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Dyslexic and Normal Readers' Eye Movements

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Dyslexic and normal readers' eye movements were compared while tracking a moving fixation point and in reading. Contrary to previous reports, the dyslexic and normal readers did not differ in their number of saccades, percentage of regressions, or stability of fixations in the tracking task. Thus, defective oculomotor control was not associated with or a causal factor in dyslexia, and the dyslexics' abnormal eye movements in reading must be related to differences in higher cognitive processes. However, individual differences in oculmotor efficiency, independent of reading ability, were found within both the dyslexic and normal groups, and these differences were correlated in reading and tracking tasks.

As part of an analytic approach to the study of reading processes, increasing attention is being directed toward developmental and individual differences (Baron & Strawson, 1976; LaBerge & Samuels, 1974; Perfetti, in press; Stanovich, 1982; Vellutino, 1983). Dyslexia is an extreme expression of individual differences in reading skill wherein children and adults are substantially retarded in reading, in spite of their normal IQ and education. The present study asks whether the abnormal eye movements commonly observed during reading in dyslexics are a cause of their reading problems because of general difficulties in oculomotor control or whether they arise from difficulties in verbal processes and are only observed during reading.

This question has a long history, and the different answers have centered around different theories regarding the etiology of dyslexia. Dyslexia has been variously ascribed to difficulties in visual processes or verbal processes (Vellutino, 1979). The visual-deficit hypothesis has been based in part on dyslexics' poor memory for visual stimuli and letter and word reversals. A recent article in the visual-deficit tradition by Badcock and Lovegrove (1981) argued that compared with normal readers, dyslexics exhibited shorter durations of visual persistence for high spatial frequencies. They also suggested that this visual deficit might be associated with dyslexics' abnormal eye movements in reading. The opposing view is that dyslexia is associated with a verbal deficit. For example, studies of memory for visual stimuli in dyslexics have shown that they perform worse than normal readers only when the stimuli can be verbally labeled (cf. Katz, Shankweiler, & Liberman, 1982). Verbal deficits have been proposed to account for letter and word reversals (Shankweiler & Liberman, 1972). Perhaps individual differences in verbal skills could also account for differences between dyslexic and normal readers' eye movements in text.

It has been frequently reported that dyslexic readers as a group tend to make more fixations and relatively more regressions than normal readers when reading the same text (Tinker, 1958). Our data have confirmed these group differences, although the differences were not nearly as large when the text difficulty was matched to the subjects' level of word recognition (Olson, Kliegl, & Davidson, 1983).

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Within the dyslexic population, we discovered that subjects with a relatively high verbal IQ demonstrated more frequent regressions and tended to skip words in their forward movements when reading paragraphs (Olson et al., 1983; Kliegl, Olson, & Davidson, Note 1). The more intelligent subjects tended to adopt an "explorer" style of reading, looking back and forth along the line. Less verbally intelligent readers, at equivalent levels of skill in recognizing isolated words, adopted a "plodder" style of reading, with fewer regressions and word-skipping movements and more within-word and word-to-word forward movements. The plodder and explorer subjects fell along a continuous and normally distributed dimension of eye-movement reading style that was also correlated with the semantic quality of their reading errors. Explorer dyslexics showed a significantly higher proportion of contextually appropriate errors than did the less intelligent plodder dyslexics.

Those who ascribe dyslexia to a visual deficit could argue that our higher IQ dyslexics were deficient in oculomotor control and that their difficulties in reading were actually caused by their abnormal patterns of eye movements. This view was held by some early practitioners who noticed the erratic eye movements of poor readers while reading text. They proposed that reading could be improved by training eye movements, but Tinker (1946, 1958) reviewed the literature in this area and found that eye-movement training programs were no more effective than practice in reading. Nevertheless, in spite of Tinker's findings, eye-movement training is still used in some reading clinics.

In the more recent literature, several articles have described case studies of patients with grossly abnormal patterns of eye movements (Cuiffreda, Bahill, Kenyon, & Stark, 1976; Jones & Stark, 1983; Pirrozolo & Rayner, 1978; Zangwell & Blakemore, 1972). It seems likely in these special and rare cases, where there are often soft signs of neurological disorders, that problems in oculomotor control may contribute to the patients' reading difficulty.

The most recent evidence that the more common syndrome of dyslexia is caused by or associated with problems in oculomotor control has been provided by Pavlidis (1981a, 1981b, 1983). He reported that dyslexic children, who read poorly in spite of normal intelligence and education, showed a marked deficiency in fixating sequentially illuminated lights along a row of five equally spaced positions. First, the dyslexic children averaged many more fixations (26) than the normal children (8), and there was no overlap in the group distributions. Second, the dyslexics made a higher percentage of regressive movements (approximately 35% vs. 12%). The group distributions did not overlap for either of these two variables, and the differences were highly significant statistically. Third, Pavlidis found that the dyslexics were much less able to hold their fixation on the lights, although no statistical tests were reported. This result was interpreted to indicate a possible attentional deficit in dyslexics. Pavlidis (1981a, p. 57) concluded that the dyslexics' grossly abnormal eye movements in the "lights test" reflected an underlying "sequential disability and/or oculomotor malfunction" and that their erratic eye movements raised perceptual problems for the orderly and sequential processing of text.

Pavlidis's (1981a) research came to our attention while we were testing a large sample of dyslexic and normal readers for their eye fixations on text.[1] As we noted earlier, it seemed that differences between normal and dyslexic readers and differences within the dyslexic population were related to verbal skills. Pavlidis's results, however, raised the possibility of an alternative interpretation: It was possible that the dyslexic group made more regressions in text because of oculomotor sequencing problems. Also, the finding that

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[1] The subjects in the present study were part of a program project that tested a total of 141 pairs of dyslexic and normal readers. The primary goal of the first phase of the project was to develop diagnostic tests and to ascertain individual differences within the dyslexic population. The second phase of the project is now evaluating the genetic basis for these individual differences by testing families and twins. The subjects were first tested with several psychometric measures in John DeFries's laboratory at the Institute for Behavior Genetics. The present report uses the WISC–R IQ and PIAT reading scores of this test session. Eye movements and other reading-related processes were tested in our laboratory at the Psychology Department. The third test session examined brain lateralization in David Shucard's laboratory at the National Jewish Hospital in Denver.

our higher IQ dyslexic readers tended to regress and skip words more often could be attributed to general oculomotor deficits because Pavlidis (1981b) reported that his lower IQ "backward" readers were similar to normal readers in the tracking task. Only his "above normal" IQ dyslexic readers showed an unusually large number of fixations and regressions.

Two recent attempts to replicate Pavlidis's (1981a) results have failed to find any differences between dyslexic and normal readers (Brown et al., in press; Stanley, Smith, & Howell, in press). Stanley, et al. tested 15 normal and 15 dyslexic readers. The groups did not differ in total number of fixations or regressions. One dyslexic female made a disproportionate number of regressions only when following the lights from left to right. It was not clear that this was a stable characteristic of this subject or that it was a contributing factor to her dyslexia. Brown et al. found that dyslexics did not differ from normals in the number of predictive eye movements, defined as making an eye movement 120 msec prior to or following the stimulus position change. In addition, analog records of the subjects' tracking movements were rated by a judge as "good to poor" on a 7-point scale. There were no significant group differences in these ratings. When the saccades of all types were totaled, the control children actually made significantly more eye movements (about 10%), a result opposite that reported by Pavlidis (1981a).

Pavlidis (in press) has responded to the Stanley et al. (in press) article by noting certain stimulus and procedural differences between the studies. Pavlidis cited pilot work showing that these procedures were critical for finding a difference between dyslexic and normal readers. Unfortunately, a few of these methodological differences were also present in the Brown et al. (in press) study. Thus, at this point we do not know whether Pavlidis's results do not replicate or whether the methodological requirements for demonstrating oculomotor differences between normal and dyslexic readers are quite stringent.

Fortunately, although we were unaware of these studies, we decided to replicate Pavlidis's (1981a) methods in all possible detail with a larger sample of 34 dyslexics compared to Pavlidis's 12 dyslexics. Related eye-movement data were available from another 107 dyslexics between 8 and 16 years of age, constituting a nearly exhaustive sample of this syndrome in our testing area. Thus it was possible to estimate the incidence of oculomotor problems in the dyslexic population and to determine the likelihood that the two studies were simply sampling different "visual" and "auditory" subtypes of dyslexia (Pollatsek, 1983). The analyses of the tracking eye-movement parameters were performed in much greater detail than in previous research. In addition, Pavlidis's contention that it is important to separate low-IQ "backward" readers from above-normal-IQ dyslexic readers was evaluated by correlating their eye-movement parameters in tracking with their IQ scores on the Wechsler Intelligence Scale for Children–Revised (WISC–R). We also compared our subjects tracking eye movements with their eye movements during reading. This comparison tested the hypothesis that there are individual differences in general oculomotor efficiency that are independent from reading ability.

Method

Subjects

Thirty-four dyslexic readers (7 girls and 27 boys) between 8.25 and 13.75 years of age ($M = 11$) were tested in the tracking task. They were referred from schools in the Boulder, Colorado, area under the following objective criteria: They had no overt physical or emotional handicaps, their IQ was 90 or greater on the WISC–R verbal or performance subscales.[2] Their reading level was assessed with the Peabody Individual Achievement Test (PIAT) word recognition, comprehension, and spelling subscales. In comparison to the normal control subjects, they averaged approximately half of expected grade level on the three PIAT subscales (see Table 1).

The 36 normal subjects (5 girls and 31 boys) ranged in age from 8.33 to 13.75 years (M age = 11.17). They read at or above their expected grade level on the PIAT and were similar to the disabled readers in school background and socioeconomic scale. Means and standard deviations

[2] The decision not to match on IQ was adopted by the Program Project. Although components of the WISC–R are strongly related to reading ability, substantial group differences in reading ability remained after IQ was partialed out. Most children with a full-scale IQ of 90 to 100 in the Boulder area read at or above the national norms for their grade level. In contrast, the reading-disabled children with IQs between 90 and 100 averaged less than half their expected grade level.

Table 1
Means and Standard Deviations for Age, Grade, PIAT, and WISC–R Scores

Variable	Normal *M*	Normal *SD*	Dyslexic *M*	Dyslexic *SD*
Age	11.2	1.4	11.0	1.5
Grade	5.7	1.3	5.4	1.4
PIAT recognition	8.1	2.2	3.8	1.4
PIAT spelling	7.1	2.4	3.6	1.3
PIAT comprehension	7.7	2.3	4.0	1.2
WISC–R IQ	115.5	13.1	100.3	10.2

Note. WISC–R = the Wechsler Intelligence Scale for Children–Revised; PIAT = Peabody Individual Achievement Test. The sample sizes for normal and dyslexic readers were 36 and 34, respectively.

for the two groups' PIAT and WISC–R scores are presented in Table 1.

Apparatus

The subject's eye fixations were monitored by a Gulf and Western Applied Sciences Model 1996. This system uses a television image to locate pupil and corneal reflection positions related to the orientation of the subject's right eye. Fixation location was sampled at the rate of 60 Hz, and the data were transferred to a PDP 11/03 computer for later analyses. During calibration and the tracking task the subject rested his or her head against a goggle frame and viewed a television display at a distance of 90 cm. At this distance, one character position on the screen subtended .33° of visual angle. Calibration was accomplished by having the subject fixate each of 9 points in a rectangular grid on the television monitor. Calibrated output of the eye monitor was later mapped to screen positions with programs described in Kliegl and Olson (1981). The accuracy of the system has been determined to be within one character position (±.33°) on 90% of the fixations. A second set of programs reduced the 60-Hz eye-position data to fixations and moves. A change in eye position of .33° or greater resulted in the detection of a move and a new fixation.

Stimuli and Procedure

Pavlidis (1981a) used a horizontal row of five LED lights, each subtending 5′ of visual angle and with a separation between lights of 5°. The first light on the left was on for 2 sec; each of the next three lights was turned on successively for 1 sec; the rightmost light was displayed for 2 sec; and then the light positions were sequentially illuminated toward the left. Three continuous left-to-right-to-left cycles were completed. The positioning and timing of our point stimuli were identical to this procedure, but instead of using lights, a black "period" character subtending 5′ of visual angle was displayed against a white background. The point appeared in character positions 1, 15, 30, 45, and 60, the whole array subtending 20°. After calibration, the subjects were told that a point would appear on the screen and would move to different positions. They were instructed to fixate the point as accurately and quickly as possible.

Results and Discussion

The analyses are divided into two main sections. The first section reports tests for between-group variance on Pavlidis's (1981a) three major variables: number of saccades, percentage of regressions, and fixation stability. The second section explores possible sources of within-group variance on these variables.

Between-Group Analyses

To provide a more fine-grained analysis than previous studies of eye movements in this task, saccades larger than 2.5° and those less than 2.5° were totaled separately for each subject. This provided a separation of large saccades, which spanned most of the distance between points from smaller saccades that may have been corrective. Also, the saccades on each left-to-right sweep, starting with the offset of the leftmost light, were totaled separately from each right-to-left sweep, starting with the offset of the right stimulus. The saccades were further divided into progressive movements, which followed the direction of the stimulus, and regressive movements, which went against the prevailing direction. The mean number of saccades for each of these divisions is displayed for normal and dyslexic readers in Table 2.

Twenty-four one-way analysis of variance (ANOVA) comparisons between dyslexic and normal readers were based on the number of large progressive saccades, the number of small progressive saccades, the number of large regressive saccades, and the number of small regressive saccades within each of the six left-to-right and right-to-left series of stimulus movements (see Table 2). Only one of these comparisons was significant. (The dyslexic readers made more large progressive saccades in the second left-to-right series: 3.82 vs. 3.36; $F[1, 68] = 4.77$, $p = .03$.) Given the large number of independent comparisons, a significant result would be expected by chance. None of the subsequent analyses based on averages across saccade size and direction showed any significant differences between dyslexic and normal readers for either the complete or

Table 2
Mean Number of Tracking Eye Movements Per Series

		Large progressive moves		Small progressive moves		Large regressive moves		Small regressive moves		Total moves	
Direction	Series	D	N	D	N	D	N	D	N	D	N
Left to right	1	3.7	3.6	3.1	3.2	12	.22	1.6	2.2	8.6	9.2
	2	3.8	3.4	3.9	3.7	.15	.11	1.9	1.8	9.8	9.0
	3	3.6	3.3	4.1	4.2	.15	.14	1.8	1.9	9.8	9.6
Right to left	1	3.7	3.4	3.5	4.1	.15	.08	1.9	1.8	9.2	9.4
	2	3.7	3.3	3.7	4.2	.15	.14	1.8	1.8	9.4	9.4
	3	3.4	3.3	3.5	3.9	.0	.0	1.8	2.0	8.7	9.1

Note. D = dyslexic; N = normal.

selected samples. Now we evaluate the data for each of the three major contrasts presented by Pavlidis (1981a).

Number of saccades. Pavlidis's (1981a) first point was that his dyslexic readers made many more saccades, and he reported mean data from each group for one left-to-right series of stimulus movements. The right column of Table 2 shows that in the present study, it does not matter which series is used for this test: None of the series shows a significant difference between dyslexic and normal readers. The same is true for the averages of the three left-to-right series, the three right-to-left series, and all runs combined (see Table 2). The significance level for the difference in total number of saccades between the groups was $F(1, 68) = .006$, $p = .93$. Although the two groups could hardly have been more similar in total number of saccades, there was considerable individual variance within the groups. The distribution was normal with a range of 29 to 83 saccades for all six series and a standard deviation of 11.6. However, our dyslexics' performances did not overlap with those reported by Pavlidis. For one series from left to right, his dyslexics averaged 26 saccades with a range from 19 to 34 (estimated from Pavlidis's, 1981a, Figure 4). Across all series our dyslexics averaged 9.24 saccades with a range from 4.8 to 13.8. In the within-group Results section we systematically explore the sources of this individual variance.

Percentage of regressive saccades. Pavlidis's (1981a) second major point was that his dyslexic readers had a significantly higher proportion of regressive saccades (35% vs. 12%). Regressive saccades are defined here as eye movements that went against the prevailing direction of the stimulus. Separate analyses were performed for group differences in large forward saccades (normal = 38%; dyslexic = 41%; $F[1, 68] = 2.15$, $p > .05$), small forward saccades (normal = 41%; dyslexic = 39%; $F[1, 68] = 1.30$, $p > .05$), large regressive saccades (normal = .14%; dyslexic = .14%; $F[1, 68] = .001$, $p > .05$), and small regressive saccades (normal = 20%; disabled = 19%; $F[1, 68] = .31$, $p > .05$). It is clear that our dyslexic and normal readers did not differ significantly in their percentage of regressive saccades.

Stability of fixations. Pavlidis's (1981a) third point, elaborated on in a subsequent article (Pavlidis, 1983), was that dyslexic readers had a more difficult time holding their fixation on the lights. We evaluated this by obtaining the mean duration of first fixations on all the stimuli for each subject.[3] Normal and dyslexic readers averaged 476 msec and 531 msec, respectively, $F(1, 68) = 1.45$, $p > .05$. Not only was this difference not significant but the trend was opposite that reported by Pavlidis. Thus, we have no support for Pavlidis's hypothesis of an attentional deficit associated with instability of fixations in dyslexic readers.

No support was found for dyslexic–normal group differences in number of eye move-

[3] The means for the duration of first fixation on a stimulus and eye-movement latency to a stimulus move were based only on events during which the eye fixation stimulus position $n - 1$ while the stimulus moved to position n. This criterion was used to avoid inclusion of anticipatory moves.

ments, percentage of regressions, or stability of fixations in the tracking task. However, there were substantial individual differences in tracking eye movements within both the dyslexic and normal groups. The following section evaluates potential sources of this individual variability in tracking eye movements. We begin with an evaluation of Pavlidis's claim that only the above-normal-IQ dyslexics show abnormal eye movements, whereas lower IQ dyslexics ("backward readers") are similar to normal readers.

Sources of Within-Group Variance

IQ. The dyslexic readers ranged in IQ from 90 to 121 full scale on the WISC–R. The group was evenly divided above and below an IQ of 100. Pavlidis's (1981a) 12 dyslexic readers were described as being "above normal intelligence," but no means or standard deviations were presented, and the particular test used to measure intelligence was not cited. Pavlidis argued that only dyslexics with "above normal" intelligence (and who fit the other usual exclusionary criteria) demonstrate abnormal tracking eye movements. This led us to believe that half of our dyslexic subjects, who had IQs between 90 and 100, would be defined by Pavlidis as "backward" readers. Given the extreme differences reported by Pavlidis, the half of our dyslexic readers above an IQ of 100 should have contributed to a significant group difference in eye movements. Perhaps the point is moot, since in a new publication describing his (1981a) subjects, Pavlidis described the IQ selection criteria as "performance or verbal IQ at least of an average level (90 or above)" (Pavlidis, 1983, p. 452). This is identical to our selection criteria.

The most straightforward test of IQ effects within the disabled group is to correlate IQ with the various measures of tracking eye movements. As can be seen in Table 3, none of these correlations even approach significance. Thus, there is no support for Pavlidis's reported tracking eye-movement differences between below-normal-IQ "backward" readers and above-normal-IQ dyslexics, at least within the 90-to-121 IQ range.

After IQ, the next subject variable that seemed to offer a potential explanation of the within-group variance was age. However, as shown in Table 3, none of the eye-movement measures was significantly correlated with age in either group. This led to an exploration of the correlations between certain eye-movement parameters that might explain the within-group variance. First, we examine the correlations between eye-movement parameters in the tracking task. Second, we test the hypothesis that individuals vary in their general oculomotor efficiency by correlating eye movements in tracking and reading tasks.

Correlations between eye-movement measures in tracking. One hypothesis about the basis for individual differences in number of saccades is that children vary in how aggressively they approach the tracking task. Those children who tried to move their eyes very rapidly to the new stimulus position or even anticipate the new position by programming an eye movement before the stimulus moved may have had to make more corrective saccades when reaching the target area than children who took more time to program their saccade. A similar explanation has been proposed by Stark, Vossius, and Young (1962) to account for differences in normal adult tracking eye movements. This hypothesis was rejected for the dyslexic readers because the correlation between saccadic latency and number of saccades was opposite the predicted direction. Mean saccadic latency was positively correlated with number of saccades ($r = .32$, $p < .05$). This correlation was also reflected in the interdependent correlations of mean latency with a percentage of long saccades ($r = -.36$, $p < .05$) and a percentage of short saccades ($r = .41$, $p < .05$). Apparently, dyslexic readers who tended to have longer saccadic latencies had proportionately fewer long saccades, proportionately more short saccades, and a greater total number of saccades. This pattern certainly does not fit our hypothesis that quick eye movements result in more corrective saccades in the target area.

An alternative explanation is that there are individual differences in oculomotor efficiency wherein subjects who require a longer time to program and initiate an eye movement are also less accurate and steady in their fixations, leading to a larger percentage of short saccades. This seems to be a plausible explanation for at least some of the disabled readers' variance in number of saccades, but the normal readers showed no significant correlations of saccadic latency with the number or proportion of saccade types. The following section explores the possibility that there are individual differences in oculomotor control for both dyslexic and normal readers that are not specific to strategy differences in the tracking task.

Correlations between reading and tracking eye movements. The present subjects' eye movements were also monitored in a separate study while they read paragraphs adjusted for their word-recognition level. These procedures are described in Kliegl (1982), Olson et al. (1983), and Kliegl et al. (Note 1). Eye movements in the tracking task were compared with those in the reading task to see if they would display similar individual differences. Before discussing these correlations, we should mention that the frequently reported group differences of longer fixations, more saccades, and proportionately more regressions in reading were also found for dyslexics in the present study. The pattern of results was similar to that reported for different groups of dyslexic and normal subjects (Olson et al., 1983).

Two eye-movement parameters in text that had been correlated with linguistic variables in a previous study (Kliegl et al., Note 1), the percentage of regressions and the percentage of word skipping, were compared with eye-movement variables in the tracking task. These variables were tested for their correlations with mean duration of first fixation, mean saccadic latency, number of saccades, and the percentages of the four types of eye movements in Table 2. Including the IQ and age variables discussed earlier, the matrix yielded 28 possible correlations for each group. Table 3 presents all of the correlations except for those with the percentage of long and short regressions in tracking, since none of these were significant, perhaps because of their relative infrequency (20% of all saccades).

Because of the large number of correlations (28 for each group), two or three would probably be significant at the .05 level by chance. Therefore, we concentrate on those correlations that were significant in both groups. The probability of both paired correlations being significant by chance is low ($p < .01$).

The reading eye-movement variable that related systematically to the tracking eye movements in both groups was the percentage of regressions in text. Subjects who had long durations for their first fixations on the tracking stimuli tended to have a lower percentage of regressions in reading. This result is consistent with a general stability parameter in an individual's eye movements. A lack of stability in fixations would naturally lead to shorter fixations on the tracking stimuli and more regressive movements in text. The correlation between saccadic latency in tracking and the percentage of regressions in text (significant only for dyslexics) is also consistent with the rationale in the previous section that longer latencies to make an eye movement are associated with a general oculomotor inefficiency. Further converging evidence is present in the correlation of the percentage of regressions in text with the interdependent tracking variables of long and short saccades. A smaller

Table 3
Correlations Between Tracking and Extratask Variables

Variable	Subject group	Fixation duration	Saccadic latency	Number of saccades	% long saccades	% short saccades
Age	D	−.25	−.04	.19	−.21	.16
	N	−.04	−.24	.04	.04	−.13
IQ	D	.09	−.14	.07	−.13	.11
	N	.24	.08	.01	−.01	−.18
% regressive	D	−.43*	.40*	.27	−.35*	.21
	N	−.36*	.17	.28	−.49**	.41*
% skipping	D	−.18	.06	.09	−.18	.07
	N	.45*	.59**	.05	.00	−.07

Note. Percentage of regression and the percentage of skipping were obtained from reading paragraphs. D = dyslexic; N = normal.
* $p < .05$. ** $p < .01$.

percentage of long saccades and a higher percentage of short saccades (significant only for normals) was associated with more regressions in text. The shift toward more short saccades in tracking would result from unstable fixations and the need for more corrective saccades.

It is tempting to try to interpret the normal readers' correlations between tracking variables and the percentage of word skipping in text. Normal readers skip words more often than dyslexics, and this may partly account for the difference between groups in the size of the correlations. These correlations need to be replicated before any serious attempt at explanation.

A general oculomotor efficiency hypothesis seems to be reasonably well supported by the correlations between the percentage of regressions in text and eye movement parameters in the tracking task, although replication and extension of these results is needed. Other studies have noted individual variability in fixation accuracy and stability (Steinman, Haddad, Skavenski, & Wyman, 1973), but to our knowledge, this variability has not been previously related to eye movements in reading or other tasks. Data are presently being collected in our laboratory that will allow comparison of subjects' eye movements in a variety of tracking, reading, and picture-viewing tasks. Our interest in an oculomotor efficiency factor is spurred on by the fact that eye movements in text were systematically related to linguistic skills, whereas eye movements in the tracking task were not. Therefore, some of the variance in the percentage of regressions in text that is not related to linguistic skills must be related to the oculomotor efficiency factor. Controlling for or removing variance associated with oculomotor efficiency may further clarify the relation between linguistic skills and reading eye movements in dyslexic and normal readers.

General Discussion and Conclusions

In the theoretical controversy between the visual and verbal deficit approaches to dyslexia, the results of the present study argue against a visual deficit associated with abnormal eye movements. Of course, this study does not exclude the possibility that oculomotor differences between dyslexic and normal readers could be found in some other task, but it does directly counter the strongest and most recent claim made for differences between dyslexic and normal tracking eye movements (Pavlidis, 1981a).

The question remains why the present results are inconsistent with those reported by Pavlidis (1981a). Pavlidis (in press) has countered other failures to find tracking differences between dyslexic and normal readers (Brown et al., in press; Stanley et al., in press) by insisting that an exact replication of his methods is critical. The present study was a replication of all the critical methodological elements cited by Pavlidis (in press), yet there was no significant difference in total number of fixations, the percentage of regressions, or stability of fixations between dyslexic and normal readers.

Our failure to replicate Pavlidis's results also cannot be attributed to differences in the stated selection criteria for dyslexic readers. Pavlidis's (1981a), selection criteria were as follows:

> The twelve 10–16-yr.-old dyslexics tested were of above average intelligence, they were from a middle class background, they did not have any overt physical or emotional handicaps, had good vision and hearing, were motivated to learn to read, but were nonetheless at least two years retarded in reading. (p. 59)

These are the traditional exclusionary criteria for selecting dyslexics, and they were also used in the present study. There may have been a difference in mean IQ between our two groups of dyslexics, but this cannot be evaluated because Pavlidis presented no data on this variable beyond the statement in the selection criteria, and the additional statement in Pavlidis (1983) quoted earlier. Even if there were IQ differences between our two samples, the results of the present study show that the dyslexics' IQ was unrelated to their tracking eye movements. This not only contradicts Pavlidis's report of a tracking eye-movement difference between below-normal-IQ "backward" readers and above-normal-IQ dyslexic readers but also allows us to rule out any obvious difference in subject selection criteria as responsible for our failure to replicate.

We are left with assuming that there are different types of dyslexic readers, and either by sampling error or unstated selection criteria, the two studies ended up with different subgroups. The case studies cited earlier reported a few dyslexics who had grossly abnormal eye movements. Pirrozolo and Rayner (1978) contrasted one such subject with another dyslexic whose eye movements were relatively normal. In addition, it has been argued that dyslexics may be subdivided into dyseidetic and dysphonetic subtypes (Boder, 1973). The dyseidetics are reputed to have difficulty with visual processing (indicated by a relatively low WISC–R performance IQ) and memory for words, whereas the dysphonetics have problems with language (indicated by a relatively low WISC–R verbal IQ). Stanley et al. (in press) have suggested that the visual dyseidetic type might demonstrate the eye-movement-control problems descibed by Pavlidis. However, the present study provides no support for this hypothesis. Our 141 dyslexic readers revealed substantial within-group differences in patterns of linguistic skill that related to eye movements in reading, but there was no relation between the performance component of the WISC–R and eye movements in tracking or reading.

The final answer must be that Pavlidis (1981a) selected 12 dyslexics of the type described in case studies, but it seems unlikely that this would have happened by random sampling in the dyslexic population, given the stated selection criteria. This is because grossly abnormal oculomotor cases are extremely rare in the dyslexic population. Our program project sample contained 141 dyslexics between 8 and 16 years of age, which was a nearly exhaustive sample of such readers in the Boulder area. Although only a subset was tested in the tracking task, the other subjects were observed during calibration, which involved successive fixations in a 9-point grid. None of the subjects demonstrated the extremely erratic patterns described by Pavlidis or the case studies. Combining these 141 dyslexics with 15 dyslexics (possibly excluding one subject) reported by Stanley et al. (in press) and 33 studied by Brown et al. (in press), it appears that the incidence of gross oculomotor deficits in dyslexics is less than 1%. Thus, there is little support for Pavlidis's contention that tracking eye movements hold the "key to dyslexia."

A possible reason for Pavlidis's (1981a) unusual sample of dyslexics was suggested by Pollatsek (1983, p. 512):

> Pavlidis has been written up in national newspapers in Great Britain and has appeared on television. These reports have emphasized his expertise in diagnosing eye movement problems. Thus, people with severe reading retardation who appear to have no language or cognitive deficits and/or have reason to believe that they have eye control problems would tend to seek him out.

(Pavlidis's dyslexics were British.) We can think of no similar biasing factor in our dyslexic sample that would have led to the exclusion of erratic oculomotor cases.

In conclusion, most research on dyslexia has pointed away from visual deficits and toward linguistic deficits as causal factors for both between-group and within-group differences in reading processes. A similar approach to understanding the role of eye movements in dyslexia is supported by the present results. Although group and individual differences in reading eye movements were associated with reading ability and other measures of linguistic skill, no such relation was found with tracking eye movements. However, the correlations found between eye-movement parameters in tracking and reading indicated that there were significant individual differences in general oculomotor efficiency in both reading and tracking tasks that were unrelated to linguistic and reading skills.

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