

# Saccadic tracking skills of poor readers in high school

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## KEYWORDS

Saccadic tracking;  
Oculomotor function;  
Reading;  
Developmental Eye  
Movement test

## Abstract

**BACKGROUND:** Oculomotor control has been implicated as a factor when reading is poor, but few studies exist for adolescents.

**METHODS:** The saccadic eye movement efficiency of 684 ninth grade students, identified as poor readers in 5 California high schools, was quantified using the Developmental Eye Movement test. Frequency distributions were produced from scores on vertical and horizontal components, and gender and test-retest factors were considered during analysis.

**RESULTS:** Vertical times were within 1 standard deviation of normal for eighth grade. However, horizontal (saccadic) times were typical of grade 3, and the average number of errors on the horizontal test was typical of grade 2. Boys and girls performed similarly. Results of retests showed slightly improved horizontal times and fewer errors, but the grade level equivalents remained dramatically low. Overall, fewer than 10% of students scored above the 50th percentile for eighth grade.

**CONCLUSION:** The results indicate that poor readers in high school may be at high risk for poor saccadic tracking skill.

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Oculomotor dysfunction can occur in children with learning problems.<sup>1</sup> Not only are eye movements of dyslexic readers different from those of nondyslexic readers,<sup>2</sup> but differences in duration of fixation, length of saccades, and number of regressions have been documented between good and poor readers who are not dyslexic.<sup>3</sup> A review published in 1996 examined the interrelationship between oculomotor function and academic performance, concluding that poor oculomotor control might be predictive of poor academic achievement.<sup>4</sup>

If poor readers tend to have poor eye movement control, and if the ability to move the eyes quickly and accurately across a horizontal line of text must be learned,<sup>5</sup> then it becomes important to be able to identify children with poor

eye movements easily and quickly so that intervention can be offered to affected individuals.

In 1990, Garzia et al.<sup>6</sup> developed a test of saccadic tracking function called the Developmental Eye Movement test (DEM). The test compares the time and accuracy of an automatic naming process when integers are read from a set of evenly spaced vertical columns with the time and accuracy of naming when the same sequence of integers is read from unevenly spaced horizontal rows, as if in a line of text. To the extent that the time required to read the horizontal array is similar to that required to read the vertical array, reading-related eye movements are well developed.

Because the only difference between the horizontal and vertical arrays is their spatial arrangement, any difference in time taken to read the horizontal array compared with the vertical array must be caused by either immature or impaired horizontal saccadic skill. The DEM is simple to administer and generally requires only a few minutes to complete.

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Developmental norms for the DEM are available by both age (from 5 through 13 years) and grade level (from U.S. school grades kindergarten through eighth).<sup>7</sup> By age 13, or eighth grade, horizontal eye movement accuracy and speed on the DEM approaches vertical eye movement accuracy and speed, yielding a ratio of horizontal-to-vertical processing times that is close to 1.0.<sup>7</sup> A recent study has found that older adults (mean age 72.9 years) also have ratios of horizontal-to-vertical times close to 1.0 and that their times are similar to those of adults of middle age on a similar test.<sup>8</sup> Thus, when reading eye movements are not impaired, it is probably safe to assume that the ratio of horizontal-to-vertical times should approach 1.0 for all ages after about 13 years. Before age 13, or eighth grade, horizontal times are slower than vertical times, producing a higher ratio score<sup>7</sup> because of developmental factors. Younger subjects also tend to make more errors.

One purpose of the DEM is to help practitioners determine whether poor saccadic tracking might contribute to poor reading behavior in their young patients or students.<sup>6</sup> It does so by factoring out the rapid automated naming component of reading in calculating the DEM ratio score. Thus, if a 10-year-old student, in fifth grade, has a DEM ratio corresponding to that of a student in third grade (typical of a child 2 years younger) and his reading is poor, the result indicates that poor saccadic control may be a factor.

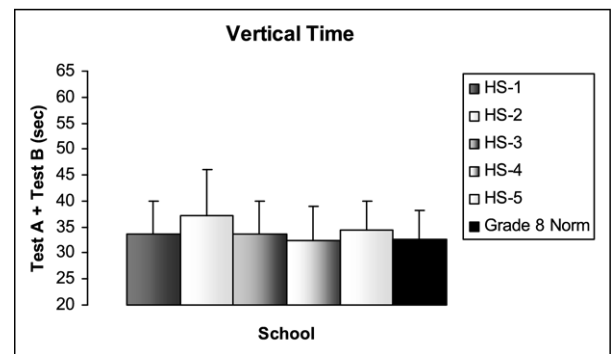
To our knowledge, no study has yet examined DEM performance of adolescents with reading grade levels lower than expected for their chronological ages. For such students, especially in higher grades, poor reading may be caused by a wide variety of factors, of which poor saccadic tracking is only one.

In this study, we administered the DEM to high school students who were outside the age range for the test (average, 15.5 years) but within the grade level range in reading ability (average reading grade level 3.0, according to school records). We asked whether a significant proportion of these “older” students who read poorly would also have relatively poor horizontal saccadic eye movements. As in our previous report<sup>9</sup> we present frequency distributions as well as average data, to allow the reader to appreciate the diversity of scores and the effect of criterion selection on determining how many subjects would be considered “normal.”

**Table 1** Number of poor readers by gender

School	Number tested	Male (%)	Female (%)
HS-1	156	91 (58)	65 (42)
HS-2	209	122 (58)	87 (42)
HS-3	171	113 (66)	58 (34)
HS-4	45	29 (64)	16 (36)
HS-5	103	67 (65)	36 (35)
Total	684	422 (62)	262 (38)

Note: The samples contained significantly more boys than girls ( $P < 0.003$ , 2-sample t-test).



**Figure 1** Mean vertical time (test A + test B, in seconds) on the DEM administered to poor readers in 5 high schools (HS-1, HS-2, HS-3, HS-4, HS-5). Grade 8 norm is indicated on the far right. Bars  $\pm$  1 SD.

## Methods

### Students

The DEM was administered to a total of 684 students (average age, 15.5 years) in 5 California high schools (see Table 1), as part of a larger vision and visual skills battery.<sup>9</sup> For 1 school (HS-5), no additional data were gathered beyond the DEM. Characteristics of the population from which the sample was drawn can be found in Grisham et al.<sup>9</sup>; however, with the addition of HS-5, some characteristics differed slightly from the previous report and are therefore reported here.

All schools were part of the East Side Union High School District in San Jose, California. The total number of students enrolled in the 5 schools was 9,703 (average per school, 1,941); thus, the DEM sample size was 7%. All but 1 school (HS-3) received Title I funds, and the percentage of students receiving free or reduced lunch ranged from 19.1% to 37.8%. The proportion of English language learners was 13.2% to 33.6%. Ethnicity varied from school to school; the largest proportion of students at every school was Hispanic (39.6% to 65.6%), followed by Asian (9.1% to 36.3%), white (2.2% to 16.9%), Filipino (4.8% to 12.2%), and African American (2.9% to 5.3%). At these 5 schools, less than 1% of students qualified for admission to the University of California (UC) system upon graduation, and average SAT scores for seniors ranged from 888 to 930. In the district as a whole, 36.4% qualified for admission to UC, and the average SAT was 1009. The basis for referral of students for assessment was poor reading performance, which was determined by the school and defined as reading 2 grade levels or more below grade level.

### Procedure

Except for HS-5, the DEM was administered at 1 station of a larger set, where visual acuity and visual skills (e.g., convergence and divergence ranges and accommodative facility) were being measured as well.<sup>9</sup> An author, a doctor, or a trained assistant administered the DEM.

**Table 2** Mean and SD times (seconds) to complete subtests of the DEM

School	N	Test A + Test B	SD	Errors A+B	SD	Test C	SD	Errors C	SD	DEM ratio	SD
HS-1	156	33.62	6.28	0.20	0.50	50.16	11.54	3.92	2.37	1.51	0.31
HS-2	209	37.17	8.91	0.17	0.76	56.32	15.60	5.27	3.02	1.53	0.32
HS-3	171	33.68	6.23	0.29	0.84	49.79	15.41	4.34	2.68	1.49	0.43
HS-4	45	32.31	6.54	0.04	0.21	50.89	14.51	4.93	2.26	1.59	0.46
HS-5	103	34.48	5.54	0.16	0.50	53.36	13.06	5.86	3.54	1.56	0.36
Mean		34.25	6.70	0.17	0.56	52.10	14.02	4.86	2.77	1.54	0.38
DEM norm	38	32.56	5.66			35.33	6.90	0.94	1.47	1.09	0.14
<i>P</i> value ( <i>z</i> )		0.252				<0.001		<0.001		<0.001	

Note: The average times and SDs for students is given by school, with males and females combined. Test A + test B is the sum of times for both vertical tests. Test C times have been adjusted for errors.<sup>7</sup> "Errors" refers to total errors of all types (o + a + s + t). Ratio is the time (A+B)/time (adjusted C). DEM norm values are from the norm tables for eighth grade.<sup>7</sup> Z-tests compared school means with DEM norm values for mean and SD. Note that no average number of errors is specified as a norm for tests A and B. Values are shown to indicate the much lower error rate for vertical versus horizontal tracking performance.

The subject was seated across a table from the tester and given test A of the DEM (the first of 2 vertical tests). The tester held a stopwatch and pencil and had a score sheet upon which to record times and errors. The student was instructed to read the numbers aloud as rapidly as possible, but without making mistakes and without stopping at the bottom of the column, and to look up when finished. Errors of omission, addition, substitution, and transposition were recorded as the student read. When the student finished test A, the tester recorded the time and errors and presented the student with test B (the second of 2 vertical tests). The student was again instructed to read rapidly without errors, and the scores were again recorded. Test C (the horizontal saccadic test) was presented and the tester pointed to the top row to illustrate that the task for this test was different; the student was to read across the page rather than down but still as rapidly and accurately as possible. The time and errors for test C were recorded.

DEM administration took approximately 5 minutes per student. Students were allowed to read the test integers in their native language when testers were fluent in those languages, under the assumption that rapid automated naming should be optimal in one's native language.

DEM ratios were calculated according to the published formula,<sup>7</sup> which adjusts the times for omitted or added

integers. The norms for eighth grade were used as standards for comparison in this study. Z-tests were used when comparing study values to published norms, and t-tests were used to compare performance between groups or conditions (male/female and test/retest).

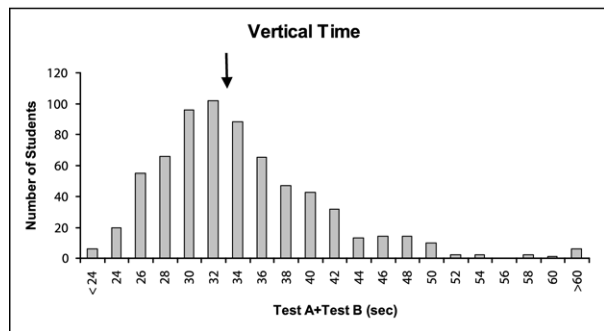
**Results**

**Gender distribution**

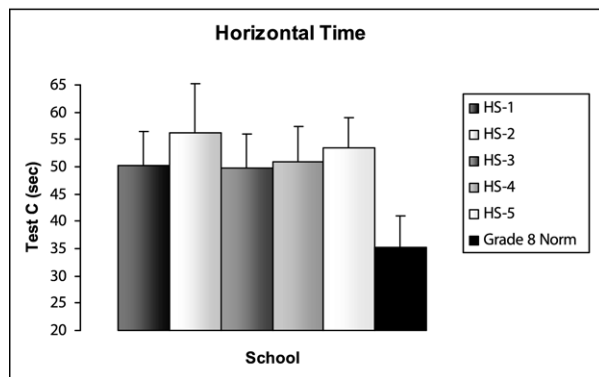
Significantly more boys than girls were identified as poor readers by their schools: 62% of those tested were boys and 38% were girls (*P* < 0.003, 2-tailed paired t-test of percentages by school; see Table 1). These percentages are nearly identical to a previous report on visual skills in HS-1, HS-2, HS-3, and HS-4,<sup>9</sup> thus underscoring the observation that more boys than girls are identified as having reading problems by their teachers.

**Vertical tests A and B**

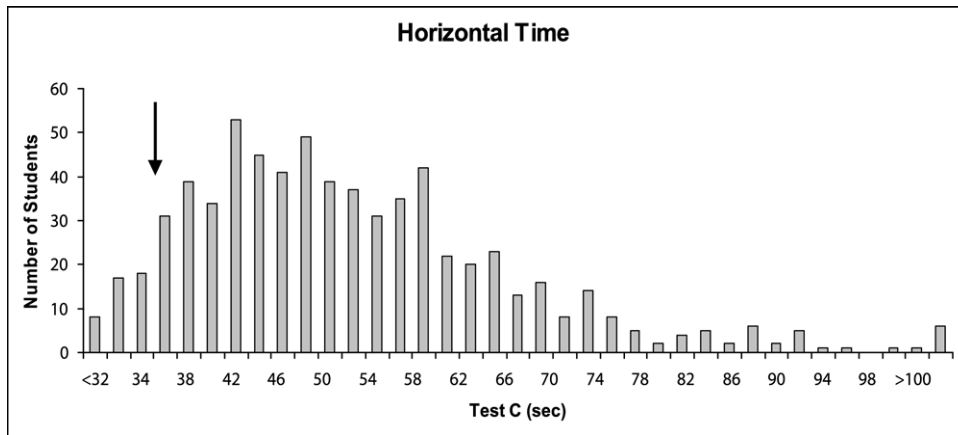
Vertical times did not differ from published norms for eighth grade. Figure 1 shows average data from each school,



**Figure 2** Frequency histogram of vertical times (test A + test B, in seconds) for poor readers in high school, by student (data combined across all schools). Arrow indicates norm for eighth grade.<sup>7</sup>



**Figure 3** Mean horizontal time (adjusted test C, in seconds) on the DEM administered to poor readers in high school. Grade 8 norm is indicated on the far right. Error bars ± 1 SD.



**Figure 4** Frequency histogram of horizontal times (adjusted test C, in seconds) for poor readers in high school, by student (data combined across all schools). Arrow shows norm for eighth grade.<sup>7</sup>

and Table 2 shows the statistics. The average vertical time across all schools was 34.25 seconds, which was not significantly different from the norm of 32.56 seconds ( $P = 0.252$ , z-test). The average number of errors on the vertical test was 0.17 (norms not available). Thus, the ability of the ninth grade subjects to decode and verbalize integers for oral reading was within expected values for eighth grade.

Because there were no significant differences among schools on this measure ( $\chi^2$  Goodness of Fit = 0.381,  $P = 0.984$ ), the individual scores can be represented in a frequency histogram, which allows consideration of the full distribution of times for all students. Frequency histograms illustrate the distribution of scores across the entire range of values rather than just the mean, and therefore give information as to how many students were at or below values predicted by the norms.

Figure 2 shows the frequency distribution of vertical times on the DEM. The norm for test A plus test B is indicated by the arrow. Even though the distribution is slightly skewed, only a little more than half of the cases are above this value, as would be expected because of the close match between subjects' times and the eighth grade norm.

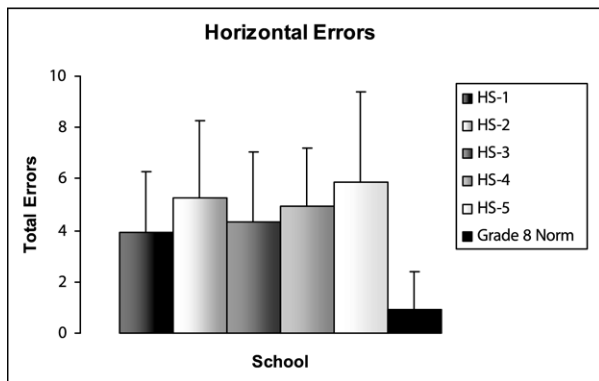
### Horizontal test C

Horizontal times were longer than published norms (see Figure 3 and Table 2), with the average time for poor readers of 52.10 seconds—nearly 50% longer than the norm of 35.33 seconds. The difference was highly significant ( $P < 0.001$ , z-test), but once again scores did not vary across schools ( $\chi^2$  Goodness of Fit = 0.575,  $P = 0.966$ ).

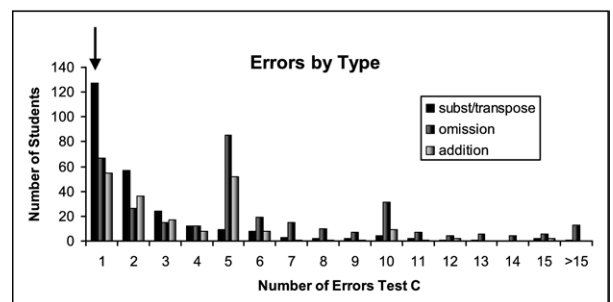
The frequency distribution of all horizontal test times shows that, in contrast to the vertical scores, most students took longer than the published norm to complete test C (see Figure 4). The eighth grade norm for test C is indicated by the arrow. Clearly the largest proportion of the population in this figure is to the right of the arrow, indicating longer than normal horizontal saccadic times for the majority of students.

Poor readers in high school also made significantly more errors than expected on the horizontal portion of the DEM, based on the norm for eighth grade (see Figure 5;  $P < 0.001$ , z-test; see also Table 2). Again, there were no significant differences among schools ( $\chi^2$  Goodness of Fit = 0.474,  $P = 0.976$ ).

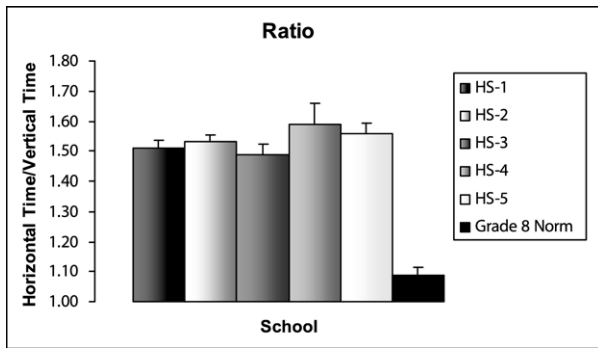
In Figure 6, the different types of errors are plotted separately to illustrate that their frequency distributions



**Figure 5** Mean number of errors on test C of the DEM administered to poor readers in high school. Dark bar = Grade 8 norm. Error bars  $\pm 1$  SD. Errors of all types were combined for this graph.



**Figure 6** Frequency distributions of errors on test C, by type. The norm for eighth grade is 0.94 errors (arrow), regardless of type. The peaks at 5 and 10 reflect either skipping (error of omission) or repeating (error of addition) an entire 5-integer line.



**Figure 7** Mean DEM ratios from poor readers in high school. Dark bar = grade 8 norm. Error bars  $\pm 1$  SD.

differ, in part because of the nature of the scoring procedures. For example, substitution and transposition errors have a very even distribution, with most students making 2 or fewer errors of these types. But omission and addition errors begin to fall off after 1 or 2 and then tend to have secondary peaks at 5 and 10. This reflects the fact that substitution and transposition errors only occur between 2 integers on the test, whereas omission and addition errors can occur with entire lines (containing 5 integers each).

**Ratio scores**

Because of the slower times and higher error rate on test C, students in this study had significantly higher DEM ratios than the eighth grade norm. Their overall average was 1.54 ( $P < 0.001$ , z-test; see Figure 7 and Table 2), which is typical of students in first to second grade.<sup>7</sup> Most of the students had ratios that were higher than 1.09 (see Figure 8), and horizontal error rates greater than 0.94 (see Figure 6), which are the norms for eighth grade students.<sup>7</sup> Thus, for most students in this sample, horizontal tracking skill was slower and less accurate than vertical tracking skill.

**Table 3** Average DEM scores with grade level equivalents

Test	HS poor readers	Norm tables grade 8	1 SD	% >1 SD	Grade equivalent poor readers
Vertical	34.25	32.56	5.66	21%	8.0
Horizontal	52.10	35.53	6.90	80%	3.2
Errors	4.86	0.94	1.47	59%	2.8
Ratio	1.54	1.09	0.14	81%	1.5

Note: Summary of results averaged over all schools, compared with norm values for grade 8.<sup>7</sup> The column labeled % >1 SD gives the percentage of students in the study who scored at or beyond 1 SD above the mean according to norms. Grade equivalent values were derived from data for other grade levels.<sup>7</sup>

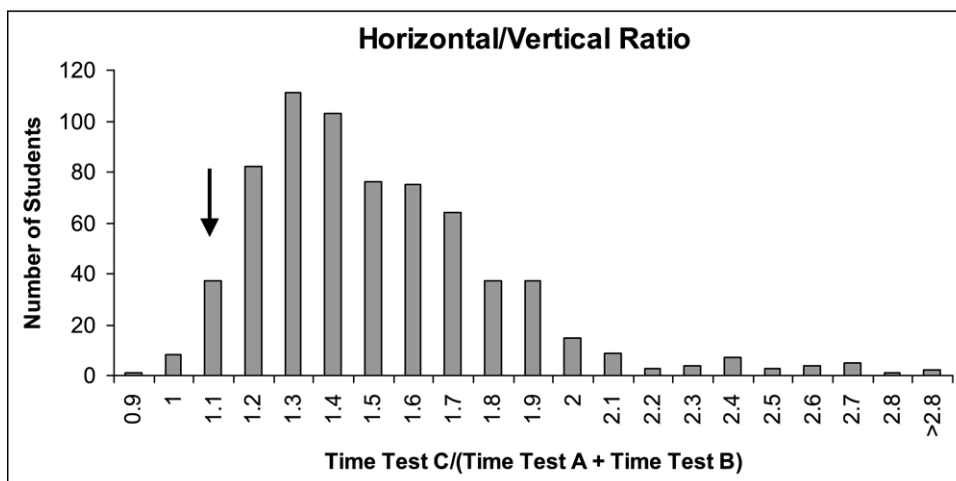
Table 3 summarizes the average results by comparison to the norms,<sup>7</sup> showing the percentage of students whose scores were greater than 1 standard deviation (SD) greater than expected and the grade level equivalent of the average scores. Although vertical times were typical of grade 8, all horizontal measures were typical of grade 3.2 or lower.

Figure 9 compares the percentile rank of the students in this study with those published in the norm tables for the DEM. In this group of struggling high school readers, fewer than 10% scored at the 50th percentile or higher. More than 80% of the students were at the 15th percentile or lower.

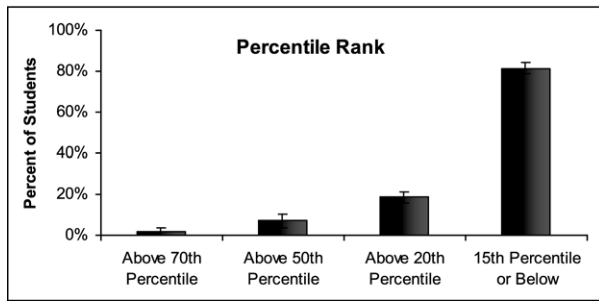
**Male-female differences and test-retest results**

Table 4 shows that although girls tended to be slightly slower on test C (horizontal) than boys, leading to a slightly higher ratio score, the differences were not statistically significant (2-tailed t-test,  $P > 0.05$  for all comparisons). Table 4 refers to the first administration of the DEM.

Twenty-three percent of students ( $N = 159$ ) at 4 of the 5 schools were retested immediately after the first administration of the DEM. This was not by design; some testers



**Figure 8** Frequency histogram of ratios on the DEM for poor readers in high school. Norm for eighth grade is 1.09,<sup>7</sup> indicated by the arrow.



**Figure 9** Percentage of the 684 students in this sample of poor high school readers whose ratios on the DEM were at various percentile ranks according to the norm tables for eighth grade.<sup>7</sup>

(typically aides at the school) felt they should allow students to try to improve their scores. Although only the first test administration was used in the analysis above, we examined the data from retests to see whether any interesting trends emerged. Table 5 shows that scores on the vertical tests (A and B) did not improve significantly on the second administration, but scores on the horizontal test (C) did improve by 8.6%, resulting in slightly better DEM ratios. Even with the improvement, however, ratios were still in the grade 1 to 2 range and errors in the grade 2 to 3 range.

### Discussion

Students in high school who are identified by their teachers as poor readers tend to have poor saccadic eye movements in the horizontal direction, as assessed by the DEM.<sup>7</sup> Moreover, these students make more errors than would be expected of eighth grade students, even though all of them have completed that grade. Although some improvement was noted upon retest, performance was still well below grade level. Because the vertical scores (and the number of errors in the vertical test) were normal, we conclude that the deficits observed in this study were not caused by an inability to decode and verbalize integers from printed text.<sup>6</sup> In fact, the students in this study had rapid automated naming ability expected of their grade level and were significantly better than learning disabled (LD) students.<sup>6</sup> It thus appears unlikely that our subjects lacked the cognitive ability necessary to process information rapidly; instead,

the results support the hypothesis that, on average, poor readers in high school tend to have poor saccadic tracking skills.

### Learning disability?

Garzia et al.<sup>6</sup> published results of the DEM administration to 60 students, ages 8 to 13 years, who had been identified as LD. They noted that the LD sample “had more difficulty with all aspects of the DEM” than their counterparts in the normative sample. The poor readers in the current study were not identified as LD by their teachers, and they had difficulty *only* with the horizontal subtest. Comparison of values for our sample to those of the LD sample at age 13 shows that although our poor readers took 1.69 seconds longer to complete the vertical test, the LD students took 10.44 seconds longer. In contrast, for the horizontal measurements, the times for poor readers and the LD sample were rather close in value (16.77 for poor readers vs. 14.67 for LD). As a result, the average ratio score of the LD students (1.18) was typical of the norms for those in grade 5 or 6, which was considerably better than the ratio of the poor readers in this study.

Thus, the DEM, as a diagnostic instrument, has the potential to differentiate between students with an identified learning disorder and students who simply lack adequate saccadic control of their eyes. The broader implication is that many students who read poorly in high school do not have a learning disorder but a dysfunction that in most cases is easily remedied.

### Age

The DEM norms were developed only through the eighth grade (age 13 years), yet the typical grade level of the students in this study was 9, and the average age was 15.5 years. An “adult” version of the DEM was published after this study was completed (A-DEM),<sup>10</sup> and it could be argued that the A-DEM would be more appropriate for this age group. However, based on the results we report, a counter argument could be made that the original test is more appropriate when reading is poor. The scores for the groups we studied were so poor on the original DEM that the more challenging A-DEM might have proven too diffi-

**Table 4** DEM performance by gender

Statistic	Test A + Test B (sec)		Adjusted C (sec)		Errors (all types)		Ratio (Adj C/A+B)	
	Male	Female	Male	Female	Male	Female	Male	Female
Mean	34.03	34.44	50.72	54.38	4.53	5.37	1.50	1.60
Standard error	0.65	1.57	1.20	1.59	0.41	0.61	0.02	0.05
t-test <i>P</i> values	0.798		0.073		0.236		0.068	

Note: Mean for all tests by school, separated according to gender. Two-tailed t-tests were performed on male compared with female data across schools. None of the comparisons reached statistical significance; boys and girls performed similarly.

**Table 5** Comparison of DEM scores on test and retest; times are in seconds

	Time A+B	SD	Errors A+B	SD	Time C (adj)	SD	Errors C	SD	DEM Ratio	SD
First test	33.48	6.01	0.20	0.56	52.94	12.40	5.37	3.02	1.59	0.32
Retest	33.26	6.16	0.12	0.70	49.01	12.35	3.49	2.40	1.48	0.32
Difference	0.22	-0.15	0.14	-0.14	3.93	0.05	1.88	0.62	0.11	0.00
t-test <i>P</i> values	<i>0.276</i>		<i>0.550</i>		<i>&lt;0.001</i>		<i>&lt;0.05</i>		<i>&lt;0.001</i>	

Note: Times on the horizontal test improved slightly on retest. Mean and SD of times in seconds (tests A+B, adjusted C) and number of errors for students who were administered the DEM twice, with *P* values in italics. Number of students was 159 (108 boys, 51 girls), from all schools except HS-4.

cult. A recent study that compared older adults on both the DEM and the A-DEM found no significant differences; the average ratio for horizontal-to-vertical times was nearly 1.0 for older subjects regardless of the test used.<sup>8</sup> Thus, we believe the measurements reported here using the DEM are valid.

### Grade level

The grade level equivalent for the average score on test C was 3.2, according to the DEM norm tables.<sup>7</sup> This grade level is similar to that reported to us by the school as the average reading level of the students who were referred for assessment. For students in the ninth grade, this represents a saccadic and reading deficit of nearly 5 grade levels. If part of that deficit is caused by visual skills such as saccadic tracking, convergence, and accommodative facility,<sup>9</sup> and those visual skills can be improved by optometric therapy, then students' reading should improve after such treatment. This possibility is consistent with existing literature<sup>11-13</sup> and remains to be tested with new technology for delivering optometric training in schools.<sup>14</sup>

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