Richard K. Olson, Reinhold Kliegl, Brian J. Davidson, Gregory Foltz

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INDIVIDUAL AND DEVELOPMENTAL DIFFERENCES IN READING DISABILITY

RICHARD K. OLSON,* REINHOLD KLIEGL,†
BRIAN J. DAVIDSON,‡
AND GREGORY FOLTZ*

**Department of Psychology*
University of Colorado
Boulder, Colorado

†Max-Planck Institut for Human Development and Education
Berlin, Federal Republic of Germany
and
‡AT&T Information Systems
Lincroft, New Jersey

I. INTRODUCTION

Some children and adults have abnormal difficulties in reading, although their IQ, quality of schooling, and emotional adjustment are normal (Benton & Pearl, 1978). These poor readers are often referred to as specifically disabled or dyslexic to distinguish them from poor readers whose disability is associated with generally low IQ, poor schooling, or emotional problems. There is an impressive amount of evidence showing that groups of normal and disabled readers differ primarily or most strongly in verbal skills (see Perfetti, 1984a; Vellutino, 1979, for reviews). We support and extend this basic finding in the present research. However, a number of recent studies have suggested that group comparisons between disabled and normal readers may conceal important individual differences (Boder, 1973; Denkla, 1977; Doehring, Trites, Patel & Fiedorowicz, 1981; Fisk & Rourke, 1983; Lyon & Watson, 1981; Malatesha & Aaron, 1982; Mattis, French, & Rapin, 1975; Mitterer, 1982; Satz & Morris, 1981). These studies have reported a variety of distinct subtypes within the reading-disabled population. In contrast to the consensus regarding group differences between disabled and normal readers in verbal processes, there has been much less agreement about how to characterize within-group differences among disabled readers or whether significant within-group differences exist (see the debate in Fletcher, Satz, & Vellutino, 1979). If there are major individual differences within the reading-disabled population, these different reading disabilities could have different genetic or environmental etiologies and require different remediation programs (Johnson, 1978; Lyon, 1983). Thus, a thorough description of individual differences among disabled readers is important for both theoretical and practical reasons.

The study reported in this article evaluates the nature and distribution of different reading disabilities for 140 children between 8.5 and 16.9 years of age. These children were referred from schools in the Boulder, Colorado area. A matched normal control sample was also tested for the purpose of group comparisons.

A. Theoretical Framework and Selection of Tests

The development of the test battery was based on the assumption that reading is a complex skill involving several component processes, and several basic cognitive and perceptual resources must be marshaled to effectively learn and integrate these component processes. Failure in reading may be due to deficits in one or more of the component processes and related cognitive resources. Therefore, we adopted a "component skills analysis" (cf. Carr, 1981; Frederiksen, 1980; Singer & Crouse, 1981) that seeks to identify the patterns of component skills distinguishing disabled and normal groups as well as within-group individual differences in reading disabilities.

The tests fell into two general categories. First, there were tests of component processes in reading and spelling that indicated each subject's use and general efficiency in phonological and direct visual access to the lexicon. The selection of these tasks was motivated by a theory of reading that postulates two different ways in which readers can identify words (cf. Coltheart, 1978; Huey, 1908; LaBerge & Samuels, 1974). Readers may analyze the sounds of letter patterns in words and see if the derived sound codes correspond to known words in their oral vocabulary. This approach is represented by the upper route in Fig. 1 that passes from visual memory for letter patterns through auditory memory for the sound of the letter patterns and finally to semantic memory. There is still a great amount of debate about the importance of this path in skilled reading (cf. Andrews, 1982; Humphreys, Evett, & Taylor, 1982; McCusker, Hillinger, & Bias, 1981; Singer, 1980; Parkin & Underwood, 1983; Treiman, Freyd, & Baron, 1983), but it is generally agreed that it must play an important role in the initial encounters with printed words as the child is learning to read. We will use the conventional term "phonological" to refer to this mediated path to the lexicon.

Alternatively, or in addition, readers may identify words directly by their unique letter patterns, without the mediation of phonological memory, as represented by the lower path in Fig. 1. Singer (1980) has argued that the direct route is of primary importance in reading for normal adults, and others have suggested that it may play an important role even in early reading development after only a few exposures to a word (Ehri & Wilce, 1979; Ehri, 1980; Reitsma, 1983a,b). The direct route will be referred to as the "orthographic" path to indicate its dependence on the specific patterns of abstract letter identities associated with different words. Although the operation of this path has often been assumed to depend upon the overall shape of a word, recent research in a variety of paradigms has indicated that letter identities are the primary basis for word recognition (see for reviews, Allport, 1977; Barron, 1980; Henderson, 1982).

The model in Fig. 1 is a much simplified representation of the alternate pathways in reading. The data will suggest that some elaboration of this model is needed to account for individual differences in reading processes associated with different types of phonological paths, and bidirectional interactions between visual, phonological, and semantic memory.

Two tests were designed to evaluate the subjects' skill in using the phonological and orthographic paths to the lexicon. Several other tasks evaluated the relation of phonological and orthographic coding to differences in reading regular and exception words, spelling error patterns, and eye movements in text. These different tests provided the convergent perspective needed to isolate important dimensions of individual differences among disabled readers. In addition, there were standardized tests for reading comprehension, spelling, and word recognition from the Peabody Individual Achievement Test (PIAT).

The second general category of tests included measures of visual and verbal skills in nonreading tasks. The Weschler Intelligence Scale for Children—Revised (WISC-R) included several relevant subtests. In addition, the children were tested for their speed in generating names for common pictures, their use of phonological codes in memory, and their eye movements in a visual tracking task. These tests allowed for comparisons of the subjects' component reading processes with their pattern of basic cognitive and perceptual skills in nonreading tasks.

B. Related Studies of Reading Disability Subtypes

Although individual differences in reading disabilities were noted as early as Bronner (1917), a theoretical interpretation did not emerge until Johnson and Myklebust (1967) proposed that reading-disabled children could be distinguished by having either an auditory or visual processing deficit. Related distinctions have been made by Ingram, Mason, and Blackburn (1970), Boder (1971, 1973), Bakker (1979), and Pirozzolo (1979, 1983). Boder's classification system has been the most influential over the past decade and it is related to several of the present tests for reading and spelling. Boder proposed that the majority of disabled readers have difficulty in phono-

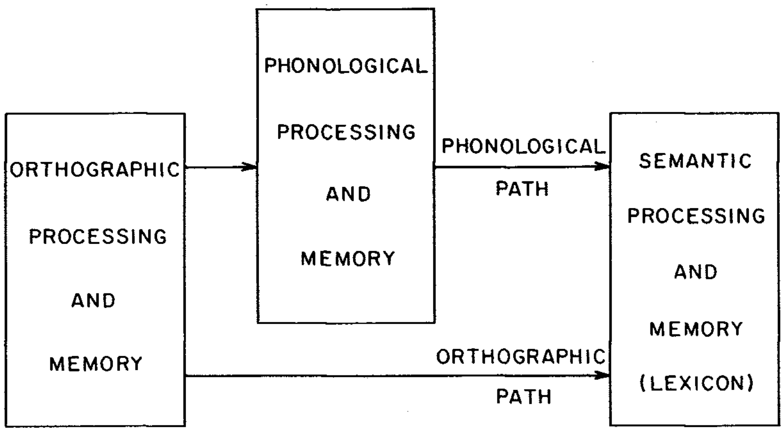

Fig. 1. Two of the possible paths to the lexicon in reading.

logically decoding words, and she labeled them "dysphonetic." In addition, a smaller subgroup was described whose phonological skills were relatively good, but their ability to recognize the visual gestalts of whole words was limited. This second subtype was labeled "dyseidetic." A more detailed description of Boder's subtypes will be presented later. What made Boder's approach unique was her reliance on distinctive reading and spelling patterns for the diagnosis of these two subtypes. In addition, she speculated that the two different reading and spelling styles were caused by different patterns of deficit in basic visual and verbal cognitive resources.

Our approach to the study of individual differences in reading disability was also stimulated by Baron and Strawson's (1976) distinction between "Phonecian" and "Chinese" reading styles among normal college students. Within the framework of a reading model that included phonological and direct visual paths to the lexicon, Baron and Strawson reported that subjects with strong phonological and weak orthographic coding seemed to rely more on the phonological path in reading (Phonecians), while subjects with weak phonological and strong orthographic coding relied more on the visual path (Chinese). Baron and other researchers have made similar distinctions among both normal and poor reading children (Baron, 1979; Mitterer, 1982; Treiman, 1984). Baron's reading styles seem similar to those described by Boder (1973), but he hypothesized that the different styles were due to "phonic" and "sight-reading" approaches to teaching reading (Baron, 1979).

C. Overview of Specific Questions and Article Outline

A number of specific issues in reading disability are addressed in this article and their complete introduction will be deferred to later sections. A brief overview is presented here to help orient the reader to the major questions and conclusions. In Section II, selection criteria and psychometric test results are presented for the disabled and normal groups.

The third section presents group comparisons between disabled and normal readers for phonological coding, nonreading linguistic skills, orthographic coding, and sensitivity to orthographic structure in regular and exception words. Consistent with previous research, the disabled readers are uniquely deficient in phonological coding and the nonreading linguistic tasks. The deficit in phonological coding is emphasized by comparing older disabled subjects with younger normal subjects matched in reading ability. The disabled subjects are still significantly worse in the phonological coding task. In contrast, the reading matched normal and disabled subjects are not significantly different in orthographic coding or in their response to orthographic structure when reading regular and exception words.

The fourth section examines individual differences in reading processes, independent from reading ability, within the disabled group. Reading style differences are inferred from tests of phonological and orthographic coding, regular and exception word reading, and spelling errors. Individual differences on these measures support a reading style dimension based on the subjects' differential use of the orthographic and phonological paths in lexical access and spelling. Analyses within younger and older age groups suggest that decoding processes change qualitatively with age, and some of the reading style differences observed among the younger disabled readers are diminished in the older subjects. Although the developmental comparisons are cross-sectional, the older subjects were identified as reading disabled in a previous study at about the same age as the younger subjects in the present study (DeFries & Decker, 1982).

The fifth section presents a "plodder–explorer" dimension of reading style defined by the subjects' eye movements when reading short stories aloud and silently. This dimension provides a base for the integration of individual differences in coding and spelling described in the fourth section. In addition, it reveals a strong link between individual differences in reading style and verbal intelligence within the disabled group. A separate test of disabled and normal readers' eye movements in a nonreading tracking task indicates that group and within-group differences in reading eye movements are not related to general differences in oculomotor control.

Finally, the sixth section considers the distribution and causes of individual differences in reading disability. Most researchers have argued that reading disabilities fall into a few distinct subtypes. However, the reading style and component skill differences observed in the present study fall on normally distributed dimensions. The implications of these distributions for the etiology of different reading disabilities are discussed. The question of etiology is also addressed by comparing individual differences in reading processes with patterns of cognitive skill in nonreading tasks. No significant relations are observed with perceptual skills and there is no evidence for a "visual–spatial" subtype that is related to differences in reading skill or style. However, the higher level verbal skills measured by the WISC-R are strongly related to individual differences in reading style among the disabled readers.

II. SELECTION CRITERIA AND PERFORMANCE ON STANDARDIZED MEASURES

Normal and disabled readers were matched on sex and age within 6 months. There were 111 males and 29 females in each group. This sex ratio is typical of many previous studies that have reported a three- or four-to-one ratio of male to female disabled readers (cf. Critchley, 1970). The subjects ranged in age from 8.5 to 16.9 years.

The exclusionary criteria for selecting normal and disabled readers were consistent with the majority of studies in the literature. The children were all from English speaking families, had at least normal educational opportunity to learn to read, and normal range IQ (at least 90 on the WISC-R verbal or performance subscales). In addition, the children could not have shown any direct evidence of neurological damage, emotional problems, or sensory deficits.

The schools were requested to refer children for the reading-disabled group who were reading at less than half of their expected grade level, and to refer normal children who were reading at or above their expected grade level. A proportional reading level criterion was used because the children ranged from the third grade to the eleventh grade. The actual deficits shown by the reading disabled children when evaluated against national norms for the Peabody Individual Achievement Test (PIAT) are generally less severe than the requested half-grade-level criterion (see Table I). The disabled group's average proportional achievement of the national grade-level norms for their PIAT word recognition is 72% (grade level would be 100%). Their PIAT spelling is slightly lower (63%) while their PIAT reading comprehension is slightly higher (76%). However, when the disabled group is compared with the normal group, the disabled readers' average deficit appears much more severe. The normal readers average 132, 114, and 128%, respectively, of the national norms for their expected grade level on the PIAT recognition, spelling, and comprehension tests. This level of performance is close to the average in the Boulder area. From this viewpoint, it is not surprising that a teacher might identify a few children as reading disabled even when they are performing near the national norm on the PIAT recognition test, since the national norm is substantially below the mean for most children in the local schools. The disabled readers averaged only slightly more than half of the normal control reading grade level.

Some of the disabled readers in the present sample are more skilled than the commonly used criteria of 2 years below grade level on the national norms, even though they are substantially below their normal controls. These children certainly fit into the common "poor" reader category used by many studies but it is arguable whether their deficit is severe enough to be identified as reading disability or "dyslexia." Certainly the half of the sample who are below 70% of their expected grade level on the PIAT would meet the reading deficit criterion used in most studies of reading disability. For example, a recent study by Finucci, Isaacs, Whitehouse, and Childs (1983) used a criterion that would be roughly equivalent to 80% of expected grade level as an upper limit for reading disability. Although most of the analyses reported in this article used the entire sample of disabled readers, separate analyses were also performed with the half of the sample below 70% of their expected grade level on word recognition. Some of these analyses are presented in the fifth section. In general, the results of the group comparisons and the within-group individual differences analyses for those subjects below the 70% criterion are similar to those for the entire sample.

A final issue in subject selection is that beyond the minimum criterion of at least 90 on either the WISC-R verbal or performance scales, there was no attempt to match normal and disabled readers on IQ, and there are significant group differences for both verbal and performance IQ (see Table I). There were two major reasons for this strategy. First, the disabled readers fall around the normal IQ range and would therefore be expected to read normally, as do most children from this IQ range in the Boulder area. Second, the primary focus of this research was on the within-group differences among disabled readers who meet the minimum 90 IQ criterion, rather than on comparisons with IQ matched normal readers. However, it can be clearly demonstrated that the group differences in reading ability are not simply based on IQ differences. Comparisons are presented in the right half of Table I for a subset of disabled and normal readers who were matched on mean verbal IQ by deleting all disabled readers below 100 full-scale IQ and all normal readers above 120 full-scale IQ. Matching on verbal IQ is a conservative approach. Most studies match on performance IQ, since reading deficits may actually cause a depression in verbal IQ. It can be seen in Table I that substantial and significant differences in reading ability are still present. (The significance criterion for all statistical analyses in this chapter is $p < .05$, two-tailed.) In fact, matching on verbal IQ results in diminished differences from the whole sample of only 11% for PIAT recognition, 13% for PIAT spelling, and 19% for PIAT comprehension. It is clear from these comparisons that the disabled group presents a specific deficit in reading, and the IQ differences between the complete samples do not make a substantial contribution to the group differences in reading ability. It may seem surprising that after reducing the verbal IQ difference for the selected groups by 13 points, there is only an 11% decrease in the substantial group difference in word recognition. This result emphasizes the relative independence in this reading-disabled sample between reading ability and the higher level verbal skills measured by the WISC-R verbal subscale.

A number of studies that have used the WISC-R have noted that disabled readers are more deficient on some of the subtests than others. About two-thirds are lower on the verbal subscale than on the performance subscale (Gordon, 1983). Two specific subtests often show the greatest discrepancy: Disabled readers matched in full scale IQ with normal readers are usually above normal in block design and substantially below normal in digit span

TABLE I

WISC-R Full Scale IQ (FSIQ), Verbal IQ (VIQ), Performance IQ (PIQ), and PIAT Reading Recognition (REC), Comprehension (COMP), and Spelling (SPELL) Grade Equivalents for Disabled and Normal Readers

	All subjects		IQ matched groups	
	Disabled (n = 140)	Normal (n = 140)	Disabled (n = 74)	Normal (n = 92)
FSIQ	102	113[a]	109	108
VIQ	100	114[a]	107	108
PIQ	104	112[a]	110	106[a]
REC	5.0	9.4[a]	5.2	9.1[a]
COMP	5.4	9.1[a]	5.7	8.7[a]
SPELL	4.3	8.1[a]	4.3	7.6[a]
Age	12.8	12.8	12.7	12.9

[a] $p > .01$, for the difference between groups.

(Gordon, 1983; Naidoo, 1972). This pattern is also present for our disabled and normal readers when they are equated on full-scale IQ. The digit-span deficit has been the focus of many studies and it is one of the more reliable findings in the literature (see Jorm, 1983, for a review). Moore, Kagan, Sahl, and Grant (1982) have also found large memory span deficits for a variety of other stimuli besides digits. Cohen and Netley (1981) reported that the memory deficit is present independent from group differences in rehearsal strategies. Katz, Shankweiler, and Liberman (1981) found that the deficit was specific to stimuli that could be labeled, which suggests that the underlying deficit is in phonetic memory. The first experiment to be described in the following section evaluated group and age differences in the use of phonetic memory codes for words.

III. GROUP DIFFERENCES BETWEEN DISABLED AND NORMAL READERS

In this section, group differences between disabled and normal readers are reported for three sets of experiments. The first set includes two tasks that evaluated the subjects' use of phonetic codes in memory and their speed of name code retrieval for pictures. Through these tests we hoped to identify basic language skills that might be related to group differences in reading ability as well as within-group differences in reading style. The second set of tests evaluated the subjects skill in using the phonological and orthographic paths in lexical access. In the third set of tests, subjects read regular and exception words, which were intended to evaluate their relative use of phonological and orthographic coding when reading.

A. Phonetic Memory

Many studies have shown that disabled readers, as a group, are deficient in their ability to deal analytically with the sounds of language. These deficits include the ability to segment spoken words into phonemes (Liberman, Shankweiler, Fisher, & Carter, 1974), and the ability to make rhyming judgments for reviews (see Gleitman & Rozin, 1977; Frith, 1981). In addition, Shankweiler, Liberman, Mark, Fowler, and Fisher (1980) found that young normal readers used phonetic codes in memory for lists of letters, but young disabled readers did not. This group difference was present regardless of whether the stimuli were presented in the visual or auditory modalities. Similar group differences have been reported for words and sentences as well as letters (Mann, Liberman, & Shankweiler, 1980), and in recognition memory as well as recall (Byrne & Shea, 1979; Mark, Shankweiler, Liberman, & Fowler, 1977).

It seemed from the above studies that a test of phonetic memory would provide a measure of individual differences in a basic language skill that was related to reading ability, and perhaps also to within-group differences in reading style and phonological skill. The present test of phonetic memory was based on the study by Mark *et al.* (1977). They found that second-grade normal readers were more likely than second-grade poor readers to recognize words falsely that were phonetically similar to words from a list they had read previously. This indicated that for normal readers but not disabled readers, the words previously seen had been stored in memory using a phonetic code.

The youngest disabled and normal readers in the present study are nearly the same age as the Mark *et al.* subjects. These younger subjects replicate the Mark *et al.* results, but our older disabled and normal readers do not (see Olson, Davidson, Kliegl, & Davies, 1984, for further details). Two other studies have failed to find phonetic memory confusion differences between disabled and normal readers around twelve years of age (Johnston, 1982; Siegel & Linden, 1984). Also, Hall, Wilson, Humphreys, Tinzmann, and Bowyer (1983) failed to replicate Shankweiler *et al.* (1980) with good and poor readers in the second grade. Hall *et al.* argued from their null result that there are no phonetic memory deficits in disabled readers. In contrast, we argue from our pattern of results that older disabled readers may use phonetic codes in memory for words, but their phonetic codes are less precise than those of normal readers. The primary basis for this argument is that the older disabled readers in the present study actually show a larger rhyming confusion effect than the older normal readers. Unfortunately, since rhyming confusion may not be linearly related to phonetic memory and the measure is somewhat unreliable, it is not suitable for comparison with the other measures of reading processes. The following task provides a measure of basic language skills that is more interpretable across the age range.

B. Picture-Naming Speed and Automatic Responses to Print

If disabled readers are generally deficient in their linguistic production abilities, then they might be deficient not only in reading words but also in naming pictures. In fact, several studies have found that disabled readers as a group are both slower and less accurate than normal readers in naming pictures of familiar objects (Denkla & Rudel, 1976; Jansky & de Hirsch, 1972; Katz, 1982; Wolf, 1981). Furthermore, Katz (1982) and Wolf (1981) have shown that the deficit is due to linguistic rather than perceptual factors.

In the present test, pictures of common objects were used so that the subjects would recognize all of them and be highly familiar with their names. Thus, errors in naming were infrequent, and the dependent variable was voice-onset time. Slower naming times could be associated with individual differences in the speed of access to the phonological code and/or speed in activating the articulatory codes (Perfetti, 1984b). In either case, slower picture naming could indicate a basic deficit in language skills outside of the reading process.

The picture-naming task was also designed to evaluate the subjects' automatic and involuntary reading of random consonants, pronounceable nonwords, and words that were superimposed on the pictures (see Fig. 2). Several studies have examined automatic reading processes by monitoring the interference and facilitation effects on picture naming that result from superimposing letters and words on a picture (Golinkoff & Rosinski, 1976; Guttentag & Haith, 1978; Posnansky & Rayner, 1977). If the subjects' response to print on a picture is activated automatically and involuntarily (the subjects are told to ignore the print), the resulting phonological and semantic codes will interact with the naming response to the picture. Unless the print generates phonological codes that are similar to the picture name, the subject's naming response to the picture will be slowed. We hypothesized that the disabled readers would be less automatic in their responses to print as indicated by the interference effects of superimposed letters and words on picture naming. Also, following Guttentag and Haith (1978), we

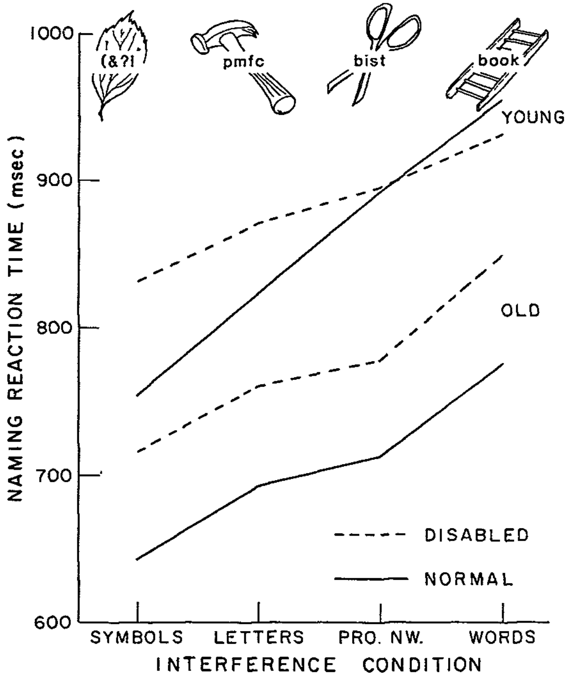

Fig. 2. Picture-naming latencies for younger and older groups of normal and disabled readers.

hypothesized that the disabled readers would show proportionally less interference from the pronounceable nonwords because of their deficiency in phonological decoding.

The major experimental conditions and important results of this study may be summarized briefly. The children named 130 pictures of common objects with four different superimposed stimuli; nonverbal symbols (e.g., =%+) that served as a measure of basic picture naming speed without linguistic interference, random consonants (e.g., *sbkw*) that would indicate automatic responses to letters, pronounceable nonwords (e.g., *dake*) that presumably would indicate the additional interference caused by the automatic generation of phonological codes, and words, that would cause additional interference from their familiar orthographic images and semantic processing (see Fig. 2).

Developmental comparisons of the naming latencies were made by separating subjects into groups above and below the median age of 12.8 years. In addition to differences in automatic responses to print associated with group differences in reading ability, there might also be independent age effects within the normal and disabled groups.

1. Basic Picture-Naming Speed

As can be seen in Fig. 2, the disabled readers are significantly slower than the normal readers in naming pictures with the nonverbal symbols. The slower naming times of the disabled readers may indicate a fundamental language deficit outside of the reading process (Denkla & Rudel, 1976). However, the size of this deficit is not very large in the present study, and naming latency is not a very powerful discriminator of group membership. The larger differences reported by Denkla and Rudel may have resulted from the rapid sequencing of naming required for a series of pictures on a page in their study.

2. Linguistically Based Interference from Print

There is a significant crossover interaction for the younger subjects between reading ability and the different linguistic interference conditions (see Fig. 2). Using naming times for the pictures with abstract symbols as a control condition, the young disabled readers show significantly less interference than the young normal readers for all of the different linguistic interference conditions. This result suggests that young disabled readers are less automatic in their processing of linguistic symbols ranging from random consonants to words. However, the interaction is not significant for the older subjects. The older disabled and normal readers show similar levels of interference from the different print conditions. This result is consistent with other studies that compared older disabled and normal readers and found no group differences in print interference (Briggs & Underwood, 1982; Golinkoff & Rosinsky, 1976). Apparently, reader ability differences in the subjects' automatic responses to print are only present for younger groups that are substantially different in reading skill.

It should be emphasized that the similar interference effects for the older groups does not necessarily imply their similarity in the type of automaticity described by LaBerge and Samuels (1974), who emphasized the importance of speed, efficiency, and a lack of demand on central processing resources in good readers' word decoding. It can be clearly seen in Fig. 2 that the older disabled readers are significantly slower in all conditions. Thus, their linguistic responses to both pictures and print may be generally less "automatic" in LaBerge and Samuels' use of the term.

The final hypothesis was that since disabled readers are uniquely deficient in phonological coding (see the following experiment), they would show proportionally less interference from pronounceable nonwords (Guttentag & Haith, 1978). However, Fig. 2 shows that the interference patterns for the different print conditions are nearly identical for the two groups. Although the interference from pronounceable nonwords was intended to be an index of automatic phonological coding processes, it is possible that the subjects' involuntary responses to pronounceable nonwords may have been based on direct lexical coding processes associated with the pronounceable nonwords' orthographic similarity to words.

Although there was no significant evidence of a qualitative group difference in the interference effects from pronounceable nonwords, phonological coding of the nonwords was not explicitly required in the picture-naming task. The following experiment will show that when phonological coding of nonwords is explicitly required, the disabled readers show a substantial deficit.

C. Phonological and Orthographic Skill

The dual encoding model provided the rationale for the next two tests of component processes in reading. Recall from the introduction that lexical access in reading single words may employ two basically different processes. Phonological coding involves the internal generation of an abstract sound-based code from the letter string that is used to access the lexicon. Orthographic coding involves accessing the lexicon directly based on the sequence of abstract letter codes (Besner, Coltheart, & Davelaar, 1984), without relying on the prior generation of a sound-based phonological code.

1. Phonological Skill

The test of phonological skill was a modification of the nonword-lexical-decision task used by Baron and Strawson (1976) and Saffran and Marin (1977). In our version of this test, the subjects viewed two pronounceable letter strings presented side by side on a television monitor (e.g., *caik dake*) and they pushed a button in their left or right hand to designate the pseudohomophone letter string that sounded like a common word (e.g., *caik*). All of the appropriate lexical entries for the pseudohomophone targets were common words from the reading vocabularies of the average second grader (Harris & Jacobson, 1972). The complete set of stimuli is listed in Table II. Eight practice and 40 experimental pairs were presented, and the subjects received error and latency feedback on each trial (see Davidson, Olson, & Kliegl, 1983, for further details). The phonological task required first that the subject generate the internal sound codes for the nonwords. (Because there was no oral response, variability in articulatory skills should not have had any direct influence on performance in this task.) Second, the task also required the subject to match the sound code for the nonword (e.g., caik) to a word (e.g., *cake*) in his/her lexicon.

A second test of phonological skill was added for the younger subjects. Fifty-nine disabled readers (mean age = 10.8) and 63 normal readers (mean age = 10.8) were given the above stimuli a second time and were asked to pronounce aloud the sound of the letter string they thought was a word. There was no time pressure in this task, latencies were not monitored, and the subjects were not given feedback on the accuracy of their responses. This second test of phonological skill was added for the younger subjects because the error rates for the disabled readers were quite high in the forced-choice-lexical-decision task, and we were not sure that they always understood the instructions. Although subjects were not explicitly required to use their phonological codes to access the lexicon in this task, it will be shown that the lexical-decision and oral-nonword-reading tasks seemed to be measuring the same underlying phonological skill.

2. *Orthographic Skill*

The test of direct orthographic access to the lexicon required subjects to distinguish words from nonword letter strings that would be identical in sound if pronounced (e.g., *rain rane*). The complete stimulus set is presented in Table II. The subjects pushed a button with their left or right hand to designate the letter string that was a word. This task requires subjects to match the orthographic patterns on the screen to a word in their lexicon. Although it does not preclude the generation of sound-based phonological codes during lexical access, and we will see that some subjects may have inappropriately used this path, phonological codes could not be used to make a correct decision between the two letter strings, since both sound the same. A correct decision had to be based exclusively on the word's orthographic code. The orthographic coding task had the same number of trials and followed the same basic procedure as the phonological task. The words were drawn from the second-grade reading vocabulary (Harris & Jacobson, 1972).

3. *Results*

Response times and errors for the orthographic and phonological forced-choice tasks for the complete sample are presented in the top half of Table III. There are clear main effects of task and reading ability, and there is a significant interaction wherein the response time and error differences between disabled and normal readers are greater in the phonological task.

The phonological task was substantially more difficult for both groups, and the interaction with performance in the orthographic task does not cross over. Since scaling problems may limit the interpretation of interactions that do not cross over (Loftus, 1978), it is not certain from this analysis that the disabled readers are uniquely more deficient than normal readers

TABLE II

	Orthographic condition		
room	*rume*	*bowl*	*boal*
young	*yung*	*clown*	*cloun*
turtle	*tertle*	*circus*	*sircus*
snow	*snoe*	*wrote*	*wroat*
take	*taik*	*word*	*wurd*
goat	*gote*	*coat*	*cote*
please	*pleese*	*rain*	*rane*
sleep	*sleap*	*store*	*stoar*
street	*streat*	*wagon*	*wagun*
answer	*anser*	*believe*	*beleav*
between	*betwean*	*choose*	*chooze*
deep	*deap*	*dream*	*dreem*
easy	*eazy*	*every*	*evry*
face	*fase*	*few*	*fue*
heavy	*hevvy*	*hole*	*hoal*
hurt	*hert*	*keep*	*keap*
lake	*laik*	*learn*	*lurn*
need	*nead*	*nice*	*nise*
roar	*rore*	*scare*	*scair*
sheep	*sheap*	*skate*	*skait*
smoke	*smoak*	*stream*	*streem*
tape	*taip*	*thumb*	*thum*
toward	*toard*	*true*	*trew*
wait	*wate*	*wise*	*wize*
	Phonological condition		
baik	*bape*	*fead*	*feem*
lait	*lote*	*fense*	*felce*
braive	*broave*	*thair*	*theer*
bloe	*blog*	*fether*	*fither*
kake	*dake*	*bote*	*boaf*
trane	*traif*	*bair*	*beal*
broun	*broan*	*caim*	*pame*
fite	*fipe*	*naim*	*nade*
ferst	*filst*	*gaim*	*gome*
ait	*afe*	*kard*	*carn*
klass	*cliss*	*craul*	*crail*
derty	*dorty*	*docter*	*doftor*
eer	*eap*	*fearce*	*fairce*
flote	*floap*	*floar*	*ploor*
hawl	*harl*	*hoap*	*hote*
joak	*jope*	*leeve*	*meave*
neer	*nerr*	*reech*	*reash*
plaice	*plice*	*saif*	*saip*
seet	*seaf*	*shaip*	*shate*
shurt	*shart*	*strate*	*strale*
teech	*neach*	*thurd*	*thord*
thrue	*threp*	*tracter*	*trastor*
tirn	*turt*	*werld*	*warld*

in the phonological task. To provide an opportunity for a more interpretable cross-over interaction and to see how disabled and normal readers similar in reading ability would perform, we compared the performance of the 50 disabled readers who were older than 14.1 years (mean age = 15.4 years) with that of the 50 normal readers who were younger than 11.5 years (mean age = 10.1 years). The mean PIAT recognition grade-levels for the older disabled (6.7) and younger normal (7.3) readers were not significantly different.

Response times and errors for the older disabled and younger normal subjects are presented in the bottom half of Table III. The response times for the two groups are not significantly different within the phonological and orthographic tasks, but there is a significant cross-over interaction for the errors. On the orthographic task, the older disabled readers make slightly but not significantly fewer errors than the younger normals (12.45 vs 12.95%), but on the phonological task they make significantly more errors than the normals (30.05 vs 17.75%, chance performance in this task is 50% errors). This result provides strong support for the hypothesis that disabled readers, as a group, are uniquely deficient in phonological skill (Bradley & Bryant, 1978; Firth, 1972; Golinkoff & Rosinski, 1976; Kochnower, Richardson & DiBenedetto, 1983; Snowling, 1981; Perfetti & Hogaboam, 1975). In addition, Bradley and Bryant (1981) reported that disabled readers matched to younger normals in reading ability were deficient in a task that involved the detection of rhyme and alliteration. This suggests that phonological skill and related language skills may play an important causal role for individual differences in reading ability.

TABLE III

Mean Response Time and Percentage Errors in the Orthographic and Phonological Tasks[a]

	Orthographic		Phonological	
	Latency (msec)	Errors (%)	Latency (msec)	Errors (%)
Disabled (all)	1397	18.1	2718	32.8
Normal (all)	900	10.8	1568	17.0
Difference	497	7.3	1150	15.8
Old disabled	1107	12.4	2041	30.1
Young Normal	1005	12.9	1901	17.8
Difference	102	−.5	140	12.3

[a]There were 50 subjects in each of the old disabled and young normal groups and their mean ages were 15.3 and 10.2 years. Means for all subjects are presented in the upper half and means for reading-matched groups are in the lower half.

Developmental analyses of the phonological forced-choice error percentages indicate that while the normal readers show only a slight and nonsignificant improvement with age in their phonological coding accuracy, the disabled readers' deficit in phonological skill is significantly larger for the youngest third of the subjects below 11.5 years (39 vs 18% errors) than for subjects between 11.5 and 14.5 years (30 vs 17% errors) and the oldest third of the subjects above 14.5 years (30 vs 16% errors). The older disabled readers seem to have reached an asymptote in their weak phonological skill, with no improvement in accuracy from the middle to the older age groups. Rudel (1981) has reported that deficits in phonological skill persist even in "remediated" adult dyslexics whose word recognition has reached or exceeded normal levels (see also, Johnson, 1980).

Results from the oral nonword reading task that was given to the younger subjects also reveal a substantial deficit in phonological skill for disabled readers. The percentage-correct responses are 58% (*SD* = 24%) for disabled readers and 89% (*SD* = 13%) for normal readers. Thus, in both the silent-phonological-lexical-decision task and the oral-nonword-reading task, the disabled group is substantially deficient in phonological skill.

A deficiency in phonological skill could contribute to reading difficulties in two different ways. First, from the perspective of the dual encoding model, having two efficient paths to the lexicon may confer an advantage in reading regular words. Some studies with normal readers have found that they read regular words faster than exception words. The regular words are presumed to be processed by both the phonological and orthographic paths, while the exception words are confined to the orthographic path. In this model, disabled readers should show a smaller regular word advantage because their phonological coding is uniquely deficient. Barron (1980) has provided some support for this prediction. It is tested with the present subjects in the following study of regular and exception word reading.

A different view of how a deficit in phonological skill could contribute to reading problems has been presented by Venezky and Massaro (1979). They suggest that phonological skill helps orient the beginning reader to the orthographic structure for words that may later be employed independently from phonological coding in lexical access. Thus, any weakness in phonological coding would hinder the development of word recognition abilities, as it apparently did for our disabled readers, whether or not phonological coding actually played a major role in lexical access for familiar words. From this point of view, one might not expect a regular word advantage for familiar words in either the normal or disabled groups, since both types of words would be read primarily through the orthographic path. The results of the following experiment will support this view. However, a second test of the regularity effect will show that there is a substantial regular word advantage for less familiar words in both the normal and disabled groups.

D. Easy Regular and Exception Word Reading

In the first test of the regularity effect, subjects read 36 regular (e.g., *maid*) and 36 exception (e.g., *said*) words. The complete set of stimuli is presented in Table IV. All words were "inconsistent" in Glushko's (1979) analysis, e.g., the same letter patterns had different pronunciations in different words. All stimuli were easy, common words from the second grade reading vocabulary (Harris and Jacobson, 1972). The exception words were slightly but not significantly higher in average frequency than the regular words (1320 vs 1053, respectively; Kucera & Francis, 1967). The exception and regular words were presented in a mixed list, one word at a time, on a television monitor. The subject's vocalization latency was timed with a voice key and errors were recorded by the experimenter (see Davidson *et al.,* 1983, for further details).

The percentage errors and mean voice-onset times (for correct responses) are presented in Table V for three age groups. The mean ages and number of subjects for the three disabled reader groups are 9.9 years, $n = 46$; 12.8 years, $n = 45$; 15.4 years, $n = 50$. Respective values for the normal readers

TABLE IV
Regular-Exception Word-Naming Task

Regular	Exception	Regular	Exception
here	*were*	*over*	*oven*
note	*done*	*gas*	*was*
had	*what*	*afraid*	*again*
seen	*been*	*open*	*woman*
did	*fruit*	*not*	*from*
eat	*break*	*cut*	*put*
spoke	*glove*	*more*	*move*
sing	*sure*	*mean*	*great*
woke	*some*	*later*	*water*
stone	*one*	*make*	*have*
mail	*said*	*no*	*who*
but	*buy*	*after*	*listen*
shout	*soup*	*that*	*want*
blue	*build*	*poor*	*door*
call	*calf*	*nose*	*none*
twin	*two*	*care*	*are*
home	*come*	*go*	*do*
bone	*gone*	*ride*	*give*

TABLE V

Mean Response Time and Percentage Errors for Easy Exception and Regular Words

Mean age (years)	Regular words		Exception Words	
	Disabled	Normal	Disabled	Normal
		Latency (msec)		
10.1	1136	601	1137	593
12.8	725	551	715	549
15.4	675	508	670	504
		Percentage errors		
10.1	22.8	3.5	30.3	3.4
12.8	8.3	1.6	9.6	3.5
15.4	5.1	1.7	5.7	2.1

are 10.1 years, $n = 50$; 12.8 years, $n = 45$; 15.4 years, $n = 45$. These are the same age groupings used in the previous comparisons of older disabled and younger normal subjects' orthographic and phonological skill, and they will also be used for the within-group analyses in the third and fourth sections. The ranges for the three age groups are 8.5 to 11.4, 11.5 to 14, and 14.1 to 16.9 years.

An analysis of variance revealed that there are significant effects of age and reading ability in the response times, but there is no significant main effect or interaction with the regular and exception word conditions. Within each group, the time taken to read regular and exception words is remarkably similar. Error rates for exception and regular words also are not significantly different within the groups, with the possible exception of the youngest disabled readers discussed below. Within the framework of the dual encoding model, and considering evidence from the previous study that disabled readers are uniquely deficient in the phonological path to the lexicon, it would appear that both groups rely on the direct path to the lexicon for these common words.

Our results are inconsistent with Barron's (1980) report that normal readers were faster in making lexical decisions for regular than exception words while disabled readers were not. It is hard to know what to make of our different results. Barron's words were less frequent than ours, his response latencies were generally longer, and his response was lexical decision rather than vocalization. Barron concluded that the latency results supported his hypothesis that normal readers used the phonological path in lexical decision and disabled readers did not. However, as we find in the following study, Barron found an equivalent regularity effect in errors for both his disabled and normal groups, apparently contradicting his hypothesis.

Perhaps regularity effects may be more readily observed for the present subjects with less familiar words. There is some limited support for this in the present study for the youngest disabled readers. Although the difference is not significant in the overall analysis of variance, the younger disabled readers made 22.8% errors on regular words and 30.3% errors on exception words. Clearly these were not "easy" words for these subjects. Perhaps the use of more difficult words adjusted for reading ability could reveal a more substantial regularity effect for all subjects and allow for a more comparable analysis of the effect for the disabled and normal readers. The following study tests this hypothesis by using regular and exception words that were selected for difficulty level according to each subject's general level of word recognition.

E. Difficult Regular and Exception Words

Differences in reading difficult regular and exception words were assessed using the word recognition portion of the Camp and McCabe test (1977). This consisted of a 20-word list that was selected for difficulty level so that the subjects read about 65% of the words correctly within a 10 second time limit for each word. Half of the words in each list were regular and half were exception words. They were roughly balanced in frequency, although one or two words were excluded from the analyses for some of the lists to achieve a better balance. Also, the definition of regularity was not as carefully controlled as in the previous study where both exception and regular words had inconsistently pronounced letter patterns such as m*aid* and s*aid* (Glushko, 1979). The basis for selection of regular and exception words is described in detail by Camp and McCabe (1977). Their selection procedure resulted in relatively more "inconsistent" exception words than regular words.

The list was shown to the subjects one word at a time and responses were scored as correct or incorrect by the experimenter. Latency data were collected with a voice key, but there were too few correct trials to yield reliable latency estimates for the regular and exception words. Only the error data will be reported.

In contrast to the results obtained with easy words, when words are selected to be difficult relative to the subject's reading level, a substantial regular-exception word difference is observed. Normal readers score 81% correct on regular words versus 53% for exception words, and disabled readers score 78% on regular and 49% on exception words. Most important is the finding that both groups show nearly the same size difference (28 and 29%) between the word types. Although most disabled and normal readers were tested with different words, it was possible to compare smaller groups of older disabled (n = 23) and younger normal (n = 26) readers who read the same list. The older disabled readers score 77% correct on the regular words vs 45% for exception words. The younger normal readers score 77% correct on the regular words and 40% on the exception words. The difference between the disabled and normal readers' regularity effect (33 vs 37%) is not significant. This result is consistent with Barron's (1980) report of a similar sized regularity effect in his error data for normal and disabled readers.

From the perspective of the dual encoding model, the substantial size and similarity of the regularity effect for both groups would suggest that they both use the phonological path to advantage in reading difficult regular words. But this interpretation seems to conflict with the substantial group difference observed in the phonological lexical decision task and the oral nonword reading task. One possible resolution of this conflict between theory and data may be based on a distinction between *use* of the phonological path and the subjects *skill* in using that path. Although the disabled readers are far below the normal readers in phonological skill, even the younger disabled readers are able to read 58% of the pseudohomophone nonwords from the phonological task correctly. It seems likely that at least some disabled readers would apply their limited phonological coding ability to aid in reading difficult words, and it is not clear that the application of less accurate or efficient phonological coding processes would necessarily lead to a significantly smaller regularity effect. For example, if a disabled reader were biased to use the phonological path rather than the orthographic path because of intense instruction in phonics, that subject might show a regularity effect that is larger than the regularity effect for normal readers with superior phonological skill. The distinction between use and skill in phonological coding will be supported in the following section when we look at within-group differences in the regularity effect for disabled readers.

Another possible cause of the similar regularity effects for disabled and normal readers is that the regular word advantage is due at least in part to their advantage in orthographic coding that is independent from phonological coding. In addition to being phonologically regular, regular words often have more common orthographic structures and these common structures could result in better processing and memory for their specific letter patterns in direct lexical access (Carr, Posner, Pollatsek, & Snyder, 1979; Massaro, Taylor, Venezky, Jastrzembski, & Lucas, 1980; Singer, 1980). The commonality of orthographic patterns was relatively balanced for the easy list of regular and exception words (e.g., *maid–said*), where there is no regularity effect for either group. In the difficult list where there is a similar regularity effect for both groups, the orthographic patterns for the exception words are less common than for the regular words.

A problem with the above orthographic familiarity hypothesis for the regularity effect is that the commonality of orthographic structures and their pronounceability are confounded in our difficult regular words. Massaro, Venezky, and Taylor (1979) separated orthographic structure associated with pronounceability (e.g., *drunet*) and structure based on high single-letter positional frequency in strings that were not pronounceable (e.g., *rdnuet*). Adults were influenced by both types of structure in letter-detection tasks. This led Massaro and Taylor (1980) to ask whether poor readers, because of a phonological coding deficit, might be significantly less sensitive than good readers to the orthographic structure associated with pronounceability. The results of their study were mixed on this question. Good- and poor-reading college students were nearly identical in their facilitation from the two types of orthographic structure. However, poor readers in the sixth grade showed less facilitation than good sixth-grade readers from orthographic structure associated with pronounceability. This later result was not significant in an overall analysis of variance that included two other structure conditions, so replication is needed. If the difference is confirmed, it would indicate a poor-reader deficit for sensitivity to the orthographic structure associated with pronounceability in a task that did not explicitly require phonological coding.

We do not wish to argue the null hypothesis for differences between normal and disabled readers in their response to orthographic regularity. The point is that both the disabled and normal groups show a substantial regularity effect for accuracy in reading words and it seems likely that any difference between the groups is quite small. In contrast, there is a substantial and significant difference between the groups when phonological coding is explicitly required, suggesting that most of the regularity effect is unrelated to the subjects' phonological skill. This view is further supported in the following study of individual differences in the regularity effect within the disabled group.

IV. INDIVIDUAL DIFFERENCES IN READING DISABILITY

This section and the following section on eye movements focus on analyses of individual differences within the disabled group. Similar analyses have been performed within the normal group, but in general, their reading style differences were not as strong and most of the correlations were not significant. Individual differences in reading style may be more salient among disabled readers because they develop unique strategies to deal with their reading problems.

Two seminal studies of individual differences in reading style influenced our selection of tests and initial hypotheses (Baron & Strawson, 1976; Boder, 1973). We begin with Baron and Strawson's distinction between "Phonecian" and "Chinese" styles by comparing the disabled readers' regularity effect with their phonological and orthographic coding skill. The second part of this section considers Boder's apparently related distinction between "dyseidetic" and "dysphonetic" disabled readers that was based on her analysis of their spelling errors. The correlations between the coding skills, regularity effects, and patterns of spelling errors support a dimension of individual differences in reading style that is based on the subjects' relative use of the phonological and orthographic paths in reading. This dimension is further supported by the analysis of eye movements in text presented in the fifth section. In the final section we discuss the normal distribution of individual differences in reading style and their etiology.

Two general approaches are used in our analyses of individual differences. First, correlations between variables are computed within the three age groups described in the previous group analyses of the regularity effect. A statistical motivation for this approach is that the different age groups vary substantially in their performance levels and variance on some of the tasks (see Table V). The computation of z scores across the whole sample could obscure important individual differences that may be observed within the separate age groups. Also, some individual differences in reading style observed among younger disabled readers are not present in the older subjects. To simplify the presentation of the age effects, only the results for the oldest and youngest thirds of the sample are presented here. In most analyses where reading style correlations for the youngest and oldest thirds were significantly different, the middle age group yielded correlations that were between those of the youngest and oldest groups.

The second general analytic approach is to observe individual differences in reading style that are independent from reading ability. Reading ability was controlled statistically by partialing out variance associated with the subjects' word recognition score on the PIAT. Thus, the correlations reported in this and the following section are based upon the subjects' performance on each variable relative to the linear effects of their word recognition scores. The simple correlations of each variable with PIAT word recognition prior to partialing are presented in the tables in parentheses.

A. Phonological Skill, Orthographic Skill, and the Regularity Effect

Baron and Strawson (1976) reported that normal readers who were selected for good phonological and poor orthographic skill (Phonecians) showed a regular word advantage in latencies, while others who were selected for good orthographic and poor phonological skill (Chinese) did not.

The Phonecian and Chinese subjects were extreme groups selected from a larger sample of college students, but Baron and Strawson thought of them as part of a continuous, single Phonecian–Chinese dimension of individual differences. Our analyses included data from all subjects rather than the extreme groups so that the variance in reading style could be estimated for the entire disabled population. In addition, we observed the independent relations of phonological and orthographic skill with the regularity effect and separately with regular and exception word reading.

The subjects' phonological and orthographic skill were computed from the number of correct responses in the phonological and orthographic tasks. The regularity effect, or relative-regular-word advantage in accuracy, was computed by subtracting the subjects' z scores for number of correct exception words from their z scores for number of correct regular words in the easy lists (see Table IV). Thus, a positive difference score would indicate a relatively strong regular word advantage in accuracy. Separate analyses were also performed with response latencies in the phonological, orthographic, and regular-exception word tasks. None of the theoretically interesting correlations described below for errors was significant in the latency data. The high error rates in these tasks limit the interpretation of the latencies, so only the accuracy data are reported here.

The correlation between the disabled subjects' regularity effect and phonological skill is $r = .10$ ($p > .05$) for the youngest subjects and $r = -.01$ ($p > .05$) for the oldest subjects (see Table VI). Thus, there is no significant relation between the regularity effect and phonological skill. A similar nonsignificant correlation between the regularity effect and phonological skill is present within the youngest group for 34 subjects whose phonological skill was estimated from the number of nonwords read aloud ($r = .05, p > .05$).

In contrast to the null results with phonological skill, orthographic skill is significantly correlated with the regularity effect ($r = -.31, p < .05$, for younger subjects; $r = -.36, p < .01$, for older subjects, see Table VI). The negative direction of these correlations indicates that subjects who perform well on the orthographic task relative to their word recognition on the PIAT are less likely to show a regular word advantage in accuracy. However, the interpretation of the regularity-effect-difference scores is limited by reliability problems arising from the combined error variance of the component scores. Conclusions drawn from the difference scores need further support and interpretation from the separate correlations between orthographic skill, regular word accuracy, and exception word accuracy. Examination of the component regular and exception word correlations in Table VI indicates that exception word accuracy contributes most of the variance in the regularity effect that is correlated with orthographic skill (r

TABLE VI

Individual Difference Correlations for Disabled Readers' Regularity Effect and Decoding Skills[a]

(PIAT rec.)	Reg. words (.76)	Exc. words (.72)	Reg.-exc. difference (.04)	Phon. skill (.58)	Ortho. skill (.55)
Reg. words (.43)		.64**	.36**	−.32*	.33*
Exc. words (.33)	.44**		−.48**	−.38**	.57**
Reg.-exc. difference (.10)	.50**	−.56**		.10	−.31*
Phon. skill (.23)	.15	.16	−.01		−.17
Ortho. skill (.20)	.03	.40**	−.36**	.07	

[a]Younger disabled readers above the diagonal ($n = 41$) and older disabled readers below ($n = 50$). All correlations are partialed on the subjects' PIAT word-recognition scores. Simple correlations with PIAT rec. are in parentheses across the top for young and down the side for old subjects. * $p < .05$; ** $p < .01$.

exc. = .57 vs r reg. = .33 for younger subjects; r exc. = .40 vs r reg. = .03 for older subjects). Regression analyses indicated that exception word accuracy predicts a significant amount of variance in orthographic skill after taking regular word variance into account, but regular word variance is not significant after taking exception word variance into account. Thus, better orthographic skill acts primarily to reduce the error rate for exception words, and thereby reduce any regular word advantage in accuracy.

How do the observed correlations between phonological skill, orthographic skill, and the regularity effect fit with the dual encoding model? The absence of a relation between phonological skill and the regularity effect in the present within-group analyses, and the absence of a significant group difference in the regularity effect in the previous section seem inconsistent with Baron and Strawson's (1976) view that subjects with better phonological skill should show a stronger regularity effect. However, as we suggested in the previous section, there may be individual differences in the *use* of the phonological path in reading that are independent from the subjects phonological *skill*. From this perspective, subjects who tend to make relatively greater use of the phonological path in reading, regardless of their phonological skill, might show a larger regularity effect. The following examination of the relation between performance in the orthographic task and the regularity effect will support this hypothesis.

The significant negative correlations between orthographic skill and the regularity effect are consistent with Baron and Strawson's (1976) view that Chinese style readers who have strong orthographic images should show a smaller regularity effect. From the perspective of the dual encoding model, if a subject has strong orthographic codes relative to their word recognition (remember that the linear effects of PIAT word recognition were partialed out), they should have relatively less difficulty processing exception words that presumably are better read through the direct orthographic path.

The subjects' accuracy in the orthographic task may also have implications for their use of the phonological path. Low accuracy in the orthographic task could result from the inappropriate use of the phonological path in this task as well as from any weakness in the subjects' orthographic codes. For example, subjects confronting the stimulus pair (*rane–rain*) could use a phonological code to achieve the same lexical response from either member of the pair, but this strategy would often lead to an incorrect response in the orthographic forced-choice task. Evidence from another study in progress with the orthographic task indicates that subjects often are able to give a correct oral response for the forced-choice pairs even though they choose the orthographically incorrect letter string (*rane*) as the word.

In summary, the present results suggest that reading style differences among disabled readers may be based on their differential use of the phonological and orthographic paths to the lexicon. A reciprocal relation is hypothesized wherein subjects with good orthographic codes tend to use the orthographic path in reading while those subjects with poor orthographic codes tend to use the phonological path, regardless of their phonological skill. While the observed correlations between orthographic accuracy and the regularity effect are consistent with this view, converging evidence is needed to support the implied relation between poor performance in the orthographic task and greater use of phonological path. The following analyses will show that younger subjects with relatively weak orthographic codes produce more phonologically accurate spelling errors. Then, in the next section, eye movement analyses will provide converging evidence for individual differences in the subjects' use of phonological and orthographic paths.

B. Phonological Skill, Orthographic Skill, and Spelling Errors

What does spelling have to do with reading? In general, spelling skill is correlated with reading skill. For the disabled and normal readers in the present study, the 4.4 grade-level discrepancy in word recognition on the PIAT is mirrored by a 3.8 year discrepancy in PIAT spelling (see Table I).

However, the correlation between reading and spelling is far less than perfect, and there are many good readers who are relatively poor spellers (cf. Frith, 1980). Among disabled readers there are relatively few good spellers, and researchers have attempted to use the specific types of spelling errors to classify different subtypes of disabled readers (cf. Boder, 1973; Camp & McCabe, 1977; Mitterer, 1982).

Boder (1973) relied primarily on spelling errors to distinguish two major groups of disabled readers that seem somewhat analogous to the Phonecian and Chinese subjects of Baron and Strawson (1976). One subgroup was classified as "dyseidetic." In Boder's clinical description, the dyseidetic subjects were able to phonologically decode regular words and nonwords by slowly sounding them out, but their sight reading vocabulary was small and they had great difficulty reading exception words. Their spelling errors tended to be phonologically similar to the test word although they were often quite different visually, and regular words were more often read and spelled correctly than exception words. In general, the dyseidetics "manifest weaknesses in visual perception and memory for letters and whole word configurations, or gestalts, with resulting disability in developing a sight vocabulary, although they have no disability in developing phonic skills" (Boder & Jarrico, 1982, p. 7).

A second subgroup was classified as "dysphonetic." These subjects could read both regular and exception words that they knew by sight, but they were deficient in sounding out unknown words and nonwords. In contrast to the dyseidetic subjects, the dysphonetic subjects showed little difference in their ability to read exception and regular words. The dysphonetics' spelling errors were distinctly nonphonological, although they might be visually similar to the target word, and the dysphonetics were able to spell regular and exception words equally well by sight. In general, the dysphonetics "have difficulty integrating written symbols with their sounds, with resulting disability in developing phonic word-analysis skills. They have no gross deficit, however, in visual gestalt function" (Boder & Jarrico, 1982, p. 7). Baron (1979) and Treiman *et al.* (1983) have noted the apparent similarity of Boder's dysphonetic and dyseidetic subtypes to their Chinese and Phonecian style readers.

Boder (1973) described a third "mixed" group comprising the most severely disabled readers who were deficient both in sight reading and phonological decoding. In a recent report, Rosenthal, Boder, and Callaway (1982) estimated that the incidence of the different subtypes in the dyslexic population was 60% dysphonetic, 20% dyseidetic, and 20% mixed. Although the three groups were described as extreme, qualitatively distinct subtypes that resulted from individual differences in basic gestalt and linguistic skills, the data were not presented in sufficient detail to evaluate Boder's clinical descriptions of the subtypes or their etiology.

In the present study we evaluated the types of spelling errors made by disabled readers to see if individual differences in the error patterns were related to differences in reading processes. Since a detailed description of Boder's (1973) test was not available when we began the research, we used the Camp and McCabe (1977) test of reading and spelling patterns which is based on the Boder approach, and is quite similar to the test recently published by Boder and Jarrico (1982). It consists of a list of 20 spelling words selected for the subjects' reading grade level. About 50% of the words on the list could be read correctly within 2 seconds for each word. The reading vocabulary level is determined with an alternate list of 20 words that was used in analyses of the regularity effect for difficult words presented in the previous section. The spelling test was given by first presenting the word in isolation, then it was used in a sentence, and finally it was read again in isolation. The subjects wrote out their spellings, and the experimenter asked for clarification of spellings that were not legible.

Both the Camp and McCabe (1977) and the Boder and Jarrico (1982) tests use dichotomous scoring procedures for classifying spelling errors and subjects into the dyseidetic and dysphonetic categories. These dichotomous divisions appeared somewhat arbitrary, so a scoring procedure was developed for analyzing several specific characteristics of each spelling error and for rating each error on a more continuous scale for their phonological and visual similarity to the target word. Phonological similarity was simply the degree to which the spelling sounded like the target. Visual similarity was based on the number of salient visual characteristics in common with the target such as number of letters and appropriately placed ascenders and descenders, but it also was a subjective rating. Each spelling error was assigned two numbers from 1 (low) to 10 (high) to separately indicate phonological and visual similarity to the target word. The ratings were averaged across spelling errors to obtain mean visual and phonological similarity scores for each subject. One rater evaluated the spelling errors for all subjects using this scoring system. A smaller group of subjects' errors was also scored by a second rater to obtain rater-reliability estimates. The rater reliabilities were .85 for the phonological rating and .82 for the visual rating across the reading disabled subjects. The mean number of errors that were made by the older and younger groups were 12.0 and 10.8, respectively, out of the 20 spelling words.

Correlations are presented in Table VII for the younger and older disabled readers' number of words spelled correctly, visual similarity ratings, phonological similarity ratings, phonological skill, and orthographic skill. The phonological and visual ratings of the spelling errors are strongly correlated, and their correlations with other variables are quite similar. This is consistent with the raters' subjective impression that a clear dissociation between visual and phonological similarity was rarely observed. It might be possible to observe a stronger dissociation by using words selected specifically for this purpose, but there were not enough suitable stimuli in the Camp and McCabe lists. It appeared that both the phonological and visual ratings indicate the general similarity of a misspelled word to the target word. Note that the similarity ratings are not simply equivalent to spelling skill defined by the number of words spelled correctly, at least for the younger subjects. Their correlations between the spelling ratings and number of words correctly spelled do not approach significance (see Table VII).

Significant age differences are present between several correlations when the oldest and youngest thirds of the disabled readers are compared. The results for the youngest subjects presented above the diagonal in Table VII will be described first. These correlations are based on 38 of the youngest subjects (mean age = 9.9 years) who have complete data for all of the relevant variables.

1. Phonological Skill and Spelling Ratings for Younger Subjects

Phonological skill is positively correlated with the similarity ratings of spelling errors, although only the correlation with phonological similarity is significant (see Table VII). In addition, for the 32 of these subjects whose phonological skill could be estimated from oral nonword reading errors, the correlations are $r = .32$, $p < .05$, with the phonological rating and $r = .47$, $p < .01$, with the visual rating. Thus, those subjects whose phonological skill is relatively good compared to their word recognition make

TABLE VII

Decoding Skill and Spelling Error Rating Correlations[a]

(PIAT rec.)	Number correct (.34)	Phon. rating (.54)	Vis. rating (.61)	Phon. skill (.61)	Ortho. skill (.55)
Number correct (.09)		.01	.11	.13	−.12
Phon. rating (.45)	.26*		.74**	.29*	−.48**
Vis. rating (.34)	.42**	.77**		.23	−.47**
Phon. skill (.23)	.01	.09	−.05		−.08
Ortho. skill (.20)	.19	.15	.14	.07	

[a]Younger disabled readers above the diagonal ($n = 38$) and older disabled readers below ($n = 50$). Simple correlations with PIAT rec. are in parentheses across the top for young and down the side for old subjects. *$p < .05$; **$p < .01$.

spelling errors that are more phonologically and visually similar to the target word. This result contrasts with the nonsignificant correlations between phonological skill and reading style defined by the regularity effect in the previous study and by eye movements described in the following section. Individual differences in spelling styles may be more closely related than reading style to phonological skill. Other researchers have suggested that spelling is more directly supported than reading by phonological processes (Barron, 1980; Bryant & Bradley, 1980; Frith, 1979; Treiman, 1984).

2. *Orthographic Skill and Spelling Ratings for Younger Subjects*

In striking contrast to the positive correlations with phonological skill, orthographic skill is negatively correlated with both similarity ratings (see Table VI). Thus, subjects who are better in the orthographic task relative to their word recognition have lower similarity ratings for their spelling errors. Conversely, subjects with relatively weak orthographic codes produce spelling errors that are more phonologically and visually more similar to the target word. Mitterer (1982) recently reported some results that are consistent with these correlations. He gave young disabled readers a yes–no lexical decision task that included pseudohomophones (e.g., *rane*) as foils. This is similar to the type of decision that our subjects had to make in the forced-choice orthographic task. Some of Mitterer's disabled readers were more likely than others to mistakenly identify the pseudohomophones as words. In a separate spelling task, these subjects' spelling errors tended to be more phonologically similar to the target word.

Our explanation for the negative correlation between orthographic skill and the spelling ratings is that subjects who have relatively weak orthographic codes tend to use phonological codes in spelling (and reading). Their greater use of phonological codes in spelling results in errors that are more phonologically and visually similar to the target. However, there are two possible problems with this explanation. First, it is not obvious why subjects with relatively strong orthographic codes could not use them to advantage in spelling, thus producing a positive correlation between orthographic skill and the spelling ratings. The reason may be that these younger subjects are quite limited in their reading experience, and although their orthographic codes are relatively stronger than those of their peers in a task that involves word *recognition,* they are still not strong enough to support the reasonable spelling of relatively unfamiliar words in a *production* task. However, these subjects may use their relatively strong orthographic codes to produce perfectly accurate spellings for more familiar words.

The second apparent problem with our explanation is that subjects who have relatively strong orthographic skill do not necessarily have weaker phonological skill. In fact, the correlation between accuracy in the phonological and orthographic tasks is not significant (see Table VII). Why then would the subjects high in orthographic skill show less tendency to use their apparently equivalent phonological coding skills to produce more reasonable spellings of unfamiliar words? The answer to this question requires further elaboration of the dual encoding model and consideration of the different ways in which subjects might read nonwords.

3. *Two (or More) Phonological Processes in Reading and Spelling*

Performance in the phonological task may be based on two different phonological paths to the lexicon, each of which allows the reading of nonwords, but dominant processing in one is associated with good orthographic skill and low similarity ratings for spelling errors while dominant processing in the other phonological path is associated with poor orthographic skill and spelling errors that are more similar to the target.

Recent models of reading have emphasized parallel and interactive processing between the different memory systems depicted in Fig. 1 (cf. McClelland & Rummelhart, 1981). These interactions could be represented in Fig. 1 by making all of the arrows bidirectional between the different memory systems. In this type of model, there are at least two possible ways to read nonwords. First, subjects could use the mediating phonological path to the lexicon already described wherein grapheme–phoneme rules are used to produce the sound of a nonword. Second, the sound of a nonword could be determined by direct activation of words or parts of words in the lexicon that are similar to the nonword. The activation of these lexical items could then feed back to phonological memory and support the phonological decoding of nonwords. Glushko (1979) and Kay and Marcel (1981) have argued that this is how older normal readers typically derive phonological codes for both words and nonwords.

Baron's model of reading (1977) included both prelexical and postlexical activation of phonological codes, and he distinguished several different ways in which the prelexical activation of phonological codes might occur. These ranged from small-unit grapheme–phoneme correspondence rules, to larger subword units, to words that could exist, disembodied from their meaning, in phonological memory. Treiman *et al.* (1983) presented evidence that normal readers use both large and small unit rules to access sound codes when reading sentences, but they left open the question whether the large units activated phonological memory prelexically, postlexically, or both. However, the prelexical–postlexical question can not be decided here, and it may not be important for the following account of our results.

Regardless of whether the phonological codes used in reading are generated prelexically, postlexically, or both, the critical issue may be the subjects' differential use of small and large units in decoding words and nonwords. Individual differences in orthographic skill may reflect the subjects' differential skill in the use of small and large units in reading and spelling. Those subjects who have relatively good orthographic codes may tend to access the lexicon directly with word units. They may also be able to use relatively large word or subword units either pre- or postlexically to access phonological memory for decoding nonwords. In contrast, subjects with relatively poor orthographic skill may depend less on the use of large units in either direct lexical access that is required for good performance in the orthographic task, or in the generation of phonological codes for the phonological task. Instead, they may rely more on the use of small-unit grapheme–phoneme rules to achieve an equivalent level of nonword reading and word recognition.

Although either small or large units could be used to derive the correct pronunciation for a nonword in our tests of phonological coding, the large and small unit phonological processes may not be equally useful for spelling unfamiliar words in younger children. When strong orthographic codes are not available for spelling a word, it may be easier to use a limited set of grapheme–phoneme conversion rules in reverse as phoneme–grapheme conversion rules in spelling. In fact, the use of these rules in both directions is often explicitly taught in programs that emphasize phonics training (Perfetti, 1984a). However, because these rules are not adequate for many words and it is not always clear from the sound which of the possible phoneme–grapheme correspondences are appropriate, precisely correct spellings often require specific orthographic knowledge. Thus, it is interesting to note that the similarity ratings for spelling errors are not correlated with the number of words spelled correctly. The overapplication of common phoneme–grapheme small-unit rules would sometimes lead to spelling errors, sometimes correct spellings, and usually spelling errors that are reasonably similar to the target word.

Subjects who are relatively unfamiliar with phonics rules and who read nonwords more by analogy or through larger units may have greater difficulty reversing these phonological processes to produce reasonable spellings for unfamiliar words. These subjects may be able to spell a number of familiar words accurately through their superior orthographic codes, but they would be at a severe disadvantage in spelling words that were unfamiliar. Thus, they show lower similarity ratings for their spelling errors. However, it is possible that older disabled readers may be able to utilize their greater orthographic knowledge more directly to spell unfamiliar words through the reverse application of the large-unit codes they use in reading.

This hypothesis will be tested by comparing correlations between orthographic skill and spelling for the younger and older groups.

4. *Age Differences in Relations between Coding Skills and Spelling Ratings*

Correlations for the 50 oldest disabled readers (mean age = 15.4 years) are presented below the diagonal in Table VII. In contrast to the younger disabled readers, there are no significant correlations between the spelling ratings and phonological or orthographic skill. Fisher's z tests indicated that the older readers' correlations of spelling ratings with orthographic skill are significantly different from those of the young readers. This difference should be interpreted with caution because the Cronbach-ALPHA reliability (Cronbach, 1951) for the orthographic task was lower for the older than for the younger subjects (.46 vs .83), probably because there are ceiling effects on this task for the older subjects. Nevertheless, it is interesting that both similarity ratings correlate positively with orthographic skill in the older group as opposed to the negative correlations in the younger group. If the positive correlations in the older group could be confirmed with a more reliable measure of their orthographic skill, it would suggest that the basis for spelling performance shifts toward orthographic codes in older disabled readers. This wold be consistent with Ellis's (1982) hypothesis that orthographic strategies in spelling are dominant in normal adult readers. The absence of a significant correlation between phonological skill and spelling ratings in the older group is also consistent with this hypothesis. Cronbach-ALPHA reliabilities were identical (.69) for phonological skill in the younger and older groups.

Another indication of a developmental shift in spelling processes is the significant correlations between the number of words spelled correctly and the similarity ratings for the older subjects (see Table VII). Recall that these correlations are not significant for the younger subjects. Fisher's z tests indicated that the correlations were significantly different between the younger and older groups for the visual similarity rating but not for the phonological rating. The significant correlation between spelling accuracy and visual similarity of spelling errors suggests that the processes involved in spelling known and unknown words are more similar in the older group.

In addition to the above evidence for developmental changes in spelling processes, some studies have suggested that there are parallel developmental changes in the relation between phonological coding and lexical access in reading. The relation is quite strong for very young readers. Firth (1972) reported that the ability to read nonwords in a group of 91 6 year olds accounted for 75% of the variance in their reading ability. In our youngest group, the correlation between phonological skill and word recognition on the PIAT was $r = .61$. This is quite high considering that the reliability of our phonological measure was .69. In contrast, the correlation for the older group ($r = .23$), was not significant, and it was significantly different by Fisher's z test from the correlation for the younger group. Other research has indicated that normal children decrease their dependence on phonological coding as they increase in age (Doctor & Coltheart, 1980; Reitsma, 1983c; Snowling & Frith, 1981), although there is not complete agreement with this conclusion (see Jorm & Share, 1983, for a review of conflicting studies).

5. *Summary*

The data presented in this section suggest that the younger disabled readers vary in reading and spelling styles based on their differential use of phonological and orthographic codes. Some subjects seem to use small-unit phonological codes in reading and spelling while other subjects rely more on large-unit orthographic codes. This view has been supported by the correlations between orthographic skill and the regularity effect and between orthographic skill and the spelling ratings. However, the preceding measures of individual differences in reading and spelling styles may not be ecologically valid as indicies for style differences when reading text for comprehension. In the following section we present a study of disabled readers eye movements when reading stories. The subjects' eye movement patterns reveal reading style differences in text that correlate meaningfully with their performance in the orthographic task and their spelling ratings.

V. EYE MOVEMENT READING STYLE

Eye movement analyses were included in the study for two reasons. First, it seemed that individual differences in word coding processes might be expressed in patterns of visual attention while reading text. Letter identification while reading is limited to a rather narrow span of about six to eight characters to the right and two to four characters to the left of the fixation in normal readers (Rayner, 1984; Underwood & McConkie, 1983), and disabled readers, as a group, are not significantly different from normal readers in their span of letter processing (Underwood, 1982). Therefore, the direction of gaze is a good indication of the words and parts of words that are being attended during a fixation (Just & Carpenter, 1980; Kliegl, Olson, & Davidson, 1982). We hypothesized that subjects who use small-unit rules for phonological coding in lexical access would show a more sequential left-to-right pattern of eye movements within and between words than subjects who accessed the lexicon through the direct path.

The second reason for studying eye movements was that some researchers have reported that basic oculomotor deficiencies may cause reading problems. These reports range from the extreme claim that abnormal eye movements are the "key to dyslexia" (Pavlidis, 1981), to Pirozzolo and Rayner's (1978) view that abnormal eye movements may be a factor for a "visual-spatial" subtype of disabled readers.

The disabled readers' eye movements were monitored while they read short stories of about 200 words at their reading grade level from the Spache Diagnostic Reading Scales (1963). One story was read aloud and another was read silently. Eight factual comprehension questions were asked at the end of each story. Subgroups of younger disabled and normal readers were also tested in a nonreading tracking task to see if there were any basic differences in general oculomotor skill.

Further details of our methods in the eye movement tasks and group comparisons between disabled and normal readers are presented in Kliegl (1982) and in Olson, Kliegl, and Davidson (1983a,b). In general, comparisons between the present disabled and normal groups show that the disabled readers make more fixations, slightly longer fixations, and proportionately more regressions. These results are consistent with many previous eye movement studies of group differences between good and poor readers (see Pirozzolo & Rayner, 1978; Tinker, 1958, for reviews). The novel contribution of the present research is its analysis of within-group differences in reading style based on matching patterns of fixations to the underlying text.

A. The "Plodder-Explorer" Dimension of Eye Movement Reading Style

Two eye movement parameters proved to be particularly useful for observing individual differences in reading style. They are the percentage of the subjects' eye movements that regressed to previous words in the text, and the percentage of forward eye movements that skipped words. The between-word regressive and progressive word-skipping eye movements were added together to represent a reading style dimension. At one end there are the "plodder" subjects who display relatively few regressions between words or word-skipping forward movements. They tend to move steadily forward, with more frequent forward saccades within the words and to the immediately following word. At the other end of the reading style dimension are the "explorer" subjects. They display relatively more regressions to previous words and forward word-skipping movements, and relatively fewer intraword and word-to-word progressive movements. These two types of readers might have equivalent word-recognition scores and they might finish reading the text in the same amount of time, but their patterns of visual attention were significantly different. The plodder and explorer subjects were also different on other important variables that we have been considering throughout the article. It should be emphasized that the plodder–explorer dimension was normally distributed and there was no evidence of distinct subtypes in eye movement reading style.

Before discussing the correlations of other variables with the plodder–explorer dimension, it may be helpful to observe the actual percentages of different types of eye movements that are obtained for subjects at different ends of the dimension. This was accomplished by dividing subjects on the plodder–explorer dimension at the median (which was .1 *SD* from the mean), and computing separate mean percentages of the different eye movements for subjects at the low (plodder) and high (explorer) ends. There were 37 subjects in the younger group and 41 subjects in the older group who had useable eye movement data.

Table VIII presents the mean percentages of six different types of eye movements that were matched to the underlying text. In addition, mean forward and regressive saccade lengths that were calculated independently from the underlying text are presented in number of character spaces. The last two variables are the mean fixation duration and the number of words read per second. The correlations of each of the percentages with the plodder–explorer dimension are presented in parentheses. The means in Table VIII are based on eye movements in the oral reading task. A similar pattern of eye movement percentages on the plodder–explorer dimension is present in the silent reading task.

Some justification is needed for adding the between-word regression and word-skipping percentages. (Actually the subjects' word-recognition-adjusted z scores for these percentages were added.) A pragmatic justification is that the correlations with the variables in Table IX are generally stronger when the two eye movement percentages are added than when either is considered alone. Also, the pattern of correlations is generally similar for the two types of eye movements across these variables. Finally, the between-word regressions and word-skipping movements are positively correlated with each other for old-subjects-oral (.28), old-subjects-silent (.32), young-subjects-oral (.35), and young-subjects-silent (.37) conditions. Multiple regression models tested whether word skipping and regression percentages entered separately do a better job of accounting for variance in the other variables than the plodder–explorer dimension. They do not.

Relations between the percentages of the six word-based eye movements are reciprocal. Since the percentages of between-word regressions and word skipping are higher for explorer subjects, their percentages must be lower on some of the other types of eye movements. In Table VIII it can be seen

TABLE VIII

Means for Eye Movement Percentages and Related Variables in Plodders and Explorers and Correlations with the Plodder–Explorer Dimension[a]

	Young			Old		
	Plodder (n = 18)	(r)	Explorer (n = 19)	Plodder (n = 21)	(r)	Explorer (n = 20)
Word to word (w.)	40.9%	(−.57)	35.0%	40.1%	(−.83)	31.0%
Word skipping	7.2%	(.82)	10.7%	12.3%	(.80)	19.2%
Regress between w.	14.6%	(.82)	19.4%	13.1%	(.80)	17.5%
Progress within w.	22.1%	(−.49)	18.7%	19.2%	(−.56)	14.8%
Regress within w.	10.3%	(.30)	11.2%	9.7%	(.27)	11.1%
Line switch	4.8%	(.11)	5.1%	5.5%	(.31)	6.6%
(total)	(100%)		(100%)	(100%)		(100%)
Fixation duration (msec)	411	(−.30)	372	332	(−.45)	293
Words read per second	1.04	(−.10)	1.15	1.52	(−.25)	1.73
Progressive saccade	4.44	(.70)	5.16	5.35	(.65)	6.57
Regressive saccade	4.67	(.16)	4.95	4.95	(−.09)	4.76

[a]Percentages are mean values for subjects above and below the median on the plodder–explorer dimension. Progressive and regressive saccades are in number of characters spanned. Values in parentheses are correlations of the variable with the plodder–explorer dimension. All correlations larger than r = .26 are significant (p < .05).

that they are significantly lower than the plodders in word-to-word and within-word progressive movements. The explorers also tend to have shorter fixation durations and longer forward-saccade lengths, but they are not significantly different in reading rate. This indicates that they make slightly more eye movements than the plodders, but they finish reading the text in about the same time. How are these different eye movement reading styles related to the other variables we have been studying?

The first part of this section is concerned with the relations between eye movements and the disabled readers' coding skills and spelling ratings. The second part is concerned with eye movement relations to verbal intelligence, semantic errors, and comprehension of the text. Correlations with each of the relevant variables are presented for the younger and older groups in Table IX, separated for oral and silent stories.

B. Eye Movements, Coding Skills, and Spelling Ratings

The correlations for the young disabled readers in the oral stories are discussed first, followed by their performance in the silent condition. Then the results for the older subjects are presented.

1. Young Subjects in the Oral Reading Condition

Recall that in the spelling analyses, the similarity ratings of spelling errors and orthographic skill are negatively correlated for the younger group (see Table VII). In Table IX, it can be seen that these measures are also oppositely related to the younger subjects' eye movements. Those readers whose spelling similarity ratings are higher and those who are relatively poor in the orthographic task tend to be on the plodder end of the eye movement dimension. Hierarchical regression analyses indicated that the orthographic task and the spelling ratings mostly overlap in the variance they account for in the plodder–explorer dimension. This suggests that performance in both tasks is based on the same underlying individual differences in coding processes.

It was argued in the spelling section that poor performance in the orthographic task and the associated higher spelling similarity ratings indicate a

TABLE IX

Correlations for Coding Skills, Spelling Ratings, Comprehension, Semantic Errors, and Verbal Intelligence with the Plodder–Explorer Dimension for Younger and Older Subjects in Oral (O) and Silent (S) Stories.[a]

	Ortho. skill	Phonol. skill	Visual spelling rating	Phonological spelling rating	Comprehension	Semantic errors	Kaufman verb. IQ
Young (O) plodder–explorer	.54**	−.25	−.38*	−.46**	.10	.31*	.56**
(S)	.39**	−.02	−.21	−.33*	.15	.15	.40**
Old (O) plodder–explorer	.11	−.08	.11	−.10	.23	.21	.58**
(S)	.13	−.16	.28*	−.03	.30*	.34*	.50**

[a] $n = 37$ in young group and 41 in old group. * $p < .05$; ** $p < .01$.

greater tendency to use small-unit phonological coding in lexical access and spelling. In relation to eye movements, greater use of small-unit phonological coding in lexical access would yield a plodder style of reading because the subject sequentially attends to the grapheme–phoneme correspondence patterns in words rather than the larger orthographic images for whole words. Thus, plodders show significantly higher percentages of within-word and word-to-word progressive eye movements (see Table VIII).

Separate analyses of the eye movement percentages indicate that both between-word regression and word-skipping components of the plodder–explorer dimension account for significant variance in orthographic skill and the spelling ratings. However, for the within-word and word-to-word movements, only the within-word progressions are significantly related to orthographic skill ($r = -.46$), and phonological spelling ratings ($r = .29$). The respective correlations in the silent condition are $r = -.34$, and $r = .41$, and again there are no significant correlations with the word-to-word progressive movements. Although word-to-word progressive movements are the modal pattern and they show significant variance in relation to the plodder–explorer dimension, their variance is not related to individual differences in coding and spelling. Also, there are no significant correlations with the percentages of intraword negative movements and line switches, or with mean length of negative saccades.

Mean length of positive saccades is strongly correlated with word skipping ($r = .68$ oral, $r = .65$ silent), for obvious reasons. It is also positively related to between-word regressions ($r = .46$ oral, $r = .36$ silent), and it is negatively related to intraword-positive movements ($r = -.52$ oral, $-.80$ silent). Thus, it is not surprising that mean-forward-saccade length relates to orthographic skill and the spelling ratings in much the same way as the plodder–explorer dimension. For the young subjects, the correlations with mean-forward-saccade length are orthographic skill, $r = .45$ oral, $r = .43$ silent; visual rating, $r = -.26$ oral, $r = -.22$ silent; phonological rating, $r = -.36$ oral, $r = -.43$ silent. It is apparent that this single eye movement parameter, which is based on a relatively simple calculation of mean-forward-saccade length independent from the underlying text, captures much of the variance in reading style for these variables. However, we will continue to discuss the data for the plodder–explorer dimension and the specific eye movement percentages because they give a better indication of the dynamics of individual differences in reading style.

The eye movement correlations with verbal intelligence will be discussed later. For now, it is important to note that orthographic skill and the spelling ratings predict variance in the plodder–explorer dimension independently from verbal intelligence. Hierarchical analyses indicated that orthographic skill and verbal intelligence account for about 20% independent variance in the plodder–explorer dimension after taking the other variable into account. Their multiple correlation with the plodder–explorer dimension is .70. Adding the subjects' phonological or visual spelling ratings to the model raises the multiple r nonsignificantly to .71. This is an impressive amount of variance considering the reliability of the measures. A conservative estimate of the reliability of the explorer–plodder dimension was obtained by correlating the subjects' position on this dimension in the oral and silent stories ($r = .77$). Since the tasks of oral and silent reading are different, reliability within the same condition should be higher. This is quite remarkable for such a brief reading task. The stories were only about 200 words in length and the mean reading time was only about 3 minutes. However, this yielded about 300 to 600 eye movements per subject for the calculation of the different eye movement percentages.

In spite of the apparent power of the eye movement measures to detect individual differences in reading style, phonological skill is not significantly correlated with the plodder–explorer dimension when measured by the forced-choice task ($r = -.25$ oral, $r = -.02$ silent), or by the oral nonword reading task ($r = -.18$ oral, $r = -.10$ silent). However, there were small but significant correlations for phonological skill in the forced-choice task with the percentage of within-word-progressive movements in both oral ($r = .27$) and silent ($r = .30$) conditions, and there were also small but significant correlations with mean-forward-saccade length ($r = -.29$ oral, $r = -.33$ silent).

The relation between phonological skill, defined by the ability to read nonwords, and reading style, presently indicated by the plodder–explorer dimension, seems to be quite small compared to the eye movement relations with the use of small-unit phonological coding and the strength of orthographic codes. Some research has suggested that phonological skill might be more related to reading style in subjects younger than ours (cf. Mitterer, 1982). The reason for this may be that very young readers have very limited orthographic knowledge and their reading of nonwords may depend more on the use of small-unit grapheme–phoneme conversion rules.

2. *Young Subjects in the Silent Reading Condition*

The correlations with the plodder–explorer dimension in Table IX are consistently but not significantly lower in the silent condition than in the oral condition for younger readers' orthographic skill and the spelling ratings. Perhaps the added stress of reading aloud accentuates individual differences in style associated with differences in coding processes. It is also possible that children's coding processes in silent reading are generally less phonological. Treiman *et al.* (1983) suggested that this may be true for normal adult readers. However, the different patterns of eye movements in oral and silent reading do not indicate a major change in coding processes. From the oral to the silent condition, regressions between words declined from 17.1 to 15.6%, word skipping movements increased from 9 to 10.1%, and intraword positive movements declined from 20.3 to 19.5%. None of these differences is significant. Thus, there is no indication from the subjects' eye movements that there is a difference in small-unit phonological coding between the oral and silent reading conditions.

3. *Eye Movements, Spelling Ratings, and Coding Skills in the Older Group*

As in the previous developmental comparisons for the spelling ratings, there are no significant relations for orthographic skill, visual spelling rating, or phonological spelling rating to the older subjects' eye movements. Differences in the size of the correlations between the age groups are significant by Fisher's z test for orthographic skill and phonological and visual spelling ratings in the oral condition. Only for orthographic skill could the reduced correlation for the older subjects be attributed to a substantial reduction in variance and reliability for the measure.

To review the developmental argument made before, the older subjects may be less likely to use small-unit phonological coding in lexical access because with their greater reading experience, they can depend more on large-unit orthographic codes. This would reduce the variance in small-unit phonological coding in the older subjects that could be related to individual differences in eye movements. The older subjects' lower percentages for within-word progressive eye movements and higher percentages for word skipping are consistent with this view (see Table VIII).

The absence of significant correlations between eye movements, spelling ratings, and coding skills in the older group might have led us to doubt the relevance of their eye movements to individual differences in reading style. However, the older subjects' strong correlation between the plodder–explorer dimension and verbal intelligence described below shows that eye movements are a valid measure of differences in reading style across a broad age range.

C. Verbal Intelligence and the Plodder–Explorer Dimension

We did not predict the correlations between the plodder–explorer dimension and verbal intelligence that appeared in both age groups (see Table IX). They were first observed at a slightly lower level for the WISC-R verbal subscale. The correlations in Table IX are based on a measure developed by Kaufman (1975) from his factor analysis of the WISC-R tests. Kaufman found that four of the WISC-R tests, Information, Vocabulary, Similarities, and Comprehension loaded on a verbal factor. Our measure of verbal intelligence is an unweighted average of these four tests, each of which was significantly correlated with the plodder–explorer dimension at a slightly lower level than the mean for the four tests. The other WISC-R tests loaded on two factors that Kaufman called Perceptual Organization and Freedom from Distractability. Neither of these is significantly related to the subjects' eye movements.

1. Younger Subjects

Analyses of the specific eye movement percentages in the younger subjects revealed similar correlations with verbal intelligence for word skipping and between-word regressions ($r = .51$, $r = .41$, respectively, for oral reading; $r = .39$, $r = .27$, respectively, for silent reading). The correlations between intraword-positive movements and verbal intelligence are $r = -.42$ (oral) and $r = -.56$ (silent). Again, as for the coding and spelling variables, there are no significant correlations with the word-to-word progressive movements, intraword-regressive movements, or the mean length of regressive movements, but the mean length of forward saccades correlated at $r = .53$ (oral) and $r = .56$ (silent) with verbal intelligence. The patterns of eye movement correlations with verbal intelligence in the younger group are similar to those with orthographic skill. A theoretical account for why the correlations are observed with orthographic skill and the spelling ratings has been presented, but the reasons for the similar correlations of eye movements with verbal intelligence may be different because verbal intelligence and orthographic skill each account for about 20% independent variance in the plodder–explorer dimension. We will return to this question after presenting the results for the older subjects.

2. Older Subjects

The pattern of component eye movement correlations with verbal intelligence is somewhat different for the older subjects. Word skipping and between-word regressions are similarly correlated with verbal intelligence ($r = .43$, $r = .52$, respectively, for oral reading; $r = .47$, $r = .39$, respectively, for silent reading). The correlations between the intraword-positive movements and verbal intelligence are $r = -.56$ in the oral condition and $r = -.21$ in the silent condition. Mean lengths of forward saccades are correlated at $r = .43$ (oral) and $r = .49$ (silent) with verbal intelligence. The main age difference is the older subjects' significant correlations between verbal intelligence and word-to-word progressive movements ($r = -.42$ oral, $r = -.53$ silent). The reason for this difference between the age groups is that the older subjects' saccades are generally longer, and they skip more words (see Table VIII). Thus, there is a much stronger trade off in the older group between the other eye movement percentages and word-to-word movements on the plodder–explorer dimension (see Table VIII).

3. Basis for the Verbal Intelligence Correlations

One possible reason the more verbally intelligent disabled readers tend to rely on a more exploratory approach is because they have the general knowledge and oral vocabulary that allows them to depend less on the use of phonological coding in reading words, and more on the use of context. The idea of less phonological coding for the more verbally intelligent subjects is only marginally supported by the direction of correlations for verbal intelligence with the younger subjects' orthographic skill ($r = .21, p > .05$), phonological skill ($r = -.23, p > .05$), and phonological spelling ratings ($r = -.35, p < .05$). However, processes indicated in the coding and spelling tasks were not measured in a situation where context could play a role. For example, the way a subject reads the word *rain* in the orthographic task could be different from his approach in the context of a story, depending on his verbal intelligence. There is some evidence to support this hypothesis from the reading errors the subjects made in the oral stories. The more intelligent explorer subjects tended to make errors that were more semantically appropriate in the text (see Table IX). However, the correlations were not very large and were significant in only two of the four conditions, perhaps because the subjects did not make enough errors in the short stories, which were adjusted for difficulty according to their word recognition scores.

The above explanation of the link between verbal intelligence and eye movements is based on the same relations of word decoding processes with eye movements that were described before. From this point of view, orthographic skill and verbal intelligence account for significant independent variance in the plodder–explorer dimension in the younger group because the two variables pick up on different sources of individual differences in word coding processes. But there may be other influences of verbal intelligence on eye movements.

In view of the greater use of context by the more intelligent explorers that was inferred above from their more semantically appropriate errors, we expected to find a correlation between eye movements and the subjects' performance on the comprehension test that was given after each story. It can be seen in Table IX that comprehension is significantly correlated with the plodder–explorer dimension only for the older subjects in the silent condition. Actually, these ambiguous results are not too surprising since the stories were short, the questions were few (eight), and they pertained to simple facts in the stories. Most subjects did quite well on the tests so ceiling effects may have obscured true individual differences in comprehension.

The strong relation between eye movements and verbal intelligence is intriguing and it invites further research with longer texts, more extensive analyses of the subjects' errors, more converging evidence on the subjects' differential use of small-unit phonological coding in text, and memory tests for the gist and surface structure of the text. One hypothesis to be tested in future research is that the more verbally intelligent subjects tend to make more exploratory eye movements because they are more concerned with monitoring their comprehension of the text and maintaining their memory for previous words. There is substantial evidence that disabled readers suffer from limitations in phonological memory (see the third section), that may be needed to integrate the words in a sentence for semantic interpretation (cf. Kleiman, 1975). The more intelligent disabled readers greater frequency of between-word regressions in text may be related to a memory restoration function.

D. Eye Movements in a Nonreading Task and the "Visual-Spatial" Subtype

Eye movements were also monitored in a tracking task to see if there is any difference in basic oculomotor function between or within groups that might account for the results in reading. Some eye movement researchers and reading therapists have argued that the abnormal eye movements observed in disabled readers during reading are a cause rather than an effect of their reading difficulties (cf. Punnett & Steinhauer, 1984). Generally there has been little evidence to support this causal interpretation (Pirozzolo & Rayner, 1978; Tinker, 1958), although Pavlidis (1981) has recently reported that abnormal eye movements in his tracking task were the "key to dyslexia." Pavlidis reported that his 12 disabled readers made many more eye movements and proportionally more regressions than normal readers in a simple tracking task, and the distributions for the two groups did not overlap.

Some of the present subjects were tested in a tracking task similar to the one used by Pavlidis (1981). Details of the methods and results of this test may be found in Olson *et al.* (1983b). Briefly, 34 disabled and 36 normal readers (mean age = 11 years) were asked to follow a point on the screen as it shifted sequentially to five positions from left-to-right and right-to-left. There are no significant differences between disabled and normal readers' tracking eye movements. Similar null results have been reported in two other studies (Brown, Haegerstrom-Portnoy, Adams, Yingling, Galin, Herron, & Marcus, 1983; Stanley, Smith, & Howell, 1983). Also, there are no significant correlations within the disabled group between tracking eye movements and Kaufman's verbal, perception, and distractability factors from the WISC-R, or any of the coding and spelling tasks.

Pirozzolo and Rayner (1978) have reported from a few case studies that there is a "visual–spatial" subtype of disabled reader whose eye movements are distinctly abnormal, but these individuals must be quite rare in the reading disabled population. Rayner (1983) has also recently reported that the "visual–spatial" subtype is very rare. His estimate is that the "visual–spatial" subtype includes less than 10% of disabled readers. To see if there was a small group of "visual–spatial" dyslexics in the present sample that might have been concealed in correlations for the whole group, 10% of the disabled readers were selected who had complete eye movement data and who had the high-verbal, low-performance pattern on the WISC-R that has been described as characteristic of the "visual–spatial" subtype (Pirozzolo, 1983). After controlling for the subjects' verbal intelligence, there were no significant differences in eye movements between the 12 high-verbal–low-performance subjects and the rest of the sample. Thus, there was no indication of a significant "visual–spatial" subtype with eye-movement problems.

As Rayner (1983) has suggested, the "visual–spatial" subtype is quite rare. The present results indicate that it probably accounts for far less than 10% of disabled readers in school-referred samples. Such cases might be more frequently observed in clinic populations, although Snowling (personal communication) has estimated that no more than one in 50 of her reading disabled patients have reading difficulties that might be related to visual–perceptual deficits. Thus, the frequent regressions and larger number of eye movements commonly observed for the vast majority of disabled readers seems to be due to their difficulty in reading, and the individual differences in eye movement reading style observed among our disabled readers reflect different ways of coping with their reading problem that are associated with their different word decoding strategies and verbal intelligence.

VI. DISTRIBUTION AND ETIOLOGY OF READING DISABILITIES

There are two remaining questions to be addressed in this final section. The first is the distribution of reading disabilities in the population, and the second related question is the cause of reading disabilities.

A. Distribution Issues

Many previous efforts at subtyping disabled readers have drawn cases from clinics in large metropolitan areas. There is no way of knowing how representative these clinic samples may be of the general problem of reading disability in the schools (Snowling, 1983). Often, subtypes have been identified on the basis of one or a few individuals, with no indication of their frequency in the population. The present sample provided a unique opportunity to assess the frequency of different reading disabilities. About half of the children who were reading disabled in several Boulder area schools participated in the project. Although the sample was not exhaustive, there was no indication that it was biased. Those disabled readers and their parents who declined to participate in the project often cited the inconvenience caused by the three extensive test sessions.

Two issues are addressed from this sample regarding the distribution of reading disabilities. The first issue is the distinctiveness of levels of reading ability in the disabled sample compared to the rest of the population. The second issue is whether different reading disabilities consist of distinct subtypes or continuous distributions.

1. Distribution of Reading Ability in the Population

Some researchers who work with school samples view reading disability as the extreme low end of the normal distribution of reading ability in the population, excluding those poor readers who have obvious neurological problems (cf. Perfetti, 1984a). More commonly, reading disability or dyslexia is viewed as a distinct syndrome that is separate from the normal distribution of reading ability. The only evidence for the statistical separation of dyslexia from the normal distribution of reading ability is the analysis by Yule, Rutter, Berger, and Thompson (1974) of five large and exhaustive samples of English school children. They reported that while a normal distribution would predict that 2.28% of the children would read less than two standard deviations below the mean for their population, the average for the groups was about 4%. However, a closer inspection of their results suggests that this overrepresentation is probably an artifact of skew in three of the five samples where the mode was clearly above 0 standard deviation. This seemed to have been caused by ceiling effects in the reading tests for these three samples. The authors acknowledged that the reading tests for these groups may have been more sensitive to skill differences in the lower range, and variance in performance was limited in the high range. It seems likely that this accounts for the larger than expected proportion of readers that was more than two standard deviations below the mean in these three samples. In the two samples that did not have obviously skewed distributions and apparent ceiling effects, the number of readers two standard deviations below the mean was not significantly greater than expected from a normal distribution. A recent study by Rodgers (1983) used tests of reading ability that were selected to avoid ceiling and floor effects. No significant deviations were observed from a normal distribution for reading ability in Rodgers's sample of 8836 10 year olds above 70 IQ. This result questions the qualitative distinction made by many researchers between "dyslexic" and less severely disabled "poor" readers.

We do not have data on reading ability for all of the children in the Boulder schools, so it can't be demonstrated that the distributions of reading ability in our population is normal. However, we can address a slightly different but related question. The present sample contained a sufficient range of reading ability in the disabled group so that separate analyses could be done with the subjects that would meet the traditional criteria for reading disability or "dyslexia," and subjects that some researchers would describe as "poor" readers who are not sufficiently retarded to be identified as "dyslexic" (see Section II for selection criteria). If the "dyslexics" are an etiologically and distributionally distinct group, they might show some qualitative differences from the "poor" readers in their reading processes. We attempted to test this hypothesis by dividing the disabled readers into groups of "dyslexics" who were below 70% of their expected grade level and "poor" readers who were above the 70% criterion, but still well below their normal controls. This was an arbitrary division, since there was no indication of any bimodality for reading ability in the present disabled sample.

There are quantitative but not qualitative differences between the "dyslexic" and "poor" groups. For example, the "dyslexic" group averaged about 2 years lower in PIAT word recognition than the "poor" group, and they made about 5% more errors on both the phonological and orthographic coding tasks. Thus, the relative-phonological coding deficit is similar for both groups and both groups show a greater relative-phonological deficit than the normal readers. Also, separate analyses of within-group differences in reading style were performed for the "dyslexic" and "poor" readers. The same patterns of individual differences are present in both groups.

The above results are consistent with the view that many readers identified as "dyslexic" may be part of the normal distribution of reading ability. Later we will discuss the implications of this view for the etiology of reading disability. It should be emphasized that while the continuum view seems to be appropriate for the disabled readers tested in the present study, it does not exclude the possibility that there are some unique "dyslexics" that may contribute to a deviation from the normal curve that is difficult to detect statistically. The uniqueness of these subjects from other disabled readers would have to be demonstrated by behavioral, neurological, and genetic analyses.

2. *Distinct Subtypes versus Dimensions of Individual Differences*

A classic study by Kinsbourne and Warrington (1963) deliberately selected extreme cases of delayed readers to highlight differences. Others who have followed Kinsbourne and Warrington have cited their work as support for distinct subtypes, but Kinsbourne (1982) has recently cautioned that the underlying behavioral distributions may be continuous. He recommended multivariate approaches to the study of individual differences.

Boder's (1973) dichotomous classification of dyseidetic and dysphonetic readers suggests a very clear separation, resulting from distinctly different causes, and requiring distinctly different remediation techniques (Boder and Jarrico, 1982). However, the present study revealed essentially normal distributions of component reading skill and style differences in the present sample. Even where there are deviations from strict normality indicated by significant kurtosis or skew, there is no evidence for multimodality in the distributions. One example is from the analysis of spelling errors. While Boder described distinct dyseidetic and dysphonetic subtypes from her analysis of spelling errors, the present subjects' spelling errors vary on continuous dimensions of visual and phonological similarity. As in a recent study by Finucci *et al.* (1983), the disabled readers' errors are generally less phonologically similar to the target word than those of the normal readers. Within the disabled group, the ratings range continuously from moderate to low similarity with the target word. A division of this continuum into dyseidetic and dysphonetic subtypes would be arbitrary.

Recent approaches to subtyping disabled readers have used cluster and Q factor analyses of their performance on various tests (Doehring *et al.*, 1981; Lyon & Watson, 1981; Naidoo, 1972; Petrauskas & Rourke, 1979; Satz & Morris, 1981; Vavrus, Brown, & Carr, 1983). These clustering approaches have yielded varying numbers of subtypes. At present there has been no attempt to integrate the subtyping results across the different studies. Within the study by Doehring *et al.*, no relation was found between subtypes defined by reading tasks and those defined by language tests and neuropsychological tests on the same subjects. Some have suggested that further research is needed to validate and clarify the meaning of subtypes identified in cluster analyses (Fisk & Rourke, 1983; McKinney, 1984; Satz & Morris, 1981).

Cluster analyses were performed by Vogler, Baker, Decker, and DeFries

(1984) on the WISC-R subtests and other psychometric measures of cognitive and reading skills for the present subjects. After examining the results of several different clustering algorithims, it was concluded that although there were substantial individual differences in the test profiles, the clusters did not define distinct and homogeneous subtypes. Rather, the subjects' variation in performance patterns on these tests were better characterized by a multivariate continuum. It appeared that the clustering routines were defining clusters due to minor and possibly random departures from a continuous distribution. The presence of continuous distributions for individual differences in reading disability is seen below to have implications for their etiology.

B. Etiology of Reading Disabilities

Three types of evidence bear on the causes of different reading disabilities in the present sample. First is the continuous distributions described above. Second is the relation between differences in reading processes and basic cognitive skills. Third is the evidence from a few of our subjects that teaching method may have a major influence on their reading styles.

1. Etiological Implications of Subtypes and Continuous Distributions

Distinct subtypes suggest distinct causes for different reading disabilities such as different training programs, localized brain damage (cf. Coltheart, 1981; Saffran & Marin, 1977), or single gene inheritance patterns (Smith, Kimberling, Pennington, & Lubs, 1983). Continuous distributions suggest multiple causes and polygenic models of inheritance (DeFries & Decker, 1982). This is also true for the distribution of reading ability. If disabled readers are distinctly separate from the normal distribution of reading ability, single gene factors or some unique environmental insult would be likely. An alternate view is that due to polygenic inheritance patterns and/or continuously varying environmental influences, disabled readers are very low in the specific cognitive skills needed for normal reading, just as superior readers may be very high in these critical skills.

Of course it is possible that the distinct subtype view is correct for some disabled readers, but they could not be distinguished with the present behavioral measures. It is also possible that our selection criteria excluded subjects who might have fit one or more distinct subtypes. Evidence of brain damage resulted in the exclusion of a few children who were referred from the schools. Such disabled readers may be more frequent in clinic samples where distinct subtypes are often reported. Their exclusion from the present sample is in accord with commonly accepted definitions of reading disability or dyslexia.

2. *Reading Style Differences and Basic Cognitive Resources*

Boder and Jarrico (1982) cited several unpublished studies that found a link between the dyseidetic and dysphonetic classification of reading-disabled subjects and their different performance patterns on the WISC-R subscales. It was concluded that the observed individual differences in reading and spelling styles were caused by different patterns of cognitive deficit. Dyseidetics were reported to be lower in the WISC-R performance subscale than in the verbal subscale while dysphonetics were lower in the verbal subscale. However, a recent study in Holland by van den Bos (1984) classified reading disabled children as dysphonetic or dyseidetic and found no significant differences between these two groups of children in specially designed tasks that separated their visual and auditory processing abilities. A second study by Hooper and Hynd (1984) classified reading-disabled children with the Boder and Jarrico test and compared the dyseidetic and disphonetic subtypes' performance on the Kaufman Assessment Battery for Children (K-ABC). There were no significant differences between the subtypes in their K-ABC performance patterns that were consistent with Boder's (1973) cognitive deficit theory.

Boder's (1973) theory was evaluated in the present study by comparing the ratio of phonological skill to orthographic skill with the ratio of verbal IQ to performance IQ, after partialing out word recognition. The correlation for all disabled readers was $r = .01$. Next, the separate partial correlations of phonological skill, orthographic skill, phonological spelling ratings, and visual spelling ratings with performance IQ were calculated. Boder's theory predicts that subjects low in phonological skill and high in whole-word reading would tend to be stronger in the performance IQ subscale than subjects who are high in phonological skill and low in whole-word reading. However, none of the correlations with performance IQ was larger than $r = -.08$.

Apparently the differences between dyseidetic and dysphonetic reading and spelling patterns bear no relation to the visual-gestalt processing skills measured by the WISC-R performance subscale. This conclusion is consistent with Vellutino's (1979) view that basic visual-gestalt processing deficits do not make a significant contribution to reading disability. Of course there have been case studies reported in the literature where visual processing deficits were associated with reading problems, but these cases must be quite rare. To see if a few of the present subjects might fit Boder's (1973) dyseidetic visual-deficit theory, 12 disabled readers who had the greatest deficit in performance IQ were compared with the rest of the sample. As reported in the previous section for eye movements, they were not significantly different from the rest of the sample in their coding skills or reading styles.

Several of the studies that have used cluster techniques with various measures of verbal and perceptual skills have identified subtypes with perceptual or perceptual-motor impairment (cf. Lyon & Watson, 1981; Satz & Morris, 1981). For example, Lyon and Watson's largest of seven subtypes contained 32% of their disabled readers and was characterized by deficits in visual perception. We argued previously that cluster analyses could identify such a subtype that was not really distinct from the rest of the sample (Vogler *et al.*, 1984). In addition, our analyses indicate that perceptual performance is not significantly related to differences in reading style or the component reading skills.

Correlations were also calculated for the coding, reading, and spelling measures with Kaufman's (1975) verbal factor. The correlations with the plodder–explorer dimension have already been discussed. In addition, there was some indication of a trade-off between phonological skill and verbal intelligence in the present sample that was opposite the relation hypothesized by Boder (1973). In the age subgroups used for the individual-difference analyses, the correlation between Kaufman's (1975) verbal factor and phonological skill was significantly negative for the older subjects ($r = -.28$). The correlation was also negative but not significant for the younger group ($r = -.23$). For the 59 younger disabled readers whose phonological skill could be estimated from their oral nonword reading, this measure of phonological skill was negatively correlated with Kaufman's verbal factor ($r = -.28$). While these negative correlations are not very strong, they suggest that there is an interaction between basic phonological coding skills and higher level verbal skills in determining the subjects ability to recognize words. The more verbally intelligent children tend to have better oral vocabularies, and they may have more reading experience. This may supplement their weak phonological skills and bring them to a given level of word recognition that less intelligent readers would have to rely more on phonological skill to reach.

3. *Environmental Influences on Individual Differences in Reading Style*

Kinsbourne (1982) has suggested that some poor readers, regardless of their basic deficit, may appear similar to Boder's (1973) dyseidetics with their slow and painstaking phonological decoding of words, because they have been overinstructed in a phonics approach such as that emphasized by the Orton-Gillingham method. Unfortunately, reliable data on precisely how the present subjects were taught to read were not available, but some anecdotal examples suggest a strong role for training methods. In a current study of reading disability in families, two brothers were tested. One showed a strong explorer reading style in eye movements while the other was a plodder. When these patterns were shown to their parents, they volunteered the information that the two boys had been taught to read by very different methods. The plodder had been taught with a heavy emphasis on phonics, and the younger explorer, who was making more rapid progress in learning to read, was being encouraged to develop his sight-reading skills and to use context as an aid in word decoding. Both children attended the same school, but the approaches of their individual teachers were quite different.

A second example suggests that individual differences in reading style may sometimes be overtly strategic, and subjects may sometimes vary their phonological reading strategies depending upon their perception of the task demands. After plodding through the oral reading task, painstakingly sounding out unknown words with only moderate success, one disabled reader mentioned after the test series that he read for us as he did in school, but he read differently when reading his comic books for pleasure. Then he did not worry about making mistakes that did not sound like the target word and would often guess the word's identity from context. His special education teacher at school discouraged this approach and was trying to teach him phonics (without much success). When he was asked to read some additional paragraphs aloud in his normal pleasure mode, this subject shifted his eye movement reading style from the plodder to the explorer end of the dimension. Observations of other subjects have indicated that sometimes reading styles may shift from explorer to plodder within a paragraph, particularly when mistakes in word decoding lead to obvious inconsistencies in the text.

There may be other more subtle influences on reading style. Francis (1982) suggested from her studies of beginning readers that general personality differences and learning styles may be influential. For example, the cautious learner who attends to every detail may be more likely to use a phonics approach. It may be necessary to consider several diverse sources of variability to understand the etiology of each child's disability and to account for the distribution of different reading styles among disabled readers.

VII. SUMMARY AND NEW DIRECTIONS IN RESEARCH

Individual differences in reading disability were explored through the analysis of component reading processes and related cognitive skills. Reading theory provided a framework for the selection of tests and for understanding the relations between variables. Although the observed individual differences do not seem to form distinct subtypes, they do indicate substantial variability in reading processes and related cognitive skills within the disabled population.

The subjects' use and skill in the phonological and orthographic paths to the lexicon were studied in detail. Comparisons between the disabled and normal groups reveal a deficit for disabled readers in phonological coding that is substantially greater than their deficit in orthographic coding. The deficit in phonological coding seems to be the most distinctive characteristic of the disabled group. Along with some related problems in basic linguistic skills, it may be the cause of most severe deficits in reading ability that are not related to low intelligence or poor education.

Individual differences in orthographic skill converge with differences in the subjects' regularity effect, spelling error patterns, and eye movements to support a reading-style dimension within the disabled group that is independent from reading ability. Orthographic skill and the use of small-unit phonological codes are reciprocally related on this dimension. Disabled readers with relatively poor orthographic skill show greater use of the small-unit phonological path to the lexicon. In addition, there is a link between verbal intelligence and reading style. In contrast to disabled readers with relatively high verbal intelligence, those with low verbal intelligence show greater use of the small-unit phonological path by their plodding eye movements in text.

Developmental changes in reading and spelling styles lead to different patterns of individual differences for younger and older disabled readers. Differences in orthographic skill and spelling indicate substantial variance in the use of the small-unit phonological path for younger subjects, but these differences are not significantly related to reading style in the older disabled readers. We hypothesized that with greater reading experience, there is a decline in the use of the small-unit phonological path, and greater dependence on the orthographic path.

Figure 3 summarizes our view of the reading-style dimension along with the orthogonal dimension of reading ability. A normal curve is drawn to represent the continuity of the reading style dimension and its essentially normal distribution in the present sample. Different performance patterns are presented for each end of the dimension, along with the inferred use of the phonological and orthographic paths to the lexicon.

The dimensions in Fig. 3 may account for much of the variance in reading disability, but several theoretical and practical questions remain to be answered. First, there may be important individual differences among disabled readers in reading and auditory comprehension processes. Measures in the present study focused primarily on word decoding. This choice was

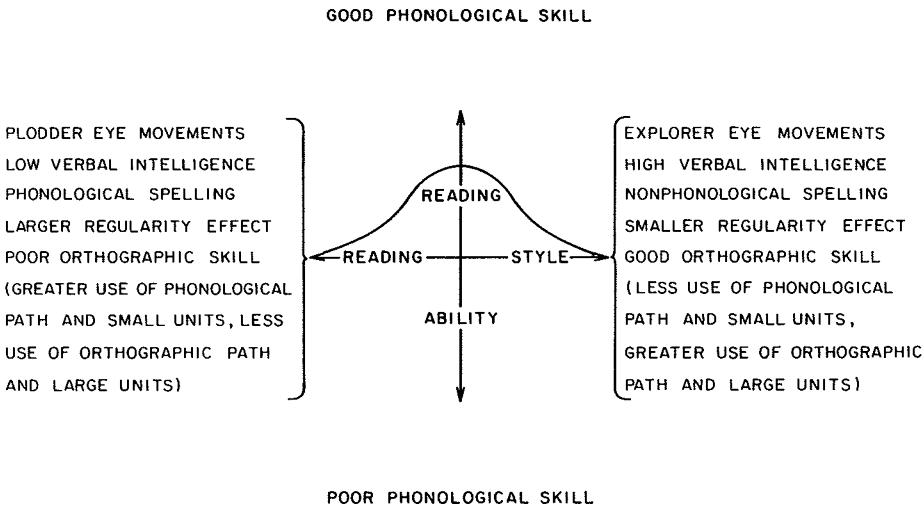

Fig. 3. Dimensions of reading style and reading ability.

made because testing time with the subjects was limited and there was substantial evidence from previous research that word decoding is the major factor contributing to the low levels of reading ability in the disabled population (for a review, see Stanovich, 1982). Nevertheless, there is variability in reading comprehension within the disabled sample that is independent from their word recognition, and comprehension of text is ultimately the best practical definition of reading ability. A complete model of individual differences in reading disability must take variance in comprehension into account (cf. Vavrus *et al.,* 1983; Maria & MacGinitie, 1982). The PIAT comprehension and the eye movement tests probably were not adequate for this purpose. We could determine that the "word-caller" syndrome that has been characterized as having normal word decoding with extremely poor comprehension is quite rare in our school sample. Only one subject seemed to show this pattern. Among the other disabled readers, there are small but significant correlations with comprehension for eye movements and verbal intelligence. These relations are currently being explored with more thorough measures of reading comprehension in longer texts.

A second remaining question concerns the etiology of reading disability and individual differences in reading style. Evidence continues to accumulate for the importance of basic language skills in learning to decode words (Venezky, Shiloah, & Calfee, 1972; Liberman *et al.,* 1974; Bradley & Bryant, 1983), but the origins of variance in these skills remain to be determined. One view is that reading disability is influenced by genetic factors (cf. DeFries & Decker, 1982). Individual differences in reading style may also have a genetic component. The genetic hypothesis is currently being tested in a study of reading disability in families and twins. In addition, environmental influences need to be more thoroughly evaluated. Evidence from a few cases in the present study indicated the influence of teaching methods on reading style in the disabled group, but most research on the consequences of teaching methods has only evaluated group differences in reading ability for normal classes (Perfetti, 1984b).

The consequences of early individual differences in reading style among disabled readers for their subsequent reading achievement are unknown. Some of the older subjects who were identified in a previous study as reading disabled showed improvement in reading ability compared to the rest of the sample while others declined (DeFries & Baker, 1982). Unfortunately, there were no measures of reading style for these subjects when they were first tested. In a current family study, we are retesting some disabled readers who were young subjects in the present study. The stability of their reading styles and relations to changes in reading ability across age are being evaluated.

Basic research on individual differences should ultimately suggest ways for the optimal remediation of different reading disabilities. It seems likely that teaching all disabled readers with the same method would not result in the maximum benefit for each individual. Although many researchers have acknowledged this possibility, there is little hard evidence on the best way to deal with different cases. The most common prescription is to put a heavy emphasis on phonics training, perhaps because this addresses the greatest deficiency in most disabled readers, and there is some indication that this may be the best approach for most children in the schools (Perfetti, 1984a). However, some of the present disabled readers who were the weakest phonological decoders had received extensive training in phonics, apparently with little benefit. We do not know how well they would have read without this training, but there is some evidence from a pilot study by Lyon (1983) that disabled readers with the weakest language skills did not benefit from phonics instruction, while those who were somewhat stronger in language skills showed substantial improvement in word recognition after phonics training.

Two recent studies have trained prereaders and beginning readers in the phonemic analysis skills that may be important for learning to phonologically decode words (Bradley & Bryant, 1983; Treiman & Baron, 1983). Both studies suggest a causal link between prereaders' training in the phonemic analysis of speech sounds and their later reading ability in the early grades. Children at risk for reading disability because of poorly developed language skills might benefit from phonemic analysis training prior to or in conjunction with reading instruction. Long ago, Huey (1908) noted the dependence of reading on language skills and advocated waiting until the child was sufficiently strong in language to learn to read without undue difficulty. Since Huey's advice is generally ignored and most schools begin the same reading instruction for all children around 5 or 6 years of age, early training in phonemic analysis for those children at risk may help reduce the negative impact of this policy.

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