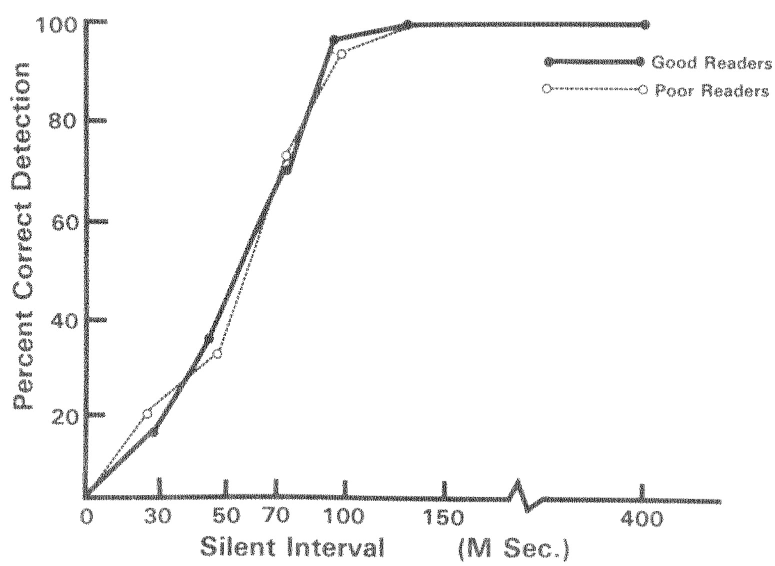

Figure 6. Percent correct detection as a function of the length of the silent interval and reading group.

views the echoic memory of poor readers as more sensitive to interference. This would explain the results of the first two experiments because performance on the nonsuffix lists was about the same for the two groups but the suffix caused more damage to the performance of the poor readers than to that of the good readers. The results of Experiment 3 could also be due to greater interference for the poor readers. Remember that the amount of auditory interference occurring between the presentation of the digit and the recall cue was confounded with the recall delay because the recall delay was filled with the presentation of letters. Thus, the faster decline in performance over cue delay for the poor readers may have been caused by the greater interference.

A third and slightly different explanation of these data is that good readers do a quick and automatic phonetic coding of the verbal stimuli used in these studies whereas the poor readers either do not construct a phonetic code or construct a code that is inconsistent and of poor quality or one that decays faster. If we assume that phonetic coding leads to a somewhat durable trace compared to echoic memory, then the good readers would have an advantage in recall even after the suffix interferes with recall from echoic memory. The poor readers would rely much more on echoic memory and, with it lost because of the suffix, their performance would show a greater decline. Implicit in this notion is that even those verbal stimuli presented to the unattended ear would lead to a phonetic coding by the good readers and that this is the basis for their better recall of the digits even after 16 s. We are aware of no direct evidence that supports this idea but some indirect support can be taken from Salame and Baddeley (1982). They showed that recall of a visually presented string of items was affected by the phonemic confusability of unattended auditorily presented items.

It is important to note that if this latter theory is correct then these data say nothing about echoic memory per se except that we have identified yet another noise factor in tasks designed to study echoic memory. Further, a case could be made that poor readers would be the very best subjects to use if we want to study pure echoic memory without these noise factors affecting our results.

Assuming, on the other hand, that these data do speak to a difference in echoic memory for good and poor readers, we need to begin thinking about how this would contribute to the reading difficulties of poor readers. If Greene and Crowder (1984) are correct in describing the echoic trace as the activation of auditory or phonetic features rather than the representation of sensory information, then ideas presented by Perfetti and McCutchen (1982) are relevant to the present data. They argue that phonetic codes are activated automatically in skilled readers but that unskilled readers (presumably the same population as our poor readers) require an effortful activation of phonetic codes and, consequently, other effortful processes involved in reading will interfere with these codes. The result is that poor readers would suffer from a faster deactivation of the speech-based phonetic codes than would good readers. That certainly fits with our data. However, Perfetti and McCutchen describe the phonological segments that are activated during reading as including primarily consonants and particularly the initial consonant segment and its place of articulation. Suffix effect studies have shown that stimuli that vary only in their consonant component do not show a suffix effect nor a modality effect but stimuli that vary in vowel components show both effects (Crowder, 1972). This suggests that the locus of interference in the suffix effect is different than the phonological code described by Perfetti and McCutchen. If we assume that echoic memory really is the retrieval of speech-based codes or auditory images (Greene & Crowder, 1984), then the two explanations presented here are not vastly different. What remains to be determined is whether in fact echoic memory is "auditory sensory memory" or the retrieval of auditory-speech codes. A determination of the precise mechanism that distinguishes between good and poor readers may depend on resolving this issue on the basic nature of echoic memory.

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Received June 17, 1985
Revision received September 6, 1985 ■