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The development of phonetic codes in memory of 141 pairs of normal and disabled readers from 7.8 to 16.8 years of age was tested with a task adapted from L. S. Mark, D. Shankweiler, I. Y. Liberman, and C. A. Fowler (*Memory & Cognition*, 1977, 5, 623–629) that measured false–positive errors in recognition memory for foil words which rhymed with words in the memory list versus foil words that did not rhyme. Our younger subjects replicated Mark et al., showing a larger difference between rhyming and nonrhyming false-positive errors for the normal readers. The older disabled readers' phonetic effect was comparable to that of the younger normal readers, suggesting a developmental lag in their use of phonetic coding in memory. Surprisingly, the normal readers' phonetic effect declined with age in the recognition task, but they maintained a significant advantage across age in the auditory WISC-R digit span recall test, and a test of phonological nonword decoding. The normals' decline with age in rhyming confusion may be due to an increase in the precision of their phonetic codes.

Most contemporary researchers agree that reading is parasitic on language and that individual differences in reading ability are related to differences in language skills (cf. Frith, 1981; Gleitman & Rozin, 1977; Shankweiler & Liberman, 1976; Vellutino, 1977, 1979). Support for this view has been provided by several recent studies of memory for linguistic stimuli, reviewed below, wherein normal readers showed significant evidence of phonetic memory codes while disabled readers did not. However, this research has been confined to young readers in the second grade. Little is known about the development of memory codes and their association with reading

skill across a broader age range. The present study evaluated the development of phonetic memory codes in a cross-sectional sample of normal and disabled readers from 8 to 16 years of age.

In general, the study of phonetic memory in reading has been motivated by two rather different concerns. The work of Kleiman (1975) demonstrated that when normal adult readers' phonetic memory is disrupted by a concurrent vocalization task, word decoding (lexical access) was unaffected, but the accuracy of semantic judgments about the sense of a passage was diminished. The main conclusion was that phonetic memory is important for the storage of words for their integration in semantic memory. No doubt this is also an important process in disabled readers, but researchers studying this population have been more concerned with basic difficulties in reading that are associated with the phonological decoding of words. From this perspective, the use of phonetic memory codes that result from hearing or reading words may be viewed as a general index of strength in the language skills that are associated with word decoding. Previous group comparisons of disabled and normal readers have revealed substantial deficits in segmenting the sounds of words, detecting rhymes, decoding nonwords (see Frith, 1981, for a review), as well as the use of phonetic memory codes (Shankweiler & Liberman, 1976). This suggests the presence of an underlying linguistic "g" factor that contributes to all of these skills. It was from this latter perspective that we chose to measure the use of phonetic memory codes in our normal and disabled readers as a general index of their skill in dealing with the sounds of language. At the time of this research, there was no indication in the literature that phonetic memory differences between disabled and normal readers varied across age, or that our dependent measure, rhyming confusion in memory, might not be linearly related to phonetic memory.

The method of the present study and most previous research on phonetic memory in disabled readers was based on Conrad's (1964) demonstration that normal readers' memory codes for lists of words and letters are at least partly phonetic because intrusion errors in recall tended to be phonetically similar to the target items. Conrad and Hull (1964) further substantiated the phonetic nature of short-term memory by showing that recall performance was disrupted by including phonetically similar letters in a memory list. Liberman, Shankweiler, Liberman, Fowler, and Fisher (1977) discovered that the disruption caused by phonetically similar memory items differed for disabled and normal readers (see also Shankweiler, Liberman, Mark, Fowler, & Fisher, 1979). Their second-grade normal readers' recall of sequentially presented letters was more disrupted by rhyming in contrast to nonrhyming lists than was the disabled readers' recall. The effect held regardless of whether the stimuli were presented

in the auditory or visual modalities. It was argued that disabled readers were less disrupted by rhyming items in the memory list because they were less likely to use a phonetic memory code.

Mark, Shankweiler, Liberman, and Fowler (1977) provided an additional test of phonetic memory differences between normal and disabled readers in the second grade. They employed a task that used words as stimuli and a surprise recognition memory test which avoided the possible interpretation that normal readers in the above study with letters showed a stronger phonetic effect because they were rehearsing more than the disabled readers. Twenty-eight words were presented for oral reading from flash cards to normal and disabled second-graders. The task was presented to the subjects as a test of reading skill. Then a surprise recognition memory test was presented that included the initial 28 words, 14 foil words that were phonetically similar to 14 of the initial words, and 14 foils that were phonetically dissimilar to any of the words. The memory-test words were read aloud by the subject from flash cards and the subject responded "yes" if he thought the word was from the old list and "no" if it was new. The normal readers made significantly more false-positive errors on the rhyming than the nonrhyming foils, while the disabled readers' performance was not significantly different between the two foil types. Mark et al. (1977) emphasized that the greater sensitivity to phonetic similarity demonstrated by normal readers was not specific to reading. They cited an earlier study by Shankweiler and Liberman (1976) who showed that auditory presentation of rhyming and nonrhyming letter strings gave the same results as a visual presentation. This was later confirmed in an auditory version of the Mark et al. task (Byrne & Shea, 1979). Thus, the insensitivity to phonetic similarity of memory items found in young disabled readers indicates a general deficit in phonetic memory rather than a reading-specific deficit.

The Mark et al. (1977) task was adapted for the present developmental study, since it avoided the potentially confounding factor of rehearsal. Experiment 1 tested children between 7.8 and 16.8 years of age. We predicted that there would be a group effect between disabled and normal readers for the difference between rhyming and nonrhyming false-positive errors (the phonetic effect). Our predictions for age trends in the phonetic effect were based in part on Conrad's (1971) finding that 6-year-old but not 4-year-old normal children used phonetic codes in a picture memory task. Perhaps a similar developmental shift occurs at later ages for disabled readers. It was hypothesized that evidence for phonetic coding in memory would eventually emerge in the older disabled readers, indicating a developmental lag behind the normal readers. However, it was predicted that the disabled readers' deficit relative to normal readers' phonetic memory codes would be maintained across the 8- to 16-year age range,

since previous research has shown no evidence that disabled readers catch up to normal readers in most reading related skills (cf. Satz, Taylor, Friel, & Fletcher, 1978; Baker, Decker, & DeFries, in press; Olson, Kliegl, Davidson, & Foltz, in press). In summary, we predicted group and age differences in phonetic memory, but no interaction between group and age.

Experiment 2 tested the phonetic effect for an older group of normal readers to validate the results of Experiment 1, and to determine whether reading the recognition test aloud (as in Mark et al., 1977) or silently (as in Experiment 1) would influence the phonetic effect. Finally, the results of the recognition memory test were compared with the subjects performance on nonword phonological decoding and digit span recall.

EXPERIMENT 1

Method

Subjects

The subjects were 141 pairs of reading disabled and normal children between 7.8 and 16.8 years old who were referred from schools in the Boulder, Colorado area for participation in a program project study of individual differences in reading disability.[1] The normal and disabled subjects were matched on age, sex, and socioeconomic status. Additional selection criteria included the absence of any apparent neural, sensory, or emotional impairment, and normal school background. The disabled subjects' mean grade level in school was 7.0 (SD = 2.4) while their mean reading-recognition grade level on the Peabody Individual Achievement Test (PIAT) was 5.0 (SD = 2.2). The normal subjects' mean word-recognition reading grade level on the PIAT was 9.4 (SD = 2.6) compared to their mean school-grade level of 7.4. The difference in reading ability between the groups was highly significant ($t(280)$ = 8.32, $p <$ .001).

The subjects were not matched on IQ.[2] The only selection criteria was a score of at least 90 on either the verbal or performance subscales of

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[1] In the Program Project, subjects were first tested with several psychometric measures in Dr. DeFries's and Dr. Decker's laboratory at the Institute for Behavior Genetics. The present report uses the WISC-R IQ, and PIAT reading recognition scores of this test session. The second session was scheduled in our laboratory. In a final test session, the lateralization of brain function was assessed in Dr. Shucard's laboratory at the National Jewish Hospital in Denver.

[2] The decision not to match on IQ was adopted by the Program Project because the WISC-R IQ test contains some components that have been shown to be strongly related to reading ability while others are not. Most children with a full-scale IQ of 90 or above in the Boulder area read at or above the national norms for their grade level. For example, there were 16 normal readers in the Project sample between 90 and 100 IQ. Their average reading ability (PIAT reading recognition) was above their expected grade level. In contrast, the average PIAT reading recognition score for 58 disabled readers between 90 and 100 IQ was about one half of their expected grade level.

the revised Wechsler Intelligence Scale for Children (WISC-R). Full-scale WISC IQ scores averaged 102 (SD = 9.9) for the disabled and 113 (SD = 12) for the normal children. Verbal and performance subscale scores displayed the usual pattern of lower verbal (V) IQ than performance (P) IQ (VIQ = 100, PIQ = 104; $t(140)$ = 4.30, $p < .001$) for the reading disabled children. There was no comparable difference for the normals (VIQ = 113, PIQ = 112; $t(140)$ = 1.43, $p = .156$). It should be emphasized that the lower IQ scores for the disabled readers do not account for their reading deficit. Substantial differences in reading skill still existed when IQ was covaried out.

The age distribution of the subjects is of great importance for the present developmental analyses. The matched pairs included 26 males and 12 females between 7.8 and 10 years, 27 males and 6 females between 11 and 12 years, 29 males and 5 females between 13 and 14 years, and 30 males and 6 females between 15 and 16.8 years. Mean age for both groups was 12.8 years. Although the developmental design was cross-sectional, over 90% of the disabled subjects between 12.8 and 16.8 years of age had been ascertained to be reading disabled 5 years prior to the present study (Foch, DeFries, McClearn, & Singer, 1977). Longitudinal data on these subjects have been described by Baker et al. (in press). Subjects younger than 12.8 years were drawn from the same geographical area under identical selection criteria.

Word Lists

The words were the same as those used by Mark et al. (1977) and are shown in Table 1. All words were monosyllables chosen to be within common first-grade reading vocabularies. The memory list contained 28 words. The test list contained the 28 memory-list words (targets), 14 foil words that were paired for phonetic similarity with 14 words in the memory list, and 14 foil words that were phonetically dissimilar to any of the other words. The foil words were selected to be as different as possible in visual configuration from the memory list. In addition, Mark et al. (1977) concluded from an analysis of the visual features that the phonetically similar foils were no more visually similar to their corresponding targets than were the phonetically dissimilar foils.

The words presented in Table 1 may be considered as four sets: target words that were phonetically similar to a foil word, target words that were phonetically dissimilar from the foils, foils that were phonetically similar to a target word, and phonetically dissimilar foils. Words from each of these sets were equally distributed in the first and second half of their relevant lists.

Apparatus

The words were presented in black lower-case letters on a television monitor which was controlled by a PDP 11/03 computer. A microphone

TABLE 1

List of Phonetically Similar Word Pairs and
Phonetically Dissimilar Words

Phonetically similar		Phonetically dissimilar	
Target	Foil	Target	Foil
know	go	year	best
my	buy	life	guess
cry	high	each	as
good	could	walk	ride
they	way	help	our
but	what	keep	did
gum	come	not	cake
shoe	two	see	duck
new	do	friend	oh
bird	word	up	off
your	for	jump	box
said	red	told	bring
run	done	yes	face
door	more	gave	brown

Note. Table adapted from Mark et al., 1977.

placed a few inches away from the subject's mouth was used in conjunction with a voice-key computer connection to control presentation rate for the memory list and to record response latency in the test list.

Procedure

Subjects were told that they would be given a "reading test." They were told to read each word out loud as accurately as possible, and to guess if they were not sure. The designation of the memory list as a "reading test" was to avoid attempts at rehearsal of the words. Each word was preceded by a fixation point for 500 msec. The fixation point was followed by a blank interval of 500 msec and then the word was presented at the fixation location. The word remained in view until 1 sec after the subject triggered the voice key with an oral response. Then the fixation point appeared for the next trial. The experimenter recorded all reading errors on a score sheet.

At the end of the "reading test," the subjects were told that a new list would be presented that contained some words from the first list, and some new words. Their task was to read the words silently and respond as quickly as possible with "yes" if the word was from the first list and "no" if it was not. Again, each word was preceded for 500 msec by a fixation point, and a 500-msec blank interval. The voice key was used to record response latencies, and the experimenter cleared the

screen by recording the subject's "no" responses with one button and "yes" responses with another button.

Results and Discussion

Equipment failures reduced the number of subjects with valid data to 130 reading disabled and 134 normal children. There was virtually no change in the IQ, reading ability, or age characteristics for this reduced sample. Although exact p values are occasionally presented, the criterion for significance in all analyses was $p < .05$.

Memory List Errors

Because it is possible that differences between subjects' errors on the recognition foils could be due to errors in reading the associated target words in the memory list, the first analysis examined reading errors. As might be expected, disabled readers made more errors (9.9% for rhyme matched targets, 5.2% for nonrhyme matched targets) compared to the normal readers (.7 and 1.1%, respectively). The reading errors were analyzed in a mixed model two-way ANOVA design by randomly deleting four normal readers so that there were 130 subjects in each group. The main effect of group was significant ($F(1, 258) = 32.2, p < .001$). The effect of error type ($F(1, 258) = 6.54, p < .05$), and the interaction of group and error type ($F(1, 258) = 12.03, p < .001$), respectively, were caused by the higher rate of errors on the rhyme matched targets for the disabled readers. Although the magnitude of the difference for disabled readers was not large (4.7%), these reading errors could influence the magnitude of the phonetic effect in the recognition test. Therefore, target words for which there were errors and their associated foils were excluded from the analyses of percent errors in the recognition test.

Recognition Test

Latencies. Although recognition errors were of greatest importance in the present study, the latency data were first analyzed for group and age differences in response to rhyming and nonrhyming foils to check for possible speed–accuracy trade-off effects on error rates. The results may be summarized as follows: Disabled readers were slower than the normals on the rhyming foils (1343 vs 1133 msec, $t(262) = 4.08, p < .001$), and they were also slower on the nonrhyming foils (1228 vs 1058 msec, $t(262) = 4.67, p < .001$). Most importantly, the size of the difference between rhyming and nonrhyming latencies for disabled (115 msec) and normal (75 msec) was not significant ($t(262) = 1.42, p > .05$). Furthermore, the size of this difference was not significantly correlated with age in either the normal ($r = .07, p > .05$) or disabled ($r = -.09, p > .05$) readers. Therefore, in the following group and age comparisons of false-positive error percentages, latency difference could not account for any sort of speed–accuracy trade-off on error types.

Errors. The data of most interest were the subjects' false-positive responses to the recognition foils. The results for disabled and normal readers are presented in the left side of Table 2. Note that both disabled and normal readers made more rhyming than nonrhyming false-positive errors and their difference between rhyming and nonrhyming errors (the phonetic effect) was nearly identical. The false-positive errors were analyzed in a mixed-design two-way ANOVA by randomly deleting four subjects from the disabled group. The main effect of error type was highly significant $(F(1, 258) = 101, p < .001)$, but the effects of group $(F(1, 258) = .38, p = .55)$, and the interaction of group with error type $(F(1, 258) = .39, p = .54)$ were not significant. Thus, there was virtually no difference in the phonetic effect for disabled and normal readers.

This surprising failure to find the reader-ability group differences reported by Mark et al. (1977) led us to examine the results more closely. First, we will consider differences between their study and ours in sensitivity of the memory task. Second, we will resolve the apparent conflict between the studies by a multiple regression analysis of group and age effects.

One contrast with Mark et al. was that the present subjects made very few false-positive errors. In the Mark et al. (1977) study, normal and disabled readers made 25.2 and 28.4% false-positive errors (rhyming plus nonrhyming false-positive errors) and 26.3 and 19.2% false-negative errors, respectively. An examination of the corresponding means in Table 2 for our subjects reveals comparable rates for false-negative errors, but substantially lower rates for the critical false-positive errors (16.7 and 18.1% for normal and disabled readers, respectively). From the perspective of signal detection theory, the present subjects had a higher criterion bias against saying "yes." The present study was not an exact replication of Mark et al. (1977), since in that study, words were shown by the ex-

TABLE 2
ERRORS, SENSITIVITY (d'), AND CRITERION LEVEL FOR NORMAL AND DISABLED READERS

	Disabled N = 130	Normal N = 134		Disabled N = 89	Normal N = 80
PE	7.1%	6.3%		9.8%	9.6%
RFP	12.6%	11.5%		16.3%	16.4%
NFP	5.5%	5.2%		6.6%	6.9%
FN	20.6%	27.4%*		18.1%	25.0%*
d'	2.10	1.92		1.86	1.57*
Crit.	3.32	4.04		1.00	1.15*

Note. Phonetic Effect (PE) = difference between rhyming and nonrhyming false-positive errors; RFP = rhyming false-rhyming errors; NFP = nonrhyming false-positive errors; FN = false-negative errors; d' = sensitivity; Crit. = criterion. Subjects on the right side of the table had a criterion level of 2.00 or less.
* = $p < .05$.

perimenter on flash cars, etc. Subtle differences in instructions and procedure could have made their subjects more willing to say "yes."

The lower false-positive error rate in the present study may have limited its sensitivity to group differences in the phonetic effect. In order to obtain a selected sample with a higher false-positive rate that was more similar to the Mark et al. (1977) study, criterion level and d' (sensitivity) were calculated for both groups according to standard methods (Swets, 1964). Subjects were selected for the age-trend analyses whose criterion level was less than 2.00. This selection procedure resulted in a mean false-positive error rate that was closer to that in Mark et al. (1977), and it retained a sufficient number of subjects for subsequent regression analyses. Analyses were also performed for subjects who made at least two false-positive errors. The results were very similar, although the number of subjects in each group was smaller. Only the results from the criterion based selection will be reported in detail.

Means for the criterion-selected disabled and normal readers are presented on the right side of Table 2. (The mean age, reading level, and IQ statistics in the selected sample were not significantly different from the subjects who were above 2.0 criterion.) Note that the false-positive error percentages were higher in the selected sample, thereby allowing for a potential increase in sensitivity to group differences in the phonetic effect. Nevertheless, the pattern of group differences for the selected subjects was quite similar to those observed for the unselected subjects. The difference between rhyming and nonrhyming false-positive errors (the phonetic effect) was still nearly identical for disabled and normal readers, indicating that a lack of sensitivity was not the reason for our failure to find a group difference in this measure. However, the following age analyses of the selected sample showed that our younger subjects replicate Mark et al. (1977), while the older subjects showed the opposite pattern. This effect was significant in a group × age interaction.

Age × group interaction with the phonetic effect. Within-group age correlations with recognition errors for the criterion-selected group are presented on the right side of Table 3. Note that the correlation of the phonetic effect with age for the disabled readers has increased from that of the unselected sample to a significant $r = .30$ ($p = .002$), while the normal readers' correlation increased in the opposite direction to a significant $r = -.33$ ($p = .001$).[3] To evaluate this interaction statistically, a variable that coded the product of age and group was added to a hierarchical regression model after age and group were entered individually.

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[3] The phonetic effect correlations with age were also computed for disabled and normal reader samples selected for having made at least two false-positive errors. For 65 disabled readers, the correlation of phonetic effect with age was $r = .38$, $p < .001$. For 67 normal readers, the correlation was $r = -.36$, $p < .001$.

TABLE 3

Age Correlations (r) with Phonetic Effect, Three Error Types, d', and Criterion
Level for Normal and Disabled Readers

	Disabled $N = 130$	Normal $N = 134$	Disabled $N = 89$	Normal $N = 80$
PE	.14*	−.11	.30*	−.33*
RFP	−.02	−.03	.08	−.23*
NFP	−.21*	.10	−.28*	.16
FN	.12	.11	.16	.14
d'	.05	−.14*	−.02	.00
Crit.	.07	−.17*	.12	.10

Note. Phonetic Effect (PE) = difference between rhyming and nonrhyming false-positive
errors; RFP = rhyming false-positive errors; NFP = nonrhyming false-positive errors;
FN = false-negative errors; d' = sensitivity; Crit. = criterion. Subjects on the right side
of the table had a criterion level of 2.00 or less.
* = $p < .05$.

The R square change was significant ($F(1, 165) = 17.9, p < .001$) and
indicated that the slopes relating the phonetic effect to age were different
for the two groups. The multiple R for the complete model was .31 ($F(3, 165) = 5.99, p < .001$). Coding group with 0 for normal and 1 for disabled
readers allowed for a convenient computation of the regression lines for
the two groups depicted in Fig. 1 (see Cohen & Cohen, 1975). There
was a significant increase across age for the disabled readers' phonetic
effect (phonetic effect = −7.23 + 1.39 Age) while there was a significant
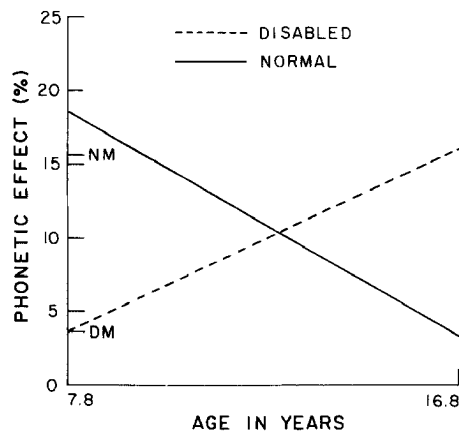

Fig. 1.   Difference between rhyming and nonrhyming false-positive errors (Phonetic
Effect) for disabled and normal readers. Best fitting regression lines predicted from age.
NM = mean for Mark et al. (1977) normal subjects, DM = mean for Mark et al. disabled
subjects.

decrease for the normal readers (phonetic effect = 32.04 − 1.71 Age). Quadratic components were not significant.

The observed group × age interaction on the difference between rhyming and nonrhyming errors (the phonetic effect) could be produced by developmental changes in either one or both types of errors. The regression lines for rhyming and nonrhyming errors are presented separately for the two groups in Fig. 2. It appears that the increase in the phonetic effect with age for the disabled readers was caused primarily by a significant decrease in nonrhyming errors (Nonrhyming Errors = 18.39 − .97 Age), coupled with a nonsignificant increase in rhyming errors (Rhyming Errors = 11.6 + .43 Age). Normal readers demonstrated the opposite pattern of a significant decrease in rhyming errors (Rhyming Errors = 31.78 − 1.17 Age) and a nonsignificant increase in nonrhyming errors with age (Nonrhyming Errors = − .26 + .54 Age). As with the disabled readers, the change in recognition memory with age seems to be qualitative rather than quantitative: There was no significant change with age in d' for either group (see Table 3).

Following the Mark et al. (1977) interpretation of their results, the developmental change in the phonetic effect for our disabled readers indicated an increase with age in phonetic memory. This interpretation was consistent with previous studies showing a developmental lag in reading related skills (cf. Satz et al., 1978; Baker et al., in press; Olson et al., in press), and with other observations that the linguistic–perceptual skills of children continue their development during the early school years (Goldman, Fristoe, & Woodcock, 1970; Finkenbinder, 1973; Schwartz & Goldman, 1974).

The results from the normal readers were puzzling. Why should the older normal readers decrease their use of phonetic codes in memory?
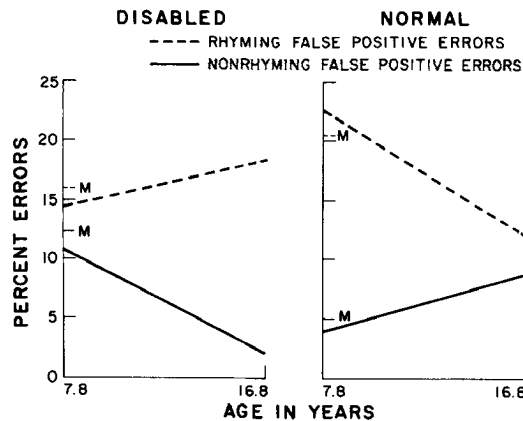

Fig. 2. Rhyming and nonrhyming false-positive errors for disabled and normal readers. Best fitting regression lines predicted from age. M = means for Mark et al. subjects.

Perhaps there was some extraneous factor that caused a decline across age in their phonetic effect, so that the effect was not linearly related to phonetic memory. Two explanations of the normal readers' decline with age were considered. The first hypothesis leading to Experiment 2 was that older normal readers did not generate phonetic codes due to developmental differences in lexical access when reading the test list silently in Experiment 1. A second hypothesis, that more precise phonetic codes of older normal readers actually led to less rhyming confusion, will be evaluated later.

EXPERIMENT 2

The first hypothesis for the normal reader's decline in the phonetic effect was suggested by two recent developmental studies that found a decrease with age in the role of phonological codes in lexical access (Doctor & Coltheart, 1980; Schwantes, 1981). If this was true for our older normal subjects, their smaller phonetic effect could be associated with developmental differences in word decoding processes in reading rather than a general decline in the use of phonetic codes in memory, independent from reading. In the present memory task, developmental differences in word decoding could influence the recognition results in reading both the target list and the recognition list. Reading of the target list was oral, so phonetic codes ultimately had to be generated at the level of speech for all subjects. Differences in the use of phonological coding for lexical access might not make much difference in the strength of the phonetic memory when reading the words aloud. However, the recognition list was read silently, and the subject simply responded "yes" or "no." Here, the subjects still had to read the words, but the older normal readers may not have had to generate a strong phonetic code during lexical access. Thus, the phonetic codes for the words in the recognition list might have been less salient, resulting in the significant decline in rhyming false-positive errors for older normal readers. Experiment 2 tests this hypothesis by requiring an older group of normal readers to read the words in the recognition list aloud before responding "yes" or "no." Experiment 2 also provides a replication of the silent reading condition in Experiment 1 that may serve as a verification of the decline in the phonetic effect with age reported above for normal readers.

Method

Subjects

It would have been most desirable to test the same subjects in Experiment 1 on the aloud recognition task, but those subjects were not available for further testing, and they would have known that the task included a memory test, introducing the potentially confounding variable of rehearsal.

Instead, 115 normal reading college students from the introductory psychology course at the University of Colorado participated in the experiment as part of their course requirements. As in Experiment 1, the subjects' criterion levels were quite high. In order to obtain subjects with criterion levels comparable to those for the previous selected group and the Mark et al. (1977) study, 46 subjects were run in the silent condition and 69 subjects were run in the aloud condition to obtain 25 subjects in each group who had a criterion level less than 2.00.

Stimuli and Procedure

The stimuli and procedure were identical to Experiment 1 for the silent recognition group. The only procedural difference for the aloud recognition group was their oral reading of words in the recognition list prior to responding yes or no.

Results and Discussion

The two groups were similar in their general memory performance. One-way ANOVA tests revealed that there were no significant differences between the groups on the phonetic effect, rhyming false-positive errors, nonrhyming false-positive errors, false-negative errors, d', and criterion level. The critical test was a group × foil type mixed ANOVA. There was no significant main effect of group ($F(1, 48) < 1.$). There were significantly more false-positive responses to rhyming foils across groups ($F(1, 48) = 31.08, p < .001$), and most important, the group × foil-type interaction was not significant ($F(1, 48) = 1.39, p = .24$). The aloud group's phonetic effect was 12.4% while the silent group's was 8%. Thus, reading the recognition foils aloud did not significantly increase the phonetic effect for this older group of normal readers, although the effect was in the predicted direction. This result suggests that developmental differences in word decoding were not the major factor leading to the normal readers' decline across age in their phonetic effect.

Comparing the two groups' results with the disabled and normal readers in Experiment 1, it can be seen in Fig. 1 that both groups fell between the older disabled and normal readers in their phonetic effect. The aloud group's phonetic effect (12.4%) was slightly closer to the older disabled readers while the silent group's phonetic effect (8%) was slightly closer to the older normal readers. Although a direct comparison is limited by the fact that the subjects in Experiment 2 were several years older than the oldest normals in Experiment 1, the results of Experiment 2 suggest that the regression line for the phonetic effect on age for normal readers may not decline as sharply as indicated in Fig. 1. Nevertheless, both the aloud and silent groups' phonetic effect remained below the level of the youngest normal readers. This provides further confirmation of a decline in the phonetic effect for older normal readers.

Precision of the Phonetic Code

Our failure to find a significant increase in the phonetic effect in the aloud condition led to the consideration of a second hypothesis for why the phonetic effect might not be linearly related to phonetic memory. The subjects' more frequent false-positive errors on rhyming foils certainly indicated the use of a phonetic code in memory, but it also implied that there was a lack of precision in the code, allowing confusion between phonetically similar words. If the precision of the phonetic code had a curvilinear relation with rhyming false-positive errors and the phonetic effect, a very weak phonological code (as in young disabled readers) would result in a small phonetic effect. Moderate precision in phonetic codes (as in young normal and older disabled readers) would allow some phonetic confusion and a maximum phonetic effect. As the precision of phonetic codes developed further, confusion among rhyming items may have declined as they became phonetically more distinct in the older normal readers. This explanation is consistent with the normal readers' significant decline across age in rhyming errors (see Fig. 2).

The above hypotheses regarding the normal readers' decline in their phonetic effect were motivated by the assumption that their phonetic coding improves rather than declines with age. What evidence do we have that this may be true for the present subjects? The following section presents the group differences and age correlations for subjects in Experiment 1 on a phonological nonword decoding task and an auditory recall task.

Nonword Decoding

Although we had no other direct measure of their use of phonetic codes in memory, the subjects in Experiment 1 were tested in a separate study for their ability to phonologically decode pronounceable nonwords (Davidson, Olson, & Kliegl, Note 1). An analysis of age trends in this task indicated that while the younger disabled subjects performed very poorly, the older disabled readers performed as well as the younger normal readers (Olson et al., in press). These age trends in phonological nonword decoding were consistent with the age trends for the disabled readers' phonetic effect reported in Experiment 1. However, the normal readers also improved substantially across age in phonological nonword decoding, while their phonetic effect in Experiment 1 declined.

It was assumed that skill in phonological nonword decoding is based on the same underlying linguistic abilities that influence the general precision of the subject's phonetic codes in a memory task. It follows hypothetically that if the normal readers' decline with age in the phonetic effect were due to the increased precision of their phonetic codes, there should be a correlation between the phonetic effect and the quadratic function of nonword decoding. When both groups were combined and the subjects'

phonetic effect was correlated with their performance in the nonword reading task, the linear regression component was not significant (r = − .08, p > .05), but the addition of the quadratic component resulted in a multiple R of .21 (p = .026). A plot of the quadratic function presented in Fig. 3 indicates an increase in the phonetic effect up to the middle range of nonword decoding and then a decline in the phonetic effect with higher levels of nonword decoding. To summarize, the older disabled and younger normal readers were similar in nonword decoding and showed similarly high levels of the phonetic effect, while those who were either high or low in nonword decoding had similarly low levels of the phonetic effect.

Digit Span

One source of evidence that our normal readers maintained their superiority in phonetic memory across age was their performance on the WISC-R digit span test. Although age effects in digit span have not typically been reported in previous research with disabled and normal readers, several investigators have found digit span to be one of the most powerful discriminators between groups. (cf. Owen, Adams, Forrest, Stolz, & Fisher, 1971; Moore, Kagan, Sahl, & Grant, 1982; Thompson, 1982). Cohen and Netley (1981) have shown that normal and disabled reader differences in digit span remain even when rehearsal is limited. Finally, Salame and Baddeley (1982) have demonstrated the importance of phonetic codes in short-term memory tasks such as digit span. By inference, the group and age differences in our subjects' digit span are offered as suggestive evidence about the development of their phonetic memory. In both the forward (DSF) and backward (DSB) versions of the test, the disabled readers' average span was significantly shorter than for the normal readers (normal DSF = 7.3, disabled DSF = 5.7, $t(280)$
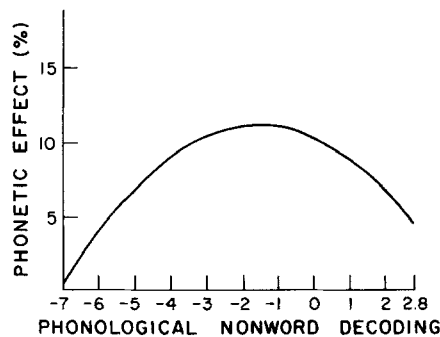

FIG. 3. Difference between rhyming and nonrhyming false-positive errors (Phonetic Effect) for all subjects. Best fitting regression lines predicted from phonological nonword decoding; units are standard deviations from normal readers' mean phonological nonword decoding.

$= 7.36, p < .001$; normal DSB $= 6.3$, disabled DSB $= 4.6, t(280) = 8.06, p < .001$).

The within-group correlations of digit span with age were $r = .36$ ($p < .001$) for disabled readers and $r = .34$ ($p < .001$) for normal readers. The younger normal and older disabled readers had similar digit spans, just as they had similar levels of the phonetic effect. The normal readers continued to improve their digit span across age, maintaining their advantage at each age level. This pattern was similar to that described above for phonological nonword decoding, but there was no significant linear or quadratic relation between the phonetic effect and digit span.

GENERAL DISCUSSION AND CONCLUSIONS

Although our young disabled readers replicated earlier studies in showing little evidence of phonetic memory in a recognition task, their phonetic effect increased significantly from 7.8 to 16.8 years of age. This age trend was consistent with similar developmental trends in their phonological nonword decoding and in their WISC-R digit span. Thus, the disabled readers demonstrated a substantial improvement across age in phonetic memory and related skills rather than a permanent deficit.

The youngest normal readers also replicated previous studies showing their substantially greater reliance on phonetic codes over age-matched disabled readers. However, in the recognition task, their phonetic effect declined across age. The older normal readers made significantly fewer rhyming errors, and their difference between rhyming and nonrhyming errors (the phonetic effect) was similar to the young disabled readers. Two hypotheses regarding the causes of this decline with age were considered. Experiment 2 tested the hypothesis that word-decoding differences associated with reading the recognition words silently may have accounted for their decline in phonetic confusion. Reading the words aloud or silently did not result in a significantly different rhyming effect for an older group of normal readers.

A second hypothesis about the normal readers' decline in the phonetic effect and rhyming errors across age was that the phonetic effect was not linearly related to phonetic memory. Other evidence of their phonological nonword decoding and digit span suggested that their phonetic skills actually improved across age. An increase in precision of their phonetic codes may have provided better discrimination of rhyming foils rather than greater confusion. Thus, low and high levels of precision in phonetic codes, inferred from phonological nonword decoding, were associated with a small phonetic effect, while the intermediate levels of the older disabled and younger normal subjects yielded the largest phonetic effect. This curvilinear relation complicates the use of rhyming errors in recognition tasks, or confusion from phonetically similar items in recall lists, as evidence for phonetic memory in older disabled and normal readers.

Personal communications stimulated by the presentation of these results elsewhere (Olson, Davidson, & Kliegl, Note 2) directed our attention to several new studies of phonetic memory confusion in older disabled and normal readers. All of these studies employed intentional letter memory tasks similar to those used by Shankweiler et al. (1979). First, a recently published study by Hall, Ewing, Tinzmann, and Wilson (1981) found the same advantage in recall of nonrhyming letters for eight reading disabled adult subjects and eight third- and fourth-grade normal readers matched for their performance on the nonrhyming letter strings. They concluded that there are no differences in phonetic memory between disabled and normal readers. Shankweiler, Liberman, and Mark (1982) questioned the empirical validity of the Hall et al. (1981) study because of the small number and poor definition of the subjects.

A more thorough study by Siegel and Linder (in press) replicated the basic finding of Shankweiler et al. (1979) by showing that disabled readers between 7 and 8 years of age did not show a significant rhyming effect while normal 7- and 8-year-olds did. However, a significant rhyming effect emerged for both 9- to 10- and 11- to 13-year-old disabled readers, and these effects were not significantly different from normal readers at the same age. There was a nonsignificant tendency toward a smaller rhyming effect in the older group of normal readers. Siegel and Linder emphasized that while the older disabled and normal readers were roughly equivalent in the rhyming effect, the disabled readers were substantially worse in overall memory for both rhyming and nonrhyming letter lists.

A third study by Johnston (in press) tested groups of disabled and normal readers at 9, 12, and 14 years of age. Separate analyses of each age group revealed no significant group × item type (rhyming vs nonrhyming lists) interaction. Thus, the rhyming effect was present at all three age levels and it was not significantly different for normal and disabled readers. Although no significance tests were performed across age, again there was some suggestion that the rhyming effect declined for older normal readers. The difference between percent correct letter responses in immediate recall of rhyming and nonrhyming lists was 42% at age 9, 28% at age 12, and 23% at age 14. Comparable values for the disabled readers were 27, 18, and 25%, respectively. Johnston did not comment on the apparent decline with age in the rhyming effect for the normal readers.

Although Johnston's (in press) data were roughly comparable to ours both in the significant rhyming effect for disabled readers older than 8 years, and in the apparent decline in the rhyming effect for older normal readers, her interpretation of these data was quite different. Taking the rhyming effect at face value as an index of phonetic memory, Johnston argued that the assertion by Shankweiler et al. (1979) that poor readers have poorer access to a phonetic code or use a degraded phonetic rep-

resentation is wrong for older readers. In contrast to Johnston's interpretation, we agree with the Shankweiler et al. assertion, but argue that the rhyming data cannot be taken at face value as an index of phonetic memory for older subjects. Although the rhyming effect may be equivalent for disabled and normal children at certain ages, reading disabled children remain relatively deficient across age in short-term memory and in a variety of linguistic skills associated with the sounds of language. Thus, it seems unlikely that equivalence in the rhyming effect necessarily indicates an equivalence in phonetic memory, and it seems even more unlikely that the normal readers' decline with age in the rhyming effect indicates a decline in phonetic memory.

Further clarification of reader-ability differences in phonetic memory will depend on the use of more direct measures of phonetic memory and more detailed descriptions of the phonetic code. We have argued that the phonetic code in older normal readers is more precise, leading to less rhyming confusion, without specifying the exact nature or source of this greater precision. Perfetti and McCutchen (1982) have offered a potentially useful approach through their distinction between vowel and consonant codes in phonetic memory. Most rhyming confusion studies of memory have been based on vowel similarity between items. The subjects' resulting confusion provides evidence that vowels are an important part of the phonetic representation. But their confusion is not necessarily complete, since the rhyming items may still be distinguished on the basis of their consonant codes. A developmental shift toward greater precision and dominance of consonant codes could lead simultaneously to a stronger phonetic memory and less rhyming confusion for items with the same vowels. On the other hand, a remaining weakness in the older disabled readers consonant phonetic codes could limit their general level of accuracy in verbal short-term memory tasks while allowing for greater confusion among items with the same vowel. Future research on phonetic code differences between good and poor readers may benefit from the more analytic approach to phonetic codes suggested by Perfetti and McCutchen.

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