405

JOURNAL OF EXPERIMENTAL CHILD PSYCHOLOGY 35, 345–367 (1983)

Speech Perception and Memory Coding in Relation to Reading Ability

SUSAN BRADY

University of Rhode Island and Haskins Laboratories

DONALD SHANKWEILER

University of Connecticut and Haskins Laboratories

AND

VIRGINIA MANN

Bryn Mawr College and Haskins Laboratories

Previous work has demonstrated that children who are poor readers have short-term memory deficits in tasks in which the stimuli lend themselves to phonetic coding. The aim of the present study was to explore whether the poor readers' memory deficit may have its origin in perception with the encoding of the stimuli. Three experiments were conducted with third grade good and poor readers. As in earlier experiments, the poor readers were found to perform less well on recall of random word strings and to be less affected by the phonetic characteristics (rhyming or not rhyming) of the items (Experiment 1). In addition, the poor readers produced more errors of transposition (in the nonrhyming strings) than did the good readers, a further indication of the poor readers' problems with memory for order. The subjects were tested on two auditory perception tasks, one employing words (Experiment 2) and the other nonspeech environmental sounds (Experiment 3). Each was presented under two conditions: with a favorable

---

The authors thank several colleagues for their helpful comments and suggestions: Carol Fowler, Vicki Hanson, Leonard Katz, Robert Katz, and Alvin Liberman. We are especially grateful to Isabelle Liberman, whose insightful comments on earlier drafts contributed to the clarity of this presentation. We are also indebted to William Holland, Superintendent of Schools, Narragansett, Rhode Island, and to the faculty at the Narragansett Elementary School for their kind cooperation: David Hayes, Principal; Judy Aiello, Reading Coordinator; and the third grade teachers (Sue Boland, Leslie Flynn, Edward O'Brien, Hope Rawlings, and Marguerite Strain). This research was supported by a grant from the National Institute of Child Health and Human Development (Grant HD-01994) to Haskins Laboratories. Requests for reprints should be directed to Susan Brady, Haskins Laboratories, 270 Crown Street, New Haven, CT 06510.

0022-0965/83 $3.00

signal-to-noise ratio and with masking. The poor readers made significantly more errors than the good readers when listening to speech in noise, but did not differ in perception of speech without noise or in perception of nonspeech environmental sounds, whether noise-masked or not. Together, the results of the perception studies suggest that poor readers have a perceptual difficulty that is specific to speech. It is suggested that the short-term memory deficits characteristic of poor readers may stem from material-specific problems of perceptual processing.

Many studies have shown that children who are poor readers tend to perform deficiently on short-term memory tasks. There is considerable evidence, however, that the memory problem is specific to linguistic material and to other material that lends itself to linguistic representation. A hypothesis has been proposed that failure to make effective use of phonetic coding in short-term memory may account for some of the deficiencies poor readers typically show in language processing (Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977). Tests of this hypothesis have utilized the well-known phenomenon that when normal adult subjects are required to recall strings of rhyming and nonrhyming letters or words, many more errors typically occur on the rhyming strings (Baddeley, 1966; Conrad, 1964, 1972). Children who are good readers, like normal adults, tend to be strongly affected by rhyme; poor readers, on the other hand, are significantly less affected. For them, phonetic similarity has relatively little effect on recall (Liberman et al., 1977).

Subsequent experiments have confirmed and extended this result under a variety of conditions: when memory is tested by recognition as well as when it is tested by recall (Byrne & Shea, 1979; Mark, Shankweiler, Liberman, & Fowler, 1977); when sentences or word strings are the stimuli as well as when letter strings are presented (Mann, Liberman, & Shankweiler, 1980); when the items are presented auditorily instead of visually (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). In each of these conditions it was found that poor readers are relatively insensitive to the phonetic characteristics of the items. Accordingly, it has been supposed that poor readers have a general problem with the use of a phonetic code, however the material is presented, and not a specific difficulty in deriving a phonetic representation from print (Shankweiler & Liberman, 1976). It would seem, therefore, that one reason for poor readers' deficient performance in short-term memory tasks is their failure to fully exploit phonetic coding.

It remains to be determined what limits full utilization of phonetic codes by poor readers. To what extent does the problem arise in perception with the encoding of stimuli, and to what extent does the problem involve the use of information already represented in phonetic form? Our intent in this study was to investigate whether the poor readers' phonetic-coding deficiency in short-term memory is related to the perceptual process as such.

A study by Rabbitt (1968) gives a way to understand how such a relationship might come about. This study points to a direct connection between stimulus variables that affect perception and those that affect recall. In Rabbitt's experiment, the subjects were required to listen to spoken digits presented with a white noise mask. In one condition the subjects' task was to repeat individual items, and in another condition they were tested for recall of strings of items. It was found that noise levels that produced no manifest effect on perception and recall of the individual items significantly impaired recall of the strings. Thus adding noise, and increasing the perceptual difficulty, adversely affected memory even when the individual items could still be identified correctly. The insight we gain from Rabbitt's findings may give us a purchase on the problem of why poor readers typically reveal deficits in verbal short-term memory. Their failure to make full use of phonetic coding in short-term memory may be traceable, as Perfetti and Lesgold have supposed (1979), to a disorder at the level of perceptual processing.

It is well known that severe reading problems often occur in children who show no obvious abnormalities in language development. These poor readers typically do not manifest clinically apparent difficulties in perception of speech. It is conceivable, however, that such children may have subtle deficiencies in speech perception that special testing procedures may bring to light.

One study (Goetzinger, Dirks, & Baer, 1960) hints that in order to discern differences in perceptual skills among good and poor readers it may be necessary to use a quite demanding task. Goetzinger et al. reported no difference between reading groups for a list of well-articulated words, but a significant difference in favor of the good readers on a list of rapidly, and somewhat indistinctly, articulated items. Although the study does not permit a direct comparison to be made (different words occurred in the two test lists), the results suggest that discrepancies in speech perception abilities may have been present for good and poor readers that would be detected on a sufficiently difficult task.

Although relevant data are scarce, there is reason to suggest that the characteristic differences so often observed between good and poor readers on memory tasks might be associated with differences in speech perception. Our purpose in the research we present here was to examine this possibility. Accordingly, good and poor readers were tested on a memory task in which the effects of phonetic coding are known to be discernible. Using the procedure of Liberman et al. (1977), we compared performance on recall of phonetically similar (rhyming) and phonetically dissimilar (nonrhyming) sequences of monosyllabic words in good and poor readers. It was expected that, as in previous experiments, good readers, in contrast to poor, would find recall of the rhyming sequences more difficult than the nonrhyming sequences, reflecting more efficient use of a phonetic code. We then addressed the question of whether the reading group differences on memory tasks are related to speech perception abilities. The subjects were tested on a speech perception task requiring repetition of monosyllabic words. The items selected included high and low frequency words phonetically balanced to permit phonetic analysis of errors and examination of error location within the syllable. The stimuli were presented under two conditions, with and without masking noise, in order to vary the difficulty of the task. In addition, a test of perception of environmental nonspeech sounds was conducted, again with and without noise masks, to enable us to investigate any differences in perceptual performance that exist beyond the speech domain.

GENERAL METHOD

Subjects

The subjects were third grade children from a suburban public school in southern Rhode Island. A school reading specialist was asked to select the poorest readers and the good readers from the third grade classes. The children were given the Word Attack and Word Recognition subtests of the Woodcock Reading Mastery Tests, Form A (Woodcock, 1973), and a test of receptive vocabulary, the Peabody Picture Vocabulary Test (PPVT; Dunn, 1965). On the basis of scores obtained on the Woodcock test, two groups were formed that were nonoverlapping in reading level.

Eight children were eliminated because their inconsistent scores on the two Woodcock subtests made them difficult to classify as good or poor readers. Three additional selection criteria were employed to determine eligibility for participation in the experiments. First, in order to restrict the range of vocabulary skills, only those children were selected whose PPVT IQ score fell between 90 and 120. An additional five children failed to meet this requirement. Second, in view of the evidence that the speech perception skills of children continue to develop during elementary school years (Finkenbinder, 1973; Goldman, Fristoe, & Woodcock, 1970; Schwartz & Goldman, 1974; Thompson, 1963), subjects were selected whose ages fell within a limited range (96–108 months). The age requirement excluded five more potential subjects. And third, the remaining children were screened for hearing loss. The right and left ears were presented with tones at 500 Hz (25 dB), 1000 Hz (20 dB), 2000 Hz (20 dB), 4000 Hz (20 dB), and 8000 Hz (20 dB), using a standard audiometer. Seven children failed the hearing screening.

Thirty children met all the requirements for participation in the study. The characteristics of the good and poor reader groups are summarized in Table 1. The 15 children who qualified as good readers were well ahead of third grade reading skills with a mean reading grade level of 5.88. The 15 children labeled poor readers averaged slightly more than

TABLE 1

MEANS FOR THIRD GRADE CHILDREN GROUPED ACCORDING TO READING ACHIEVEMENT

Group	N	Age	IQ[a]	Reading grade[b]
Good	15	8 years 5 months	106.8	5.88
Poor	15	8 years 6 months	102.5	2.76

[a] Peabody Picture Vocabulary Test.

[b] From the average of the reading grade scores obtained on the Word Attack and Word Recognition subtests of the Woodcock Reading Mastery Tests, Form A.

½ year below their expected level (with a mean reading grade level of 2.76).

The ages of the good (mean = 8 years, 5 months) and poor readers (mean = 8 years, 6 months) did not differ significantly. Nor were the IQ scores as assessed by the PPVT significantly different. The mean IQ score for the good readers was 106.8, for the poor readers 102.5.

Procedure

Each child was tested individually for three sessions. The first session included the screening procedure, the speech perception noise-masked condition and one half (Set A as explained below) of the memory experiment. The second session, occurring at least a week later, consisted of the speech perception unmasked condition and the other half (Set B) of the memory experiment. The third session, approximately 2 months after the first, was devoted to the environmental-sounds experiment.

The experiments were conducted in a quiet room. The tape-recorded material for the memory, speech perception, and environmental sounds tasks was played to subjects over earphones. The subjects' responses were recorded on audiotape. Transcriptions of the subjects' responses were also made during the testing session. The tapes were played back within an hour of the experimental session in order to corroborate the transcription and to allow any necessary corrections.

EXPERIMENT 1

The first experiment employed a short-term memory task with rhyming and nonrhyming word strings. Our aim was to confirm previous evidence that poor readers make less effective use of phonetic coding in short-term memory than do good readers.

Stimuli

Twenty strings of five monosyllabic words were created, ten rhyming and ten nonrhyming. A single list of 50 common nouns was used as the word source for the rhyming and nonrhyming tests. Thus, word frequency, phonetic structure, and word length were strictly controlled for the two conditions. The five words in each rhyming string had the same vowel and the same final consonant, if any. The five words in each nonrhyming string all had different vowels and final consonant.

The 20 strings were recorded on magnetic tape in two sets (A and B) of 10 lists read by a phonetically trained male speaker. Each set comprised an alternating presentation of rhyming and nonrhyming strings. Within each string the items were spoken with a neutral prosody at the rate of 1 per second. The two sets are presented in Table 2.

Procedure

Each subject heard Set A during the first session and Set B during the second. On both occasions the same procedure was followed. The child was told that a list of words would be played and that the task was to repeat the list in the order given. After practicing with two lists read by the experimenter, the subject then heard the prerecorded set of 10 five-item word strings.

Results and Discussion

First, an analysis was made of the correct responses in terms of item recall and serial order. Secondly, the errors were analyzed qualitatively in relation to phonetic structure of the stimulus words.

TABLE 2
EXPERIMENT 1: WORD LISTS

Set A					
1	chain	train	brain	rain	pain
2	cat	fly	score	meat	scale
3	pair	air	hair	chair	bear
4	roar	wheat	fat	tail	sky
5	state	plate	weight	gate	fate
6	tie	hat	nail	floor	sheet
7	cell	shell	well	bell	spell
8	mail	pie	store	cap	feet
9	bee	tree	knee	tea	key
10	treat	door	eye	sail	map
Set B					
1	bell	state	knee	pain	chair
2	fly	pie	tie	eye	sky
3	bee	cell	train	air	plate
4	cat	hat	fat	map	cap
5	gate	brain	pair	tea	well
6	tail	scale	mail	sail	nail
7	bear	key	weight	shell	chain
8	score	roar	door	floor	store
9	rain	hair	spell	fate	tree
10	meat	wheat	sheet	feet	treat

Analysis of Correct Responses

The subjects' responses were scored in two ways. In the first procedure, a response was considered correct only if the item was accurately reported and if it was assigned to the appropriate serial position. The second procedure ignored serial position and counted as correct all responses of words that had occurred in the given string, regardless of order of report.

The error data for each scoring procedure (summarized in Table 3) were subjected to analysis of variance. We examine first the results from the more strict scoring procedure. In agreement with earlier studies (Naidoo, 1970; Miles & Miles, 1977; Shankweiler et al., 1979; Mann et al., 1980) the overall accuracy of recall was greater for good readers, $F(1, 28) = 5.6$, $p = .025$. There was, as expected, a significant effect of list type, $F(1, 28) = 44.2$, $p < .001$. And, as predicted, the good readers made fewer errors on the nonrhyming word sequences than on the rhyming. The poor readers also showed an effect, though a smaller one, of phonetic similarity. Thus, while we obtained significant effects of reader group and of list type that conformed to the pattern of earlier studies (Shankweiler et al., 1979; Mann et al., 1980), the interaction between reading group and list type did not reach significance, $F(1, 28) = 2.9$, $p = .098$.

Evidence that the two reading groups differed in the recall strategies they employed emerges when the data were reexamined after applying the more lenient scoring procedure. As in other studies utilizing lists of high intralist similarity, item information suffers less than order information. So for both groups the order-free recall scores are markedly higher, particularly for the rhyming strings. Overall, the performance level of the two reading groups was not significantly different, $F(1, 28) = 3.6$, $p = .071$, nor was there a main effect of rhyme, $F(1, 28) = .1$, $p > .500$. In Table 3 we can see, however, that while the scores for the two groups were very close in the rhyming condition, they were dissociated on the nonrhyming sequences. Thus, we find a significant in-

TABLE 3

EXPERIMENT 1: MEAN NUMBER CORRECT SUMMED OVER SERIAL POSITIONS[a] FOR STRICT ORDER SCORING AND FOR ORDER FREE SCORING

	Order correct scoring		Order free scoring	
	Rhyme	Nonrhyme	Rhyme	Nonrhyme
Good	15.8	28.0	32.7	35.5
Poor	12.2	19.4	31.7	29.5
Difference	3.6	8.6	1.0	6.0

[a] Maximum = 50.

teraction between reading group and list type, $F(1, 28) = 6.7, p = .016$). The good readers showed improved performance in the nonrhyming condition, $F(1, 28) = 4.2, p = .05$, where an efficient phonetic strategy can operate to advantage. The poor readers, in contrast, did not improve on the nonrhyming sequences, $F(1, 28) = 2.6, p < .20$; indeed, they tended to do worse.

The memory experiment undertaken here was intended mainly as a replication. In previous research, good readers evidenced generally superior recall but were relatively more penalized by phonetic similarity within a list than were poor readers. The present study does generally conform to this picture, though here the differences between the groups were somewhat less marked, perhaps because the subjects were a year older than those in the earlier research. At present, the appropriate studies to examine developmental changes in use of a phonetic strategy have not been done. If poor readers are employing a nonphonetic strategy, as has been suggested (see Byrne & Shea, 1979), we might expect their use of this strategy to diminish with increasing age (Conrad, 1972).

Qualitative Analysis of Errors

The construction of the present experiment, using words as stimuli rather than letters, permits a closer inspection of the nature of the difficulty poor readers have in preserving order information. In analyzing the response sequences, it became apparent that the recall problems of poor readers apply not only to the order of the stimuli in a string but also to the retention of phonemic sequences within individual words. The subjects' response sequences (for both good and poor readers) included items that had not occurred in the strings. These errors were often obvious recombinations of phonetic components that had been present in the presented sequence (e.g., for the target items *train* and *plate* several subjects reported *trait* and *plane*). Such errors of transposition have previously been reported in memory experiments with adults (Drewnowski, 1980; Ellis, 1980). We undertook to analyze the phonetic errors in the present experiment to determine how often the incorrect responses could be accounted for as transposed phonetic segments from adjacent items. In this analysis, the given string and the previous sequence were considered as the available source of phonetic information.

The data base for determining whether errors of transposition were present was the 451 phonetic errors obtained from all 30 subjects. Seven of these errors were whole words from previous lists and were disregarded. An additional seven were discounted because they were phonetically unrelated to any item in either word list. The phonetic composition of the remaining 437 responses could, for the most part, be accounted for in terms of the phonetic units present in the particular string and the preceding string. In Table 4 we present a breakdown of the transposition errors. Good and poor readers' transposition errors were very similar in pattern. When a phonetic unit was transposed, it was recombined in the same syllable position in which it had originally occurred. Most commonly, vowel and final consonant (or consonant cluster) were preserved as a unit with a substituted initial consonant (or consonant cluster). (A representative sample of the observed error responses is listed in Table 5.) This error pattern suggests that phonetic segments are not equally free to dissociate and recombine in memory. If they did operate as independent units on recombination, there would be no reason to expect greater cohesion between the vowel and the final consonant than between the initial consonant and the vowel.

To ascertain whether the incidence of transposition errors differentiates the reading groups, an analysis of variance was carried out on the proportion of transposition errors to correct responses for the rhyming and nonrhyming conditions. The overall proportion of transposition errors to correct responses did not differ significantly for the two reading groups, $F(1, 28) = 1.8, p = .194$. However, while both groups produced a higher proportion of transposed responses in the nonrhyming condition, the difference was more pronounced for the poor readers. These effects are manifested by a significant effect of list type, $F(1, 28) = 10.4, p = .004$, and by a significant interaction between list type and reading group, $F(1, 28) = 4.9$, $\mathrm{p} = .036$. Thus, it seems that the greater difficulty poor readers have in retaining the order of words in the nonrhyming sequences may be compounded by a problem with the preservation of order information within a word. In the case of the rhyming strings, of course, subjects may well produce transposed responses that would be undetectable. This may account for the better preformance of the poor readers in the order-free scoring of rhyming words.

The present study confirms earlier reports that poor readers recall fewer items than good readers and that they are less affected by phonetic similarity within a list than are good readers (Liberman et al., 1977; Mann et al., 1980; Mark et al., 1977; Shankweiler et al., 1979). In this study the result of the phonetic error analysis allows us to extend our understanding of poor readers' performance on memory tasks. It indicates first of all that the poor readers definitely obtained the phonetic information in the stimuli. However, the greater incidence of transposition errors by poor readers (in the nonrhyming condition) also points to inferior retention of the correct combinations of phonetic sequences specifying the individual items. This finding is consistent with other indications (Katz, Shankweiler, & Liberman, 1981) that poor readers encounter difficulty in preserving serial order information in linguistic tasks. It further suggests that the problem extends to the ordering of segments within the syllable.

TABLE 4
EXPERIMENT 1: ANALYSIS OF INCORRECT RESPONSES

Reading group	Condition	Incorrect responses / Total responses	Composition of incorrect responses[a]				
			Initial consonant	Vowel	Final consonant	Initial consonant and vowel from same word	Vowel and final consonant from same word
Good	Rhyme	15	66	99	98	0	79
	Nonrhyme	17	81	97	97	19	68
Poor	Rhyme	16	59	99	97	2	75
	Nonrhyme	26	79	98	92	16	73

[a] The percentage with phonetic information that was available in the two strings.

TABLE 5
EXPERIMENT 1: EXAMPLES OF TRANSPOSITION ERRORS

Presented items	Responses
roar + fat	rat
bear + shell	bell
score + cat	scat
knee + state	neat
chair + pain	chain
hair + spell	hell
spell + fate	spate
pie + feat	peat
tea + brain	tain

EXPERIMENT 2

We now turn to the second question: the speech perception abilities of the good and poor readers. The aim of Experiment 2 was to investigate whether the language deficits of the poor reader are evident in phonetic perception as well as in short-term memory.

Stimuli

The perception test consisted of 48 words especially chosen to control for syllable pattern, phonetic composition, and word frequency. There were 12 words for each of the following syllabic patterns: CVC (consonant–vowel–consonant), CCVC, CCVCC, and CVCC. Within each syllable pattern, half of the words selected were judged to have high frequency of occurrence in children's literature and half had low frequency (Carroll, Davies, & Richman, 1971). The frequency values were validated with a second word frequency source (Thorndike & Lorge, 1944).

In order to permit a clearcut analysis of phonetic errors and of errors of position (i.e., initial, medial and final word position) words were chosen to provide a systematic phonetic set. Twenty words began with stop consonants (/b/, /d/, /g/, /p/, /t/, /k/) and twenty words began with fricatives or affricates (/tʃ/, /s/, /f/, /ʃ/, /dʒ/, /v/).[1] For each of the above phonetic categories half of the occurrences were in high-frequency words and half were in low-frequency words. Of the remaining eight items, four began with nasal consonants (/m/, /n/) and four with liquids (/r/, /l/). The same distribution of phonetic elements occurred in word final position.

The occurrences of segments in medial position were not controlled except in one respect: every syllabic pattern that occurred in a high-

---

[1] In word final position the fricative and affricate set was slightly different, consisting of /f/, /s/, /tʃ/, /ʃ/, /θ/, and /z/.

frequency word was matched in a low-frequency word (e.g., front [high frequency] and flint [low frequency] were matched in syllabic pattern: Each consisted of the sequence: fricative, liquid, vowel, nasal consonant, stop consonant). The word list is presented in Table 6.

The words were recorded by a phonetically trained male speaker, each being produced as the final word of a meaningful sentence. The sentences were subsequently digitized at 10,000 samples/sec and each stimulus word was excised from the rest of the sentence, using the Haskins WENDY waveform editing system (Szubowicz, Note 1). The words were then arranged into a fixed random sequence and recorded onto magnetic tape. When the stimuli were replayed, a comfortable listening level was selected, approximately 78 dB SPL.

The noise-masked condition was then constructed by following the method described by Schroeder (1968). The technique involves computing the masking noise signal directly from the digitized speech sample to be masked. Each speech sample of the digitized waveform of a stimulus word is multiplied by another, randomly chosen with equal probability. The waveform that results from this manipulation preserves the time-

TABLE 6
EXPERIMENT 2: SPEECH STIMULI

High-frequency words	Low-frequency words
door	bale
team	din
road	lobe
knife	mash
chief	chef
job	fig
grain	tram
breath	grouse
crowd	crag
sleep	slag
scale	spire
speech	skiff
front	flint
plant	clamp
friend	frond
clouds	glades
blocks	drapes
planes	prunes
bank	kink
chance	finch
list	rasp
month	nymph
child	vault
ships	shacks

varying amplitude characteristics of the speech signal while having a flat long-term frequency spectrum. Thus, it is referred to as an amplitude-match noise signal. Each digitized word and its amplitude-matched noise signal were added linearly to yield a 0- dB signal-to-noise (S/N) ratio. The words in noise were subsequently arranged into a fixed random order and recorded on magnetic tape.

Procedure

Each subject listened to the noise-masked words during Session 1, and the unmasked words during Session 2. The child was told that a list of words would be played (and, in the noise-masked condition, that the words were recorded in some noise). The subjects were instructed to repeat each item clearly immediately after hearing it. The test sequence was preceded by four practice trials.

Results and Discussion

Few words were missed by either the good readers (mean errors = 1.3) or the poor (mean errors = 2.0) in the unmasked condition. As we can see in Fig. 1a, whereas both groups made considerably more errors in the noise-masked condition, the poor readers (mean errors = 20.7) did markedly worse than the good readers (mean errors = 15.1).

These effects were analyzed by a two-way factorial analysis of variance. The between-groups factor, reading achievement, was significant, $F(1, 28) = 17.6$, $p < .001$, with good readers misreporting fewer words than poor readers. In addition, there was a significant main effect of noise, $F(1, 28) = 687.4$, $p < .001$. From previous perception research with adults (e.g., Licklider & Miller, 1951), the detrimental effect of masking noise on intelligibility is well known. What is new, from our

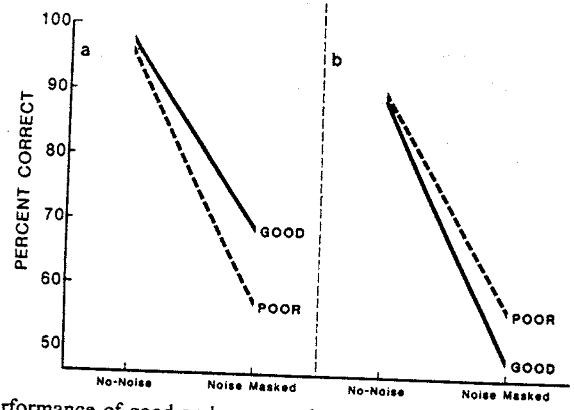

FIG. 1. Performance of good and poor readers on (a) the speech perception task (Experiment 2) and (b) the environmental sounds task (Experiment 3), plotted in mean percent correct.

point of view, was the finding that there were notable differences in the magnitude of the effect of noise on perception for the two reading groups. A significant interaction between the effect of masking and reading group was obtained, $F(1, 28) = 15.8, p < .001$. When the stimuli were presented clearly in the unmasked condition, all the subjects reported the stimulus items accurately. The addition of noise, however, made it significantly more difficult for the poor readers to perceive the stimuli than for the good readers to do so. Thus it seems that the speech perception skills of poor readers are less effective than those of good readers but that this difference is observable only when they are required to respond to degraded stimuli.

Words of high and low frequency of occurrence were employed in the experiment as a means of examining whether differences between the groups in perceptibility of the items were attributable to differences in vocabulary skills. In Fig. 2 we can see the performance of the two reading groups on the high- and low-frequency items. While the variable of word frequency had a large effect on the perceptibility of a word, $F(1, 28) = 155.0, p < .001$, there was no interaction between the word frequency variable and reading group, $F(1, 28) = .015, p > .500$. The poorer performance of the poor readers cannot, therefore, be attributed to possible differences in word knowledge. Instead, it points to a problem in perception of speech.

Thus far we have examined the results by viewing each response either as being totally correct or as an error. In order to determine where the perceptual mistakes were occurring, it is useful to examine the nature of the errors as was done by Shankweiler and Liberman (1972). Accordingly, each stimulus was broken into three segments: the initial cluster, the medial vowel, and the final cluster. A given error response could deviate from the target stimulus at one, two, or all three word

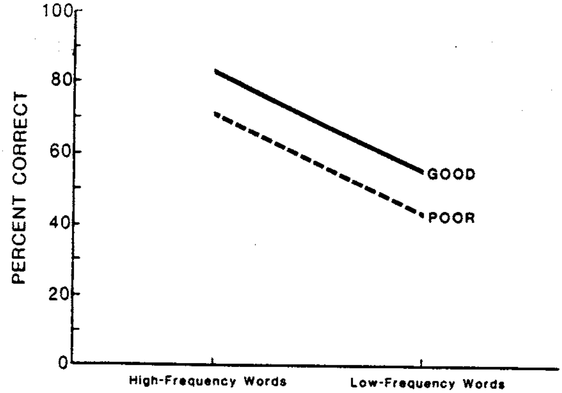

FIG. 2. Speech perception (Experiment 2): mean percent correct on the noise-masked condition replotted as a function of word frequency.

positions. The error data for this analysis are summarized in Table 7. For both reading groups, the greatest number of errors occurred in the initial portion of the word, the final position was second in error rate, and very few errors were made on the vowel in medial position. This position effect was significant, $F(2, 55) = 169.2$, $p < .001$, with no difference in error pattern between the good and poor readers. The lack of an interaction between position effect and reading group suggests that the basis for the error pattern was the same for both good and poor readers. We will briefly digress to consider what these factors might have been.

The uneven distribution of errors across the three word positions seems to correspond with the relative acoustic saliency of the segments. The vowel in acoustic terms is more intense than consonants and is longer in duration. It is therefore not surprising to observe superior identification of vowels on a listening task. Our finding that the initial consonant (or consonant cluster) is misheard more often than the final consonant (or consonant cluster) parallels research with CV and VC syllables (see Ohde & Sharf (1977) for a major paper in this area: and Ohde & Sharf (1981) and Pols & Schouten (1981) for recent discussions of those findings), and again seems to be related to the acoustic characteristics of the segments. The results of research on the speech cues suggest that the consonant in final position is more clearly represented in the acoustic signal than is the initial consonant. Syllable final formants have been observed to have transitions of greater duration (except following the vowels /e/ and /i/) (Lehiste & Peterson, 1961) and greater frequency change (Broad & Fertig, 1970) than have initial transitions. Further, the vowel nucleus of the syllable has been found to provide a variety of cues that may aid in identification of final segments. Peterson and Lehiste (1960) observed vowel lengthening accompanying voiced final fricatives and voiced final consonants, and greater nasalization of vowels preceding nasal consonants than for vowels following nasal consonants. Thus final consonants may be easier to perceive because a greater amount of information specifies their identity.

TABLE 7

EXPERIMENT 2: SPEECH-IN-NOISE: ERROR LOCATION WITHIN THE STIMULI[a]

	Mean errors on 48 trials		
	Initial	Medial	Final
Good	11.27	2.2	7.07
Poor	14.67	3.7	8.93

[a] Error position not exclusive.

In view of the position effects obtained here, it seemed appropriate to examine the phonetic composition of errors occurring in initial and final position. For both positions, an adequate sampling was available to compare the relative frequencies of occurrence of errors on stop consonants and fricatives (see Table 8), but not on liquids or nasals. Accordingly, an analysis of variance was carried out on the stop consonant errors and the fricative errors with error position, initial or final, specified. In this analysis our previous findings were again substantiated: good readers made fewer errors, $F(1, 28) = 10.0$, $p = .004$; more errors occurred on initial position than on final, $F(1, 28) = 51.2$, $p < .001$; and there was no interaction between reading groups and the position effect. A significant difference was obtained between the two phonetic categories examined. More stop consonants were missed than fricatives, $F(1, 28) = 51.1$, $p < .001$ and an interaction between reading group and phonetic category was obtained, $F(1, 28) = 5.4$, $p = .03$. The poor readers missed the stop consonants significantly more often than did the good readers. This could be taken as an indication that poor readers have particular difficulty in processing stop consonants. At the present, we are inclined to make the more conservative speculation that, with the particular noise utilized, the stop information in the signals was relatively more obscured than was fricative information. Given that the amplitude characteristics of the word were preserved in the noise signal, an important cue for fricative identity would also be preserved while place information for the stops would be less salient.

In sum, we found that on the unmasked condition the poor readers did as well as the good readers. When the perceptual system was stressed by the addition of noise, the poor readers made significantly more errors in perceiving the stimuli than did the good readers. With these results in hand, we may now consider the question whether the difficulties the poor reader has with reading may stem from a more general problem in auditory perception. If poor readers are generally inferior to good readers on another auditory perception task, where speech processing is not required, a different interpretation of the nature of the poor readers'

TABLE 8
EXPERIMENT 2: SPEECH-IN-NOISE: ANALYSIS OF ERROR POSITION AND PHONETIC CATEGORY[a]

Reading level	Initial position		Final position	
	Stops	Fricatives	Stops	Fricatives
Good	25.1	12.7	11.8	12.9
Poor	35.4	17.7	17.7	13.4

[a] Relative occurrence of errors of a phonetic category: for example, the stop consonants missed in initial position/the stop consonants that occurred in the initial cluster.

problem would be necessary than would be appropriate if the problem were specific to speech.

EXPERIMENT 3

In the final experiment the subjects listened to a tape of environmental sounds: first with the stimuli in noise, then in quiet.

Stimuli

The stimuli for this experiment were selected and edited from a magnetic tape recording of environmental sounds that had been obtained from the Neuropsychology Laboratory at the University of Victoria (Spreen & Benton, 1969). The source tape had 26 sounds, two of which were excluded for use here because they contained speech.

The remaining 24 stimuli included human nonspeech sounds (coughing, whistling, baby crying), human activities (knocking on a door, dialing a phone, clapping, typing), mechanical sounds (machine gunfire, water running from a faucet, phone ringing, airplane engine, door opening and closing, car starting up and driving away, train whistle), musical sounds (church bell (time), organ (wedding march), drum, piano, trumpet fanfare), animal noises (frogs croaking and crickets chirping, birds calling, dog barking, cat meowing) and sounds of nature (thunder) (see Table 9).

TABLE 9

Experiment 3: Environmental Sounds Stimuli

1	Knocking on a door
2	Water running from a faucet
3	Organ—wedding march
4	Phone ringing
5	Whistling
6	Airplane engine
7	Door opening and closing
8	Artillery
9	Car starting up and driving away
10	Dialing a phone
11	Drum
12	Birds
13	Church bell-time
14	Frogs and crickets
15	Piano
16	Dog barking
17	Trumpet fanfare
18	Train whistle
19	Cat meowing
20	Clapping
21	Coughing
22	Baby crying
23	Thunder
24	Typing

Each sound was digitized on the Haskins Laboratories DDP-224 PCM system and recorded on magnetic tape. One taped sequence, for the unmasked condition, contained the sounds presented in a fixed random order. In constructing the noise-masked sequence, it was not advantageous to use amplitude matched noises as we had done in the case of the speech perception experiment, since the amplitude characteristics of the environmental sounds often provided strong cues to the identity of those sounds. We therefore chose instead to use a broad band (0 to 10 kHz) white noise signal as the masking stimulus. Pilot work suggested that a 0 dB S/N ratio, as employed in the speech task, did not sufficiently mask the stimuli, but that a −2 dB S/N ratio would be appropriate. A second sequence for the noise-masked condition was recorded with each sound masked by the white noise signal at the −2 dB S/N ratio. The stimuli for the two listening conditions were replayed at a comfortable listening level of approximately 75 dB SPL.

Procedure

Both the noise-masked and the unmasked stimuli were presented in a single session, with all subjects listening to the noise-masked tape first. Prior to the testing the examiner explained that the child would hear two sets of sounds and that in the first set the items were recorded with noise. The child was asked to identify the source of each sound immediately after hearing it, providing as much detail as possible. Three practice trials were conducted, without noise, to familiarize the subject with describing nonspeech sounds.

Results and Discussion

The subjects' responses were compiled into a single list. Before scoring, all the responses to each sound were evaluated. A point system was devised ranging from 0 to 3. A score of 0 was assigned if the response bore no relation to the stimulus; 3 was awarded if a fully specific identification had been provided. For the intermediate scores, a score of 1 was given if the response reflected the nature of the sound although wrong in detail (e.g., for coughing, if the subject responded "talking" or "laughing" that person had correctly determined that a human vocal tract was the source); 2 was assigned if the response was not inaccurate but somewhat unspecific (e.g., for an organ playing the wedding march, the response "music"). Responses distributed themselves somewhat unevenly: for some of the stimuli not all four of the scoring categories were assigned. The scoring was reviewed by a colleague who did not know which responses came from good readers and which from poor ones. Discrepancies in numerical assignment by the two scorers occurred for two responses and these were resolved by joint discussion of the two cases. The subjects' answer sheets were then scored and tabulated. The mean error score in the unmasked condition was 6.7 for the poor readers and 7.6 for the good readers (maximum = 72). In the noise-masked condition the mean error scores were 31.4 for the poor readers and 36.9 for the good readers. These performance levels are displayed in Fig. 1b.

As in the speech perception experiment, few errors were made by either reading group in the unmasked condition. With the addition of masking noise, performance for both groups was markedly reduced. The analysis of variance revealed a main effect of noise, $F(1, 28) = 510.9$, $p < .001$, and a main effect of reading group, $F(1, 28) = 4.7$, $p = .04$. We note that the poor readers performed better than the good readers on the nonspeech task. However, if age and IQ are controlled, the difference did not reach significance, $F(1, 26) = 3.6$, $p = .071$.[2] Given the equality of the performance of the poor readers with that of the good readers on this nonspeech auditory task, we can rule out inattention as the explanation for their inferior performance on the noise-masked speech perception task. The results of this control experiment further suggest that the difficulty the poor readers manifested in perceiving speech in noise is not the consequence of generally deficient auditory perceptual ability, but rather is related specifically to the processing requirements for speech.

GENERAL DISCUSSION

Earlier work has demonstrated that children who are poor readers have short-term memory deficits in situations where the stimuli lend themselves to phonetic coding. The present experiments were intended to investigate the basis of this deficit, by asking whether the language processing problems of poor readers may extend to the area of phonetic perception. Third grade school children selected for reading ability were first tested on serial recall of word strings, a task that previously had been found to differentiate good and poor readers (Mann et al., 1980). As before, the poor readers made more errors than the good readers. The results are consistent with the hypothesis (Liberman et al., 1977; Shankweiler et al., 1979) that a failure to use phonetic coding efficiently leads to the poor reader's deficiency in short-term memory for labelable stimuli.

In order to investigate the origin of this memory coding problem, the subjects were further tested on two tasks. One of these employed spoken words, and the other nonspeech environmental sounds. Each task was presented under two conditions: one with a favorable signal-to-noise ratio and one with masking noise. The results indicated a deficit for the

---

[2] In Experiments 1 and 2, the data were likewise reanalyzed controlling for age and IQ. In these experiments, the significance of the differences between reading groups was not reduced when age and IQ were controlled.

poor reader group that was specific to speech stimuli and occurred only in the noise-masked condition. Significantly more errors were made by the poor readers than the good readers when listening to speech in noise; the groups did not differ, however, in the perception of nonspeech environmental sounds, whether noise-masked or not. This pattern of results suggests that the poor readers could process the speech signal adequately, as expected, but they required a higher quality signal for error-free performance than the good readers. The absence of differences between the reading groups on the control experiment with environmental sounds suggests that the poor readers' problem is not manifest on just any auditory task in which the stimuli are noisy, but is instead more selective. The joint outcome of these perception studies suggests that poor readers require more complete stimulus information than good readers in order to apprehend the phonetic shape of spoken words.

The present experiment has demonstrated associated deficits on the same group of poor readers: inferior performance on serial recall and inferior performance on a stringent test of speech perception. We now turn to consider how these two deficits might be related. First, we have noted that poor readers show weak effects of phonetic similarity in recall tasks, a fact that has been taken as evidence that they make inefficient use of phonetic coding in short-term memory. In the memory experiment of the present study, the analysis of the error responses provides direct evidence that the poor readers were using a phonetic code to retain material in short-term memory, although, of course, less effectively than the good readers. The errors that occurred were rarely semantically related to the target items, which might have indicated use of an alternative coding strategy; instead, they consisted of transpositions of phonetic segments from adjacent syllables. Such an error pattern seems possible only if the subjects were indeed using a phonetic coding strategy. Whereas both good and poor readers were phonetically coding the stimuli, the poor readers were more apt to exchange segments across word boundaries and they experienced greater difficulty in retaining the order of words within each word string.

Thus, the suggestion that poor readers have greater difficulty in correctly retaining phonetic representations is corroborated by the pattern of their errors on the serial recall task. In the word perception task, we obtained evidence that poor readers also experience greater difficulty perceiving the phonetic form. On the contrary, analysis of errors in word perception showed that good and poor readers did not differ in the effect of word frequency on item identifiability. Therefore, the greater susceptibility of the poor readers to errors of identification apparently does not arise from differences between good and poor readers in vocabulary level. In perception as well as in recall of linguistic items, the poor readers' problems would seem to stem from failure to adquately internalize certain formal properties of language: in these instances, properties relating to the phonetic pattern.

We may speculate, therefore, that the problems of poor readers, evident on both the memory task and the perceptual task, arise at least in part from a common cause. In this connection, it may be relevant to recall the finding by Rabbitt (1968), in which there was shown to be a relationship between recall performance and the stimulus factors that affect perceptual clarity. When adult subjects were asked to recall strings of digits, recall of items presented without noise was impeded if subsequent items were presented in noise. Thus, making some items difficult to perceive seems to reduce ability to rehearse the nonnoisy items of the string also. We may speculate, by extension, that poor readers' recall suffers in part from the difficulties they incur in perceptual processing.

Thus, one may surmise from our results that the recall performance of poor readers for words presented auditorily suffers as a result of faulty phonetic coding of the stimuli. Moreover, we suppose that this difficulty may arise whenever a phonetic representation is formed, irrespective of the sensory modality of the signal. We base this conjecture on the outcome of earlier findings (Liberman et al., 1977; Shankweiler et al., 1979) which have shown that the failure of poor readers to make full use of phonetic coding in recall occurs both with auditory presentation and with visual presentation of the stimulus items. These parallel findings for presentation of stimuli by ear or by eye led us to suppose that poor readers' problems in memory coding are of a linguistic nature.

It is noteworthy that other investigators who have employed similar criteria for subject selection, but who have used very different experimental approaches, have reached a similar conclusion. Using the memory scan procedure of Sternberg (1966), Katz and Wicklund (1971) have found slower encoding times for poor readers than for good readers with visually presented word strings. If we are correct in supposing that the memory deficit in poor readers at least in part has its origin in phonetic perception, it should be possible to demonstrate differences in a variety of situations in the facility and accuracy with which good and poor readers process linguistically codable material that is presented either visually or auditorily.

REFERENCES

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

Broad, D. J., & Fertig, R. H. Formant-frequency trajectories in selected CVC-syllable nuclei. *Journal of the Acoustical Society of America*, 1970, **47**, 1572–1582.

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

Carroll, J. B., Davies, P., & Richman, B. *Word frequency book*. New York: Amer. Heritage, 1971.

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

Conrad, R. Speech and reading. In J. Kavanagh & I. Mattingly (Eds.), *Language by ear and by eye: The relationships between speech and reading*. Cambridge, Mass.: MIT Press, 1972. Pp. 205–240.

Drewnowski, A. Memory functions for vowels and consonants: A reinterpretation of acoustic similarity effects. *Journal of Verbal Learning and Verbal Behavior*, 1980, **19**, 176–193.

Dunn, L. M. *Peabody Picture Vocabulary Test*. Circle Pines, Minn.: Amer. Guidance Service, 1965.

Ellis, A. W. Errors in speech and short-term memory: The effects of phonemic similarity and syllable position. *Journal of Verbal Learning and Verbal Behavior*, 1980, **19**, 624–634.

Finkenbinder, R. L. A descriptive study of the Goldman–Fristoe–Woodcock test of auditory discrimination and selected reading variables with primary school children. *The Journal of Special Education*, 1973, **7**, 125–131.

Goetzinger, C., Dirks, D., & Baer, C. J. Auditory discrimination and visual perception in good and poor readers. *Annals of Otology, Rhinology and Laryngology*, 1960, **69**, 121–136.

Goldman, R., Fristoe, M., & Woodcock, R. W. *Goldman–Fristoe–Woodcock Test of Auditory Discrimination*. Circle Pines, Minn.: Amer. Guidance Service, 1970.

Katz, L., & Wicklund, D. A. Word scanning rate for good and poor readers. *Journal of Educational Psychology*, 1971, **63**, 138–140.

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

Lehiste, I., & Peterson, G. E. Transitions, glides and diphthongs. *Journal of the Acoustical Society of America*, 1961, **33**, 268–277.

Liberman, I. Y., Shankweiler, D., Liberman, A. M., Fowler, C., & Fischer, F. W. Phonetic segmentation and recoding in the beginning reader. In A. S. Reber & D. L. Scarborough (Eds.), *Toward a psychology of reading: The proceedings of the CUNY Conferences*. Hillsdale, N.J.: Erlbaum, 1977. Pp. 207–225.

Licklider, J. C. R., & Miller, G. The perception of speech. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951.

Mann, V. A., Liberman, I. Y., & Shankweiler, D. Children's memory for sentences and word strings in relation to reading ability. *Memory & Cognition*, 1980, **8**, 329–335.

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

Miles, N. C., & Miles, T. R. Dyslexia as a limitation in the ability to process information. *Bulletin of the Orton Society*, 1977, **27**, 72–81.

Naidoo, S. The assessment of dyslexic children. In A. W. Franklin & S. Naidoo (Eds.), *Assessment and teaching of dyslexic children*. London: Invalid Children's Aid Association, 1970.

Ohde, R. N., & Sharf, D. J. Order effect of acoustic segments of VC and CV syllables on stop and vowel identification. *Journal of Speech and Hearing Research*, 1977, **20**, 543–554.

Ohde, R. N., & Sharf, D. J. Stop identification from vocalic transition plus vowel segments of CV and VC syllables: A follow-up study. *Journal of the Acoustical Society of America*, 1981, **69**, 297–300.

Perfetti, C. A., & Lesgold, A. M. Discourse comprehension and sources of individual differences. In M. Just & P. Carpenter (Eds.), *Cognitive processes in comprehension*. Hillsdale, N.J.: Erlbaum, 1979.

Peterson, G. E., & Lehiste, I. Duration of syllable nuclei in English. *Journal of the Acoustical Society of America*, 1960, **32**, 693–703.