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Eye Movements during Reading: Case Reports*

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ABSTRACT

Since the time of Javal, it has been well established that normal reading eye movement patterns have 3 principal components: (1) small saccades that move the eyes from word to word, (2) large saccades that return the eyes to the beginning of the next line, and (3) fixation pauses between each saccade for information processing.

We discuss the vision analysis results and show the quantitative reading eye movement records, measured with the infrared photoelectric method, of 5 patients examined in the Neuro-optometry Clinic. The reading records showed a wide variety of behavior: 1 patient performed normal reading movements, 1 "slow reader" manifested an excessive number of fixations as well as extended fixational durations, another "slow reader" only exhibited an excessive number of fixations, a patient with dyslexia performed backward reading movements, and 1 patient exhibited nystagmus superimposed upon the reading pattern.

As we read, our eyes make a series of small, jerky movements across the line of print. This basic pattern of oculomotor behavior during reading was first carefully investigated and described by Javal, the visual scientist who called these fast eye movements saccades.[1] Referring to Javal's work, Woodworth[2] stated, "His very eminent predecessors had assumed the truth of the common belief in 'sweeping' the eyes over a scene or along a line of print . . . the old conception of reading supposed that each letter in turn came into the center of clear vision. . . . (Javal) found not a steady sweep, but a series of little jumps with intervening fixation pauses. The eye moved, as he said, 'par saccades'. . . not all letters get into foveal vision; some use must be made of indirect vision." The spatial and temporal characteristics of the eye movement reading pattern were later quantified by Erdmann and Dodge,[3] Huey,[4] and Tinker.[5, 6]

The principal components of reading eye movement patterns are fixation pauses and saccades. The fixation pauses represent the time between saccades when the eyes are steady and information processing occurs. Recently, Abrams and Zuber[7] have categorized the fixation pauses based upon their time durations. They found the shorter pauses, about 180 msec, related primarily to positional information processing. These shorter pauses typically occurred near the beginning and the end of the line. In contrast, longer pauses of approximately 255 msec duration were present in the middle of the line. During these longer pauses, both positional and text processing were believed to occur. Thus, the temporal differences between the 2 types of pauses, about 75 msec, may reflect the text processing time. This, the "Zuber effect," has been subsequently confirmed by Hawley et al.[8]

Small and large saccades occur in reading. The small amplitude saccades move the eyes rightward from word to word. Sometimes these small saccades are directed leftward and are then called regressions. It is believed that regressive movements are executed to correct misreadings, to glance back at interesting details, or to verify particular details.[2] The large, leftward return-sweep saccades move the eyes from the end of one line to the beginning of the next line. Often, the amplitude of the movement is too small and results in static undershooting, followed by 1 or more smaller corrective saccades.

Eye movements other than saccades may

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occur in reading. Small vergence adjustments may be necessary, especially if the reading material is rotated, and successive portions of the line lie at different distances from the eyes. The vestibular system may also be activated during reading.[a] For example, suppose a small child holds a book in his lap as he reads; head and general body movements will invariably take place. The vestibular system will be called upon to compensate for the head movements and to attempt to maintain precise fixation. Residual target position and velocity errors must then be corrected by the saccadic and smooth pursuit systems, respectively. Thus, all 4 eye movement systems: saccadic, smooth pursuit, vergence, and vestibular, are interacting constantly in everyday reading situations.

We present 5 case reports of patients examined in the Neuro-optometry Clinic. Reading eye movements, as well as saccadic, pursuit, and fixational movements, were tested on each patient, and samples of the reading records are presented. These patients include 1 performing normal reading movements and 4 manifesting anomalous oculomotor behavior during reading.

METHODS

Horizontal eye movements of both eyes were measured by monitoring the amount of infrared light reflected from the nasal and temporal limbal regions of each globe. Emitter-sensor pairs (Optron OPB 125) were mounted in front of both eyes on a spectacle frame worn by the patient. The photocells were part of a bridge network whose outputs were sent to differential amplifiers that drove 2 channels of a strip chart recorder. The overall bandwidth of the system was 70 Hz. The patient's head was stabilized by a chinrest and headrest. These methods for recording eye movements were discussed more extensively by Bahill et al.[b]

The target utilized to test saccadic, smooth pursuit, and fixational eye movements was a red, circular spot of light subtending 15 minutes of arc at the patient's eye. This test spot was reflected with a pair of mirror galvanometers onto a curved, translucent screen 57 cm from the patient. The use of the galvanometers allowed the spot to be moved in any fashion in an x-y plane, although usually only horizontal target movements were made.

To test saccadic tracking, the spot was displaced 10 degrees across the patient's midline; thus, it appeared either 5 degrees to the left or the right of the zero position on the screen. Smooth tracking was tested by moving the spot with either sinusoidal or triangular target motion of 0.2 to 3.0 Hz over the same 10-degree range. The spot was maintained on the midline (zero screen position) for about 1 min to measure fixational eye movements. To test reading eye movements, the adult patient read a 180-word excerpt from a household magazine mounted on a stand 50 cm away, while for children, a 90-word excerpt from a third-grade level text was read. The reading material subtended a visual angle of 11 degrees at the patient's eye.

For this report, eye movement records of the right eye are presented; records of the left eye were similar. None of the patients was taking any drugs or medications. Although corrective lenses were not worn during the testing, the targets were easily seen by the patients. Details of the testing protocol and the criteria adopted to distinguish the abnormal aspects in each type of movement tested will be more fully discussed in a future communication by Stark et al.[c]

CASE REPORTS

Case 1: Normal reading eye movements

The chief complaint of this 25-year-old female college student was moderate asthenopia after reading for 30 min. The patient also remarked that she saw "ghost images" of the previously fixated words as she continued to read. All findings of the general vision analysis were within normal limits.

Saccadic, smooth pursuit, and fixational eye movements were normal. In the reading record (Fig. 1), a normal adult staircase pattern was evident. A sequence of saccades that moved the eyes rightward (1 to 4-degree amplitude, 24 to 35-msec duration),[11] fixation pauses (~175 to 325 msec), and large return-sweep saccades to the beginning of the next line (~11-degree amplitude, 38- to 43-msec duration)[11] were present. The reading rate calculated from the

[a] In fact, according to recent reports, a large segment of the children with learning disabilities *may* have vestibular system dysfunctions.[9, 10] However, careful quantitative eye movement studies on children diagnosed as having a learning disability, utilizing precise recording methods, are needed to substantiate these claims.

[b] A. Terry Bahill, Kenneth J. Ciuffreda, Robert V. Kenyon, and Lawrence Stark, Dynamic and static violations of Hering's law of equal innervations, accepted for publication in the *American Journal of Optometry and Physiological Optics*.

[c] Lawrence Stark, A. Terry Bahill, Kenneth J. Ciuffreda, Robert V. Kenyon, and Stephen Phillips, Neuro-optometry: An evolving specialty clinic, accepted for publication in *American Journal of Optometry and Physiological Optics*.

entire record was approximately 350 words per minute. Thus, we could detect no abnormal reading eye movements. Normal reading movements, like those exhibited by this patient, are commonly reported by others and have been confirmed by us in some patients complaining of reading difficulties.

Under our testing conditions, based upon a series of 40 patients and several control subjects, we found normal adult values to be 50 to 85 fixations per 100 words, 5 to 15 regressions per 100 words, fixational durations of 150 to 375 msec, and a reading rate of 225 to 400 words per minute. Our values are in basic agreement with those determined by Buswell[12] and Taylor.[13]

Case 2: Slow reader, adult

A 26-year-old male college student, seen in the general clinic, complained of severe asthenopia after reading for about 15 min. The patients stated that he was performing poorly in school and considered his reading rate to be below that of his colleagues. Following a recent neurological examination, a diagnosis of narcolepsy was made. The vision analysis revealed moderate simple myopic astigmatism, which closely agreed with his present spectacle correction, and anisometropia.

Saccadic, pursuit, and fixational movements were within normal limits. However, several abnormalities were noted in the reading record (Fig. 2). After reading the 1st half of the line well, the patient then exhibited an abnormal eye movement pattern for the remainder of the line. In this abnormal pattern, numerous small amplitude saccades (<1 degree), regressive movements, and extended fixation pauses (400 to 600 msec) were present. An analysis of the entire record indicated an average of 140 fixations per 100 words, 40 regressions per 100 words, and a reading rate of approximately 150 words per minute.

Case 3: Slow reader, child

A 9-year-old female was seen in the general refraction clinic for a routine examination. The refractive error was slight; however, the clinician measured a reduced amplitude of accomodation and constricted visual fields of possible psychogenic origin. Furthermore, there was some question regarding the quality of her saccadic and pursuit eye movements. Static

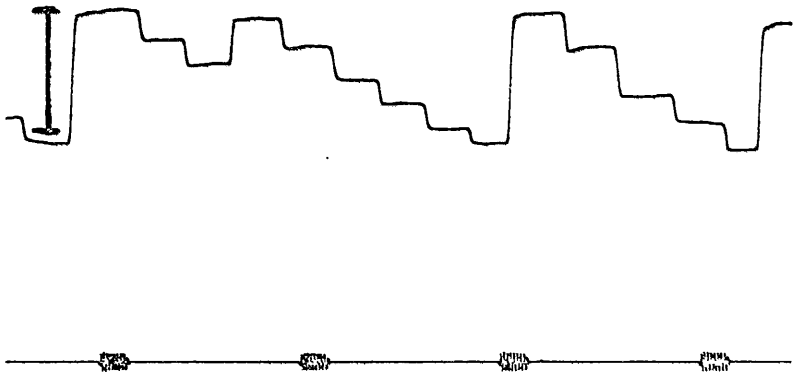

FIG. 1. Eye position as a function of time for an adult showing a normal reading eye movement pattern (staircase pattern). For this and all subsequent figures, upward deflections denote leftward movements, and the calibration bars represent 10 degrees. The lowest line is a timing trace with a 60-Hz burst each sec.

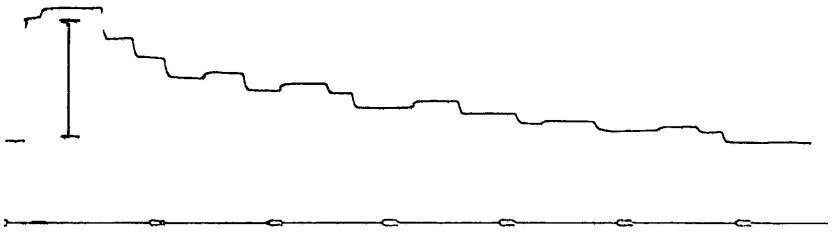

FIG. 2. Eye position as a function of time for an adult "slow reader." Note the hypometric saccade (static undershooting) and the subsequent small corrective saccade in the beginning of the record. Numerous small amplitude saccades, regressive movements, and extended fixation pauses occurred as he read the latter half of the line.

accommodation testing in our clinic with a Fincham coincidence optometer revealed an abnormally low amplitude of accommodation, for her age, of 5.0 diopters in the right eye and 3.5 diopters in the left eye.

In our eye movement testing, saccadic, pursuit, and fixational movements appeared normal. However, in the reading record (Fig. 3), an abnormally high number of fixations were observed and were responsible for the reduced reading rate of 120 words per minute. Although the fixational durations were within normal limits and few regressions were noted, the hypometric return-sweep saccades necessitated 2 or 3 smaller corrective saccades to place the eyes at the beginning of the line.

Case 4: Dyslexic reverse-staircase phenomenon

This 24-year-old male college honors student, seen in the general clinic, complained of headaches following short periods of reading. He stated that many of his relatives had reading difficulties and that he and his twin brother had taken several remedial reading courses in school but continued to read slowly. A diagnosis of dyslexia had been made by the school officials after extensive testing. Superior grades in high school and in college were attained only by intensive studying; on standardized examinations, his scores fell between the 2nd and 3rd quartile. Also he became a disc jockey in college to force himself to overcome word confusions during oral reading, a frequent complaint of dyslexics. The vision analysis indicated slight compound myopic astigmatism, for which he was already fully corrected, and a reduced amplitude of accommodation. Static and dynamic accommodation were measured in our clinic; the results indicated an increased accommodative latency, a reduced accommodative amplitude, and a decreased accommodative velocity.

Saccadic and pursuit movements were normal. However, upon attempted sustained fixation, numerous unusually large microsaccades (0.5 to 1.0 degrees amplitude) were noted. Many abnormalities were observed in the reading record. Although the fixational durations were within normal limits, the total number of fixations and regressions were abnormally high. While reading with the left eye covered, there was an average of 25 regressions per 100 words. In contrast, there were only 10 regressions per 100 words with the right eye covered. During binocular reading, there were 20 regressive movements executed per 100 words of text. The patient's overall binocular reading rate was only 175 words per minute. For much of the record, left to right sequences of saccadic eye movements were executed. However, at times, a dramatic change in the reading pattern occurred which produced the "reverse-staircase" patterns evident in Fig. 4. These records contain sequences of *right-to-left* saccadic eye movements interspersed with the more typical rightward-directed saccades.

Case 5: Congenital jerk nystagmus

A 12-year-old female with congenital jerk nystagmus of unknown etiology and a possible esotropia was examined in both the general clinic and the strabismus clinic. She had severe developmental problems, physically, academically, and socially, and was receiving remedial reading instruction to improve her reading skills from their present third-grade level, according to her reading teacher.

The patient could not make saccadic eye movements in response to target displacements. While fixating a target on the midline, jerk nystagmus of 5 to 7 degrees in amplitude, with the fast phase to the right, was recorded. When tracking a sinusoidally moving target (0.4 HZ), the amplitude of the nystagmus decreased to about 2 degrees. During reading (Fig. 5), nystagmoid eye movements of variable amplitude (3 to 9 degrees) slowly but steadily moved the eyes accross the line of print. This nystagmoid element during reading produced a modified staircase pattern. Since 10 to 20 sec were required to read each line, her reading rate was drastically reduced from the normal six-grade level of 185 to 235 words per minute to 30 to 60 words per minute, far below even a third-grade level (~140 words per minute).

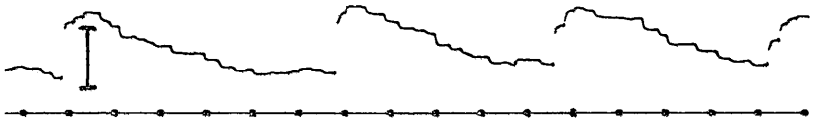

FIG. 3. Eye position as a function of time for a 9-year-old "slow reader." This patient typically undershoots on the return-sweep saccade, thus necessitating 2 or 3 small corrective saccades for proper positioning. The rounding of the corners is due to glissadic undershooting and not to low-pass filtering. An abnormally high number of fixations was noted throughout the record.

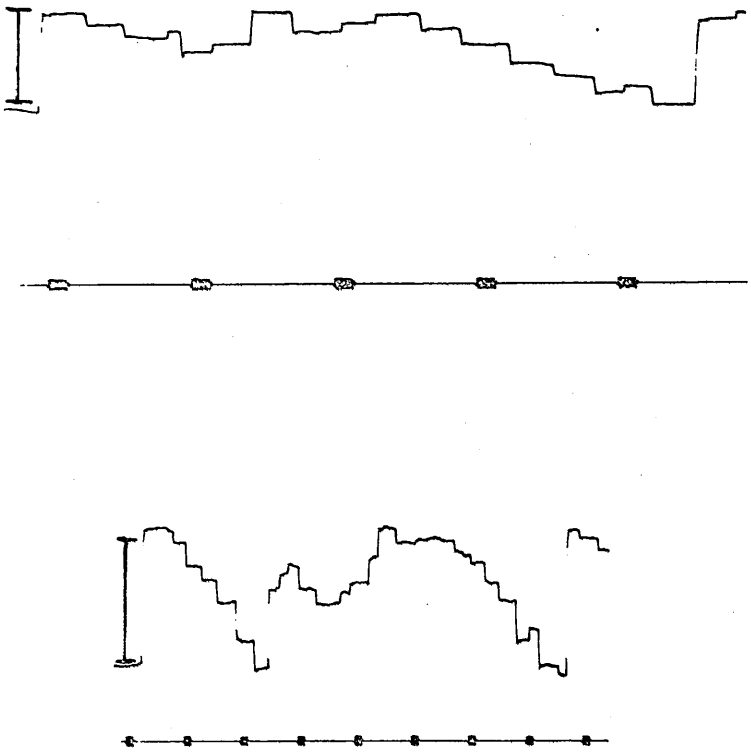

FIG. 4. Eye position as a function of time for a dyslexic patient performing reverse-staircase reading patterns. Note that the fixation pauses are not extended. The upper figure (left eye occluded) has a double reverse-staircase in the middle of the line. The lower figure (binocular viewing) shows a normal reading pattern for the 1st 2 sec of the record followed by a double reverse-staircase movement during the next 2 sec. For the balance of the record, the patient has reverted to a more normal staircase pattern.

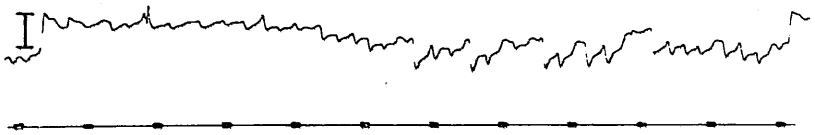

FIG. 5. Eye position as a function of time for a patient with congenital jerk nystagmus. The mean fixational duration is about 2 sec. These abnormally long fixation pauses are the result of the 3 to 4 Hz nystagmus superimposed on the staircase reading pattern. Observe the reversal in the direction of the nystagmus at the beginning of each line.

DISCUSSION

These case reports reveal the variability in chief complaint, case history, and general clinical findings for each patient, and our quantitative measures of oculomotor behavior during reading show corresponding variation in the recorded abnormalities and verify, in most cases, the patient's awareness of a basic reading problem.

In our oculomotor testing protocol, saccadic, smooth pursuit, and fixational eye movements, along with reading eye movements, were measured in patients complaining of reading difficulties. In this way, any basic eye movement abnormalities for simple tracking and fixation tasks were observed, quantified, and differentiated from those eye movement anomalies that were recorded as the patient read. It is important to note that, for our patients who exhibited abnormal reading patterns (excluding the nystagmus patient), performance on simple oculomotor tasks was generally within normal limits. Thus, this basic difference in oculomoter performance suggests higher-level motor control or information-processing difficulties when a complex stimulus array, such as reading material, is presented to these patients.

In Case 1, asthenopia and ghost images were reported by the patient, yet her eye movements

appeared normal. Perhaps additional information could be obtained by recording reading eye movements before, during, and after an extended period of reading to ascertain the effects of fatigue, either physiological or psychological, from prolonged reading on the oculomotor system.[14, 15]

The 2nd patient was a slow reader, had marked asthenopia after reading, and was performing poorly in school. Abnormalities in the reading record were evident: extended fixational durations and frequent regressions contributed to or resulted from an inefficient, slow reading process. Further research is required to determine if extended fixation pauses reflect difficulties in positional processing, higher-level text-information processing, or just inattention.[16]

In the 3rd case, the child's reading pattern was laden with excessive fixation pauses, about 170 per 100 words, of normal duration. These excessive fixations were responsible for the reduced reading rate of 120 words per minute. According to Taylor's normative data,[13] a child at this grade level (4th) should have a reading rate of 160 to 180 words per minute with 20% fewer fixations.

Records from the 4th patient included the presence of frequent backward reading eye movements. Gruber[17] believed that the presence of "reverse-staircase" patterns indicated a lack of control in performing the return-sweep saccade to the beginning of the next line; therefore, the patient backtracked over the line he had just read in order to aid in arriving at the beginning of the subsequent line of print. Taylor proposed a similar hypothesis for the execution of these reverse movements which he frequently observed in children with accommodation and vergence abnormalities; furthermore, he believed the development of proper directional attack, essential for accurate return-sweep saccades, was a learned, and therefore trainable, phenomenon.[13] However, Fig. 4 shows more irregular initiation and termination of the reverse movements and, thus, does not support the simple form of Gruber's or Taylor's hypothesis. Zangwill and Blakemore,[18] who verified Gruber's reverse-staircase movement in an adult dyslexic, explained this problem of directional scanning as an "irrepressible tendency" to move the eyes leftward and suggested therapeutic training of rightward scanning. A combined effort by the eye movement physiologist and the reading specialist to study patients exhibiting reverse reading patterns is essential for a more thorough understanding of the unusual eye movement maneuvers executed by these patients.

The recordings of the young girl with nystagmus allow us to appreciate the severe handicap under which these patients are forced to read. The reading records showed a slow, tedious, rightward progression of the eyes as each word or group of letters was processed. The extremely long fixational durations, 2 sec on the average, were, in part, due to the nystagmus superimposed on the basic reading pattern.[d] The strategies used in reading by patients with nystagmus or other neurological disorders affecting oculomotor control and the application of auxiliary lenses or prisms to enhance reading performance in these patients need to be studied in a careful, quantitative manner. Early studies by Taylor,[13] who investigated reading patterns in nystagmus patients, indicated that, at least in 1 patient, reading speed could be improved from 132 to 279 words per minute following intensive prism reading therapy.

CONCLUSION

We are most enthusiastic about documenting reading eye movement defects with our precision photocell monitors, and we plan further clinical studies in which the vision analysis data and the quantitative eye movement records on specific patients or diagnostic groups, performing a wide range of simple oculomotor tasks, as well as reading, are presented. We hope these studies may help to elucidate the relationship between reading disability and the eye movement control system and will contribute to the understanding of the underlying psychological, physiological, and neurological mechanisms involved in the reading process.

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[d] These fixational durations during reading are in basic agreement with the findings of Dell'Osso and Daroff,[19] and Abadi and Sandikcioglu,[20] regarding foveation strategy in congenital nystagmus. They concluded that the target fell on the center of the fovea on 1 peak of the nystagmoid waveform. Thus, in our patient, with an average nystagmus frequency of 4 Hz, a mean nystagmus amplitude of about 4 degrees, and a region of high resolution centered around the fovea and having a radius of 0.8 degrees, the *foveal* fixation duration during reading was 400 msec (50 msec × 8 cycles), certainly close to the normal range.

REFERENCES

1. Javal, Emile, Essai sur la physiologie de la lecture, Ann. d'Oculistique; 82: 252, 1879.
2. Woodworth, Robert S., Experimental Psychology. New York, Henry Holt and Co., 1938, pp. 577, 719.
3. Erdmann, B., and R. Dodge, Psychologische Untersuchungen uber das Lasen auf Experimenteller Grundlage, Halle, Universitat, 1898.
4. Huey, Edmund Burke, The Psychology and Pedagogy of Reading. Cambridge, Mass, MIT Press, 1968 (reprint of 1908 version).
5. Tinker, Miles A., Time relations for eye movement measures in reading, J. Educ. Psychol., 38 (1): 1–10, 1947.
6. Tinker, Miles A., Fixation pause duration in reading, Reading Res. Q., 8 (1): 40–51, 1972.
7. Abrams, S. G., and B. L. Zuber, Some temporal characteristics of information processing during reading, Reading Res. Q., 8 (1): 40–51, 1972.
8. Hawley, T. T., J. A. Stern, and S. C. Chen, Computer analysis of eye movements during reading, Reading World, 13 (4): 307–317, 1974.
9. de Quiros, Julio B., Diagnosis of vestibular disorders in the learning disabled, J. Learning Disability, 9 (1): 39–47, 1976.
10. Frank, Jan, and Harold Levinson, Dysmetric dyslexia and dyspraxia, J. Am. Acad. Child Psychiat., 12: 690–701, 1973.
11. Bahill, A. Terry, M. R. Clark, and Lawrence Stark, The main sequence, a tool for studying human eye movements, Math. Biosci., 24: 191–204, 1975.
12. Buswell, Guy Thomas, Fundamental Reading Habits: A Study of Their Development, Suppl. Educ. Monogr. #21, University of Chicago Press, Chicago, Illinois, 1922.
13. Taylor, Earl A., The Fundamental Reading Skill, Springfield, Ill., Charles C Thomas, 1966, pp. 42, 45, 108–112.
14. Hoffman, Arthur C., Eye movements during prolonged reading, J. Exp. Psychol., 36 (2): 95–118, 1946.
15. Bahill, A. Terry, and L. Stark, Overlapping saccades and glissades are produced by fatigue in the saccadic eye movement system, Exp. Neurol., 48:95–106, 1975.
16. Stern, J. A., D. A. Bremer, and J. McClure, Analysis of eye movements and blinks during reading: Effects of Valium, Psychopharmacologia, 40: 171–175, 1974.
17. Gruber, Ellis, Reading ability, binocular coordination, and the ophthalmograph," Arch. Ophthalmol., 67 (3): 280–288, 1962.
18. Zangwill, O. L., and Colin Blakemore, Dyslexia: Reversal of eye movements during reading, Neuropsychologia, 10 (3): 371–373, 1972.
19. Dell'Osso, L. F., and Robert Daroff, Congenital nystagmus waveforms and foveation strategy," Documenta Ophthalmol., 39 (1): 155–182, 1975.
20. Abadi, R. V., and M. Sandikcioglu, Electrooculographic responses in a case of bilateral idiopathic nystagmus, Br. J. Physiol. Optics, 29 (2): 73–85, 1974.

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