Article

Eye Movement Patterns in Dyslexic Children

R.D. Elterman, MD, L.A. Abel, PhD, R.B. Daroff, MD, L.F. Dell'Osso, PhD, and J.L. Bornstein, MEd

In this study we recorded eye movements during reading tasks for five dyslexic children and two controls. The subjects had vertical as well as horizontal eye position monitored with an infrared recording technique and performed a symbol-simulated reading task. We demonstrated the importance of both the symbol simulation and the vertical monitoring in evaluating the eye-movement patterns in dyslexics. Without the symbols, motor and comprehension defects cannot be distinguished. Without vertical eye position information, the horizontal eye-movement pattern is not properly interpretable.

The nature of the eye movements in children with developmental dyslexia is controversial. A recent study by Adler-Grinberg and Stark (1978) established clearly that these children make normal, rapid, refixational (saccadic) eye movements as they attempt to fixate on meaningless targets suddenly displaced in the visual field. However, the situation during an actual reading task is usually different. Although some dyslexics display a normal eye-movement reading pattern of repetitive rightward refixational saccades (as the eyes move from the beginning to the end of a line) followed by a large leftward saccade (return sweep) back to the beginning of the next line, most reports have stressed an increased number of fixations, longer pauses between saccades, frequent regressions (leftward saccades on the same line), and abnormalities in the return sweep such as "reverse staircase" (multiple, small, leftward saccades rather than a single, large, return movement). Most investigators have concluded that the disturbed eye-movement pattern was secondary to a primary defect of impaired comprehension (Critchley 1964, Ciuffreda, Bahill, Kenyon, & Stark 1976), but others have either implicated a primary eye-movement abnormality as the cause of developmental dyslexia (Mosse & Daniels 1959, Zangwill & Blakemore 1972) or regarded it as a distinct possibility (Rubino & Minden 1973, Pirozzolo & Rayner 1978). A causal eye-movement disturbance is difficult to reconcile with the normal eye-movement pattern displayed by dyslexics during the visual search of pictorial stimuli (Adler-Grinberg & Stark 1978) as well as their impaired Morse code and Braille learning (Rudel, Denckla, & Spalten 1976). However, descriptions of readers "getting lost" on the page (Mosse & Daniels 1959) suggest a problem of ocular motor control or spatial confusion.

Those claiming a primary impairment of eye-movement control failed to have their dyslexic subjects simulate the reading situation by moving their eyes along a series of symbols. An ocular motor disturbance should manifest an impairment even in a symbol-simulation situation. Furthermore, previous studies of English language dyslexia reported measurements of only horizontal eye movements. Without knowledge of vertical eye position, it is impossible to determine the true position of the eyes.

This is a report of a preliminary study of dyslexic children analyzing symbol refixations as well as reading texts, with the eye movements recorded in both the horizontal plane and the vertical plane. We studied seven subjects: one normal adult reader (case 1), one normal 7-year-old reader (case 2), and five dyslexic children, all 7 years of age. All of the dyslexic children had developmental dyslexia (normal IQ and neurological examination), but two (cases 4 and 7) also had seizure disorders under good control with medication.

METHODS

Eye movements were recorded with infrared oculography (Young 1963) using direct-current amplification and electronic differentiation of the position signal to obtain peak velocities. Horizontal eye movements were measured from the right eye, and vertical movements were measured from the left. Vertical eye movement recordings with the infrared technique required modification of standard methods. The left lower lid was held down with tape. The diode assembly was angled toward the edge of the limbus, yielding a voltage proportional to vertical eye movement. In the vertical measuring mode of our infrared system, the outputs of the detectors were summed. Calibration was made between ± 10 degrees vertically. Symmetrical calibration for upward and downward gaze was difficult, but movements above primary position were of less concern during reading than those in a downward direction. Horizontal eye movements were calibrated in a usual fashion between fixation lights at ±5 degrees and 10 degrees.

Each subject was placed in a dental chair, and his head was stabilized with chin and head rests. Following calibration each subject performed four tasks: (1) symbol simulation consisting of reading a paragraph of five lines of *X*s (each line contained five *X*s, one and one-eighth inches apart; the lines were spaced one-half inch apart; (2) reading a paragraph from a school reader approximately one year below the student's reading level; (3) reading a paragraph from the student's current school reader; and (4) reading a paragraph from a school reader approximately one year above the student's current reading level. After each task general comprehension was established. Reading material was held 14 inches from the subject. The average paragraph was 4 inches by 4 inches, subtending an angle of 20 degrees by 20 degrees.

We did not perform a quantitative analysis of fixations, pauses, and regressions; instead we identified gross eye-movement reading patterns and will present those that are of interest.

CASE REPORTS

Case 1

A normal adult reader was used as a control for methodological standardization. The reading material

LEGEND FOR FIGURES

In the following figures, HOR indicates horizontal; VERT, vertical; pos, position of eyes; vel, velocity of eye movement; R, right; L, left; U, up; D, down; 10° refers to the position tracing, and 200° per second provides the scale for velocity measurements.

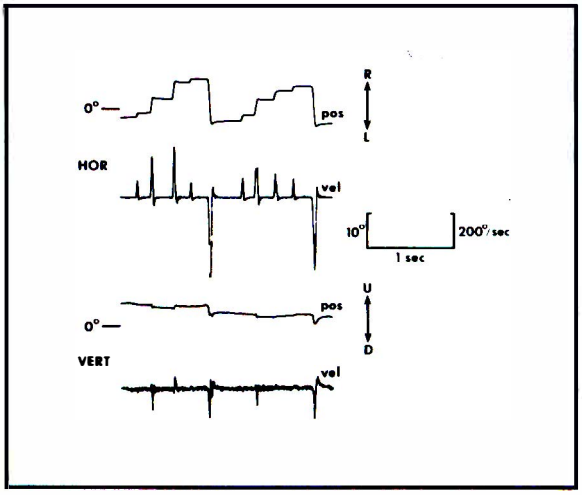

FIGURE 1. A normal reading pattern demonstrated by the adult control subject (case 1).

Looking at the horizontal tracing, the beginning of the line is slightly to the left of the straight-ahead position (0°). The eyes then make four movements (saccades) before reaching the end of the line. After each movement there is a fixation pause as the word or phrase is being read. The velocity tracing gives the speed of each movement. In general the larger the movement, the greater the velocity. When the end of the first line is reached, there is a large leftward saccade back to the beginning of the next line. There is then a pause before the eyes begin to move in a rightward direction across the next line. Looking at the vertical position channel, there is a small downward and then upward deflection that can be seen to be synchronous with two horizontal eye movements and represents electronic crosstalk and not an actual vertical deviation. The next vertical deflection is in the downward direction and occurs along with the leftward horizontal return of the eyes to the beginning of the next line. Following this there is another small artifactual crosstalk deflection before the next true downward eye movement occurring at the same time as the horizontal leftward deflection to the next line.

was considered below his current reading level. A typical portion of his reading pattern is shown in Figure 1, which displays a normal rightward staircase. The vertical monitor clearly demonstrated the downward deflection coincident with the leftward horizontal return sweep; the return sweep was therefore diagonal, since actual eye position can only be determined by summating the horizontal and vertical positions.

Case 2

A 7-year-old hyperactive boy considered to be a normal reader was studied, and his reading pattern and comprehension were indeed normal. He made an interesting movement that could not be properly interpreted without vertical monitoring (Figure 2): prior to starting a new line, he looked at the last word of the previous line. Without benefit of vertical eye position, this appropriate eye movement could have been interpreted as a refixation to the end of the same line followed by a return to the beginning of the same or the next line.

Case 3

This 7-year-old dyslexic boy had a relatively normal reading pattern despite poor comprehension. He occasionally had long pauses at the beginning of new lines before rightward reading movements were started (Figure 3). Such pauses were not present during the symbol simulation.

Case 4

This 7-year-old dyslexic boy had a history of seizures that were being controlled with phenobarbital (30mg twice daily). He never generated a normal pattern with the symbol refixations. He did demonstrate an interesting sequence while reading at his own level (Figure 4). He made a return sweep on the same line, without downward vertical deflection (arrow), reread that line, and then dropped down to the next line. Note from the vertical channel that while he was rereading the line he momentarily glanced briefly at the line below. Without the vertical monitor, the horizontal pause would have been misinterpreted. He had difficulty getting started on this next line and made two large rightward movements and then a regression back to the beginning of the line before proceeding, again demonstrating the value of a vertical monitor. He also made a reverse staircase on a return sweep, dropping down to the next line with the first leftward horizontal saccade (Figure 5).

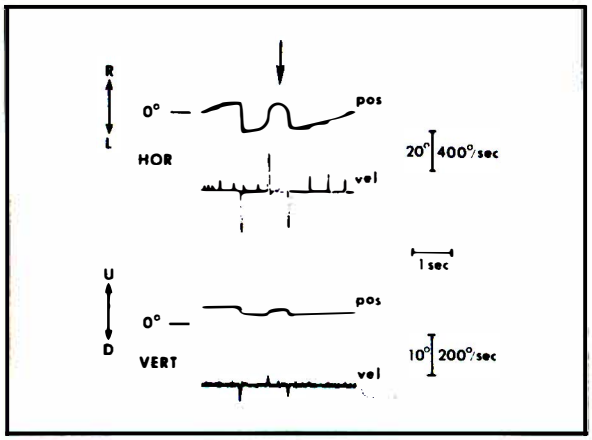

FIGURE 2. A normal 7-year-old reader (case 2) making refixation (arrow) to the end of the previous line prior to beginning an appropriate reading pattern on the next line.

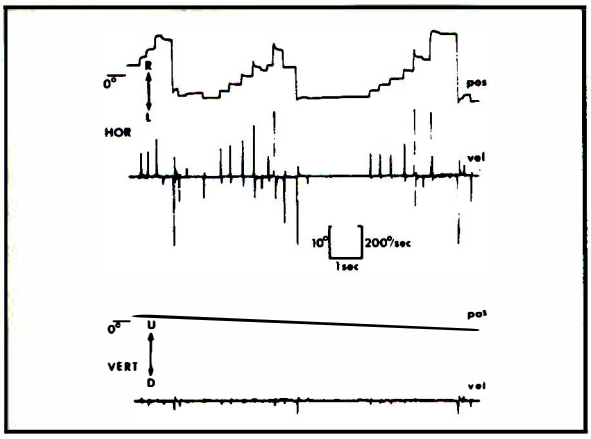

FIGURE 3. A 7-year-old dyslexic (case 3), illustrating a long pause at the beginning of a new line.

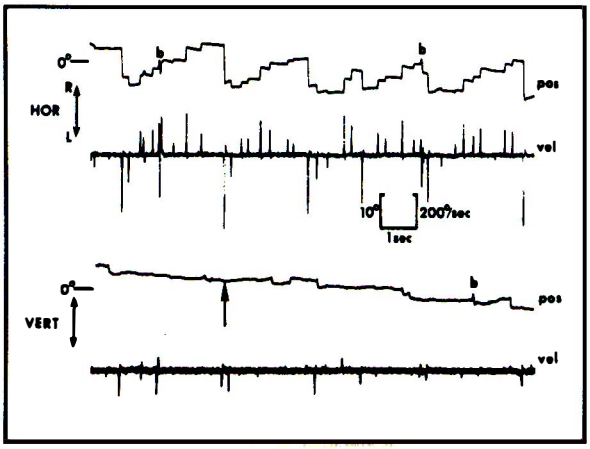

FIGURE 4. Reading patterns of a 7-year-old dyslexic (case 4). (See text for description; *b* indicates blink.)

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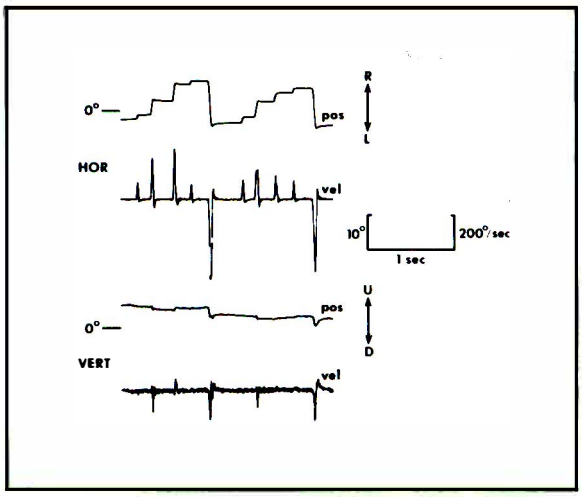

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Case 5

This 7-year-old dyslexic boy made a reverse staircase return sweep during one of five lines of symbols but never during actual reading.

Case 6

This 7-year-old dyslexic boy was taking methylphenidate hydrochloride for hyperactivity. He displayed an excellent eye movement pattern with the symbols but demonstrated several interesting features with regular reading material. With sublevel reading material (Figure 6), he spent 3 seconds fixed at the end of a line (*a*) before making a return sweep to the beginning of that line. He then made a large rightward saccade to the end of the same line (*b*) before making an appropriate return sweep down to the next line (*c*). He remained at the beginning of this next line for approximately 5.5 seconds, and instead of moving rightward, he moved down a line (*d*), followed by some irregular forward and regressive movements. The long 5.5-second pause at the beginning of a line was unexplained. He had a very poor comprehension for this material even though it was supposedly sublevel.

No readily recognizable reading pattern was present with materials at his appropriate level (Figure 7).

With reading materials above his comprehension level, he tended to reread the same line (Figures 8 and 9), which could not have been suspected without the vertical monitor. Also, the diagonal movement shown in Figure 8 (arrow) would have been regarded as a rightward and regressive leftward movement if only the horizontal eye position had been recorded.

Case 7

This 7-year-old girl had a seizure disorder well controlled with anticonvulsant medication. Scores on the Wechsler Intelligence Scale for Children (WISC) were as follows: Verbal, 91; Performance, 106; Full Score, 98. Despite the normal intelligence and apparent understanding of our instructions, she was unable to move her eyes along the pattern of symbols, although they were pointed out to her sequentially while she was urged to look at the designated target. Even with this prompting she was unable to generate a good eye-movement pattern (Figure 10). She made a reverse staircase return sweep (arrow) along the next line of symbols while being exhorted to fix on the pointer that was at the beginning of the next line.

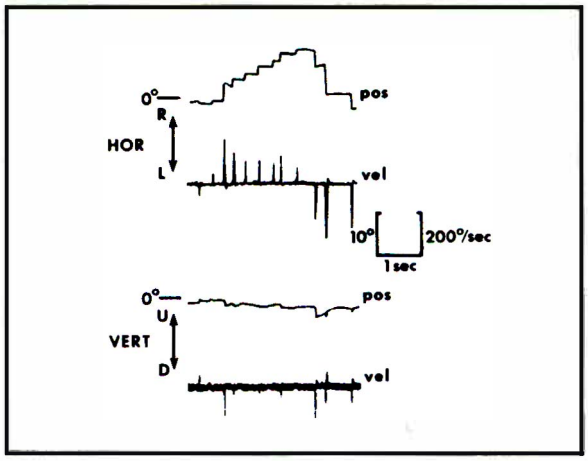

FIGURE 5. A reverse staircase on the return sweep (case 4).

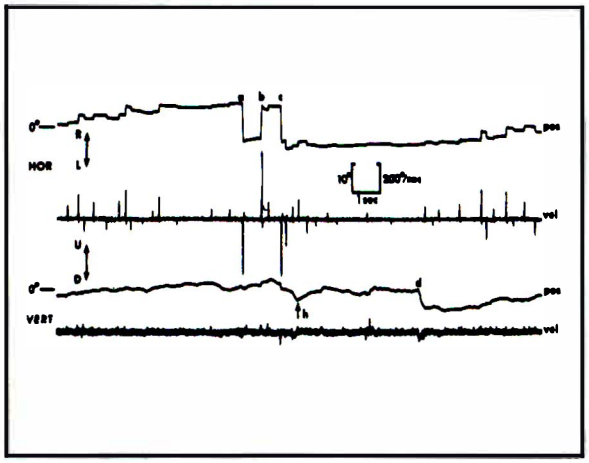

FIGURE 6. A 7-year-old dyslexic (case 6). (See text for explanation; *h* indicates head movement.)

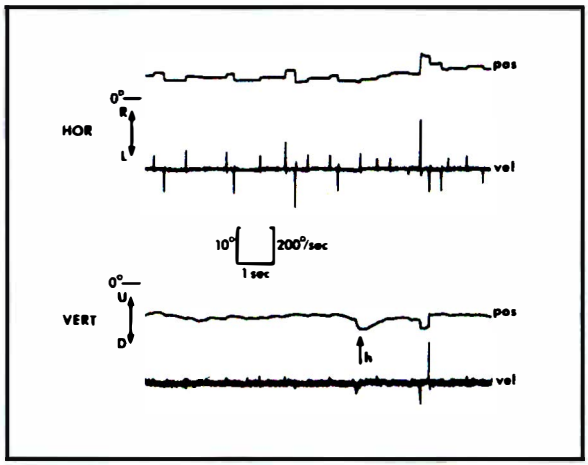

FIGURE 7. The lack of a normal reading pattern during an attempted reading of an at-level text (case 6).

DISCUSSION

Our study of the eye-movement patterns in dyslexic children differed from other studies because of the inclusion of a symbol-simulated reading task and the concomitant measurement of vertical eye position.

Symbol-Simulated Reading

We had our dyslexic subjects move their eyes along a series of large *X*s in a fashion designed to simulate a reading pattern but excluding the factor of comprehension. Our intent was to isolate the ocular motor aspect of the reading process. We felt it untenable to attribute dyslexia, as some previously mentioned investigators have done, to an inability in the generation of sequential rightward movements, followed by a large leftward return sweep, without demonstration of an analogous disability with symbol simulation. The reading pattern in case 6 graphically demonstrated the point. This child had considerable difficulty with all reading material (Figures 6 through 9) but displayed an excellent eye movement pattern to the symbol task. Furthermore, case 3 made exceedingly long pauses at the beginnings of new lines during regular reading, which had not occurred during the symbol simulation. To our surprise the reverse was also manifested. Case 5 made a return staircase during the symbol reading, which he never did with regular reading.

Two of the dyslexics (cases 4 and 7) demonstrated abnormal patterns on the symbol as well as during actual reading. The overall disturbance in case 7 was so profound that the child could not move her eyes sequentially across the *X*s even though each was pointed out individually. Without recognition of this profound primary abnormality of ocular motor control, traditional reading training might prove fruitless.

Thus two of the five dyslexic children demonstrated a disability with sequential eye movements during symbol simulation as well as during actual reading, which is supportive of the contention that a primary eye movement abnormality may play a contributing role in some cases of developmental dyslexia. This strongly supports the contention that a variety of disturbances underlies so-called pure dyslexia (Mattis 1978, Denckla 1979).

Our finding should not be taken as an endorsement of any of the multiple programs of eye-movement exercises (Heath, Cook, & O'Dell 1976) presently in

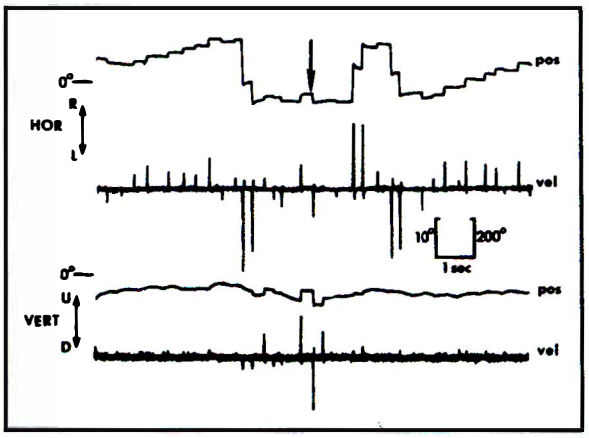

FIGURE 8. Reading of an above-level text, illustrating unusual diagonal movement (arrow) and the tendency to reread the same line (case 6).

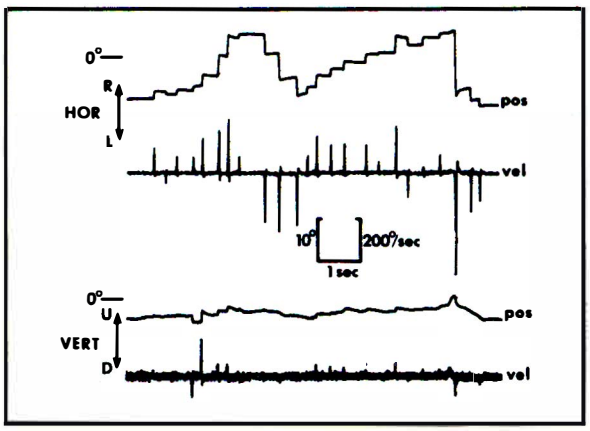

FIGURE 9. Reading of an above-level text, illustrating the reverse staircase and rereading of a line (case 6).

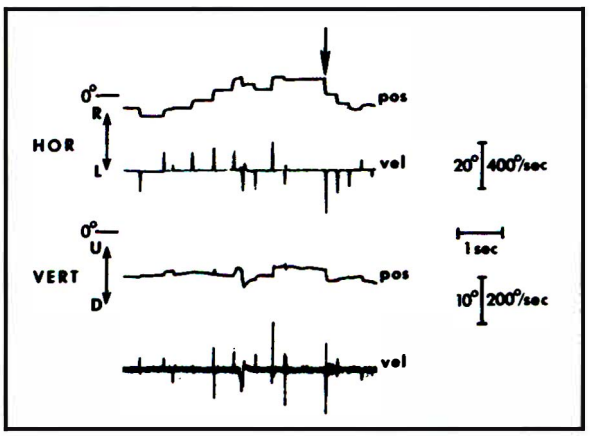

FIGURE 10. A 7-year-old dyslexic demonstrating inability to make proper movements between symbols, even when guided by a pointer (case 7). Arrow indicates the reverse staircase return sweep.

vogue for the therapy of dyslexia. Until a controlled study demonstrates their efficacy, such programs cannot be regarded as more than investigational.

Vertical Eye Position

Our observations established the necessity for simultaneous measurement of vertical eye position. The patterns of the normal adult control reader (case 1) confirmed Hartje's (1972) observation that the horizontal and vertical components of the return sweep to the left occur roughly simultaneously, indicating that the movement is diagonal. Without knowledge of vertical position, many eye movements during reading would be grossly misinterpreted, as demonstrated in the recordings of cases 2, 4, and 6. This was particularly critical for the child in case 6, who had a propensity for rereading the same line; such could never be detected with traditional reading recordings using only horizontal monitoring. It is impossible to interpret the record provided by Zangwill and Blakemore (1972) because of their failure to provide vertical eye position.

The lack of vertical monitoring also affects interpretation of speed-reading. Taylor (1937) presented the horizontal eye-movement tracings of an 8-year-old boy with a reading rate of up to 2,200 words per minute with "excellent comprehension." Return sweeps were in a reverse staircase pattern. This probably included a distinct downward deflection across a number of lines, but this can only be inferred without vertical eye position. Thus whether recording the eye-movement characteristics of normal children, dyslexics, or even speed-readers, information on vertical as well as horizontal eye position is essential.

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