

# SACCADIC EYE MOVEMENTS:

## THEORY, TESTING & THERAPY

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### Abstract

*This paper reviews the theory, testing, and therapy procedures for saccades. These eye movements and their relationship to reading and academic success are also considered. Research on saccadic eye movements, fixations, span of recognition, and regressions is reviewed. Current arguments on the relationship between eye movement skills and reading disabilities are discussed. The King-Devick test, Developmental Eye Movement Test, Observation Saccades, and the computerized Visagraph are utilized to evaluate eye tracking. The advantages and disadvantages of each of these methods are reviewed. And, finally, therapeutic procedures for enhancing fixational skills, tachistoscopic visual memory skills, and the components of saccadic eye movements are considered.*

### Key Words

*Developmental Eye Movement Test, dyslexia, fixations, King Devick Test, regressions, saccadic eye movements, span of recognition, visagraph, vision therapy*

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hen average readers are asked how their eyes move when reading, most respond that they move continuously from left to right and then jump back to the left to begin the next line of print. Careful observation, however, clearly indicates the eyes do not make a steady sweep across a line of print when reading, but rather, a series of small, precise jumps from word to word.

Eye tracking during reading is composed of saccadic eye movements followed by fixational pauses. Saccadic eye movements are very fast, requiring only 20 msec. to make a 3 degree movement. When the end of a line of print is reached, a larger return saccade occurs, requiring about 65 msec to make the 10 degree return sweep.<sup>1</sup> The primary function of the saccade is to bring a new area of text onto the central area for sequential visual processing. The number of fixations required to read a given amount of text actually reflects the number of saccadic eye movements made to read that text. The number of eye movements necessary to read a given amount of text normally decreases with age and eventually plateaus. The average first grader, for example, makes 224 eye movements to read 100 words while the average college student makes only 90 saccades.

### THE COMPONENTS OF SACCADIC EYE MOVEMENTS

#### Fixations

Saccades are separated by short periods of non-movement called fixations.

During the fixational stop, imagery focused on the fovea is translated into neural code and transmitted through the neural-retinal pathways to the optic nerve. The neuro-encoded information then continues to the visual processing centers of the brain. For a skilled reader, each fixation lasts between 200 and 250 msec. Individual fixation times tend to be relatively consistent when the reading material is simple. As the text becomes more complex or less familiar to the reader, fixation times tend to increase and become more variable from one fixation to the next. Fixation times tend to be longer for unfamiliar words and shorter for easier words.<sup>2</sup>

The average length of the fixational pause decreases with grade level and reading experience.<sup>3</sup> When reading grade level material, first graders are found to have an average fixation time of 0.33 second. The duration of fixation tends to decrease to 0.24 second in adults with normal reading skills. The shortest duration found in thousands of eye movement recordings was 0.16 second. The developmental decrease in fixational time represents both a faster retinal processing time as well as increased cognitive processing skills.

#### Regressions

Saccadic eye movements typically occur in a left to right direction coincident with the way text is read in most Western cultures. However, regressive eye movements occur in a right to left movement about 15% of the time. Regressive eye movements are normal for even the fastest

readers. The exact nature of these reverse saccades is unknown, but they might serve a contextual or comprehension function. Regressions tend to increase when the vocabulary is unfamiliar to the reader or when comprehension of the text becomes more difficult. Children with decreased visual acuity or binocular vision deficiencies may also make an excessive number of regressive eye movements. Taylor<sup>4</sup> noted that uncorrected hyperopic children tend to make consistent regressive eye movements following the return sweep. He postulated that these tracking errors resulted from over-convergence and accommodative adjustments occurring in the hyperope during the return sweep.

Regressive eye movements are habitual in nature. The reader is seldomly aware of their occurrence and is unable to consciously increase or decrease the number made. Regressive eye movements are not the same as rereading. Rereading is characterized by larger saccades that return the reader to sections of previously read text. A rereading saccade is cognitively initiated by the reader when comprehension or word recognition decreases.<sup>5</sup>

Regressions tend to decrease as reading skills improve. The average first grader makes 52 regressive eye movements per 100 words while the average college student makes only 15.<sup>3</sup>

### Span Of Recognition

The span of recognition is also an important component for evaluating eye tracking skills. It is defined as the number of words or word parts that the reader can cognitively process during the fixation. It does not measure the amount of visual data actually focused on the retina but rather the amount of text that can be processed without any additional eye movements. The width of the span may vary from one fixation to the next and by the degree of difficulty of the reading material. A skilled reader has an average span of recognition of 4 characters to the left of fixation and 15 characters to the right.<sup>6</sup> However, not all characters processed within the span of recognition during a fixation contribute to word recognition or comprehension. Word recognition and processing for comprehension occurs only to 7 or 8 characters to the right of fixation. Information from 8 to 15 characters to the right of fixation helps to direct subsequent

saccades and fixations. Within this outer area of the span of recognition, the reader is primarily identifying word shape and length information. This is predictable since visual acuity declines as focused image distance increases from the fovea.<sup>7-</sup>

<sup>9</sup> As reading skill increases, the span of recognition widens. The typical first grader has an average span of recognition of 0.45 words while a college student has a span of 1.11 words.<sup>3</sup>

A demonstration of this concept can be easily administered. Instruct the observer to fixate a word in the middle of a column of print. Ask the reader to concentrate on NOT moving his/her eyes. Then, ask the observer to try to read the word to the right of the word being fixated. Without an eye movement, this task is difficult. If a long word is chosen, for example: "instruction," and the observer is asked to fixate the beginning "i," it is difficult to "see" the end of this word without making an eye movement. This demonstration makes the reader aware of the importance of accurate, precise saccadic eye movements for directing the span of recognition onto each sequential word or word part. During reading, if the next word is "overshot" by a misguided saccade, the tracking system will have to redirect the span of recognition back to the missed word. Inefficient eye movements such as these can be time consuming, fatiguing, and visually confusing if several occur in each sentence.

### Reading Speed

Reading speed is usually measured in words per minute (WPM) and depends upon ocular motor skills, difficulty of text, comprehension, and cognitive processing skills. Reading for comprehension differs from skimming or speed reading. During speed reading, large, scanning saccades are employed to fixate key words within limited portions of text. All words are not read or even visually fixated during scanning. When reading for comprehension, most words within the text must be fixated. How fast the text can be read will depend on the number of eye movements made, the length of each fixation, the number of regressive eye movements, and the span of recognition.

These oculomotor factors tend to place an upper limit on the maximum speed when reading for comprehension. The maximum span of recognition for even the most accomplished readers is about 2.5

words per fixation. Depending upon the text difficulty, most accomplished readers will make at least four fixations per second. Thus, even the most efficient readers, when reading for comprehension, have the potential for reading, at most, 600 words per minute.<sup>5</sup> These oculomotor limitations raise serious questions about the validity of speed reading claims of 1200 to 1500 words per minute for an average reader. Skim reading and scanning are certainly possible at this level, but analytical reading for comprehension is not.

### Saccadic Eye Movement Control

Eye tracking is a complex ocular motor task requiring constant monitoring and feedback by higher cerebral control centers. As reading begins, the eyes must focus and achieve binocular coordination on the first word of text to be read. Binocular fixation must be steady and accurate. The text focused on the central retina is transposed into neurological code that is transmitted through the neural retinal layers to the optic nerve. From there, the information continues to the various cerebral processing centers for word recognition and comprehension. Text information is stored and sorted in short term memory centers. While central foveal areas are processing information for word recognition, parafoveal retinal areas and their corresponding cerebral centers are analyzing word shape and length information. This data will be used to guide the next saccade to the next fixation point. When comprehension is difficult or the fixated word is not recognized, cerebral control centers may instead initiate a regressive eye movement.

The control of eye movements during reading can be attributed to dual, interacting mechanisms. The first process determines where the eyes will look during the next fixation. This is determined by parafoveal input from upcoming word length and word shape information. The second mechanism determines how long the eyes will continue to fixate the current word. This is determined by how quickly recognition and comprehension of the currently fixated word or word group occurs. During the actual eye movement, saccadic suppression occurs. Without saccadic suppression, the print would appear to blur and run together.

Both anatomical<sup>10</sup> and electro-physi-

ological studies<sup>11</sup> confirm at least two groups of neural retinal pathways that control eye movements. These are the magnocellular (or transient) and parvocellular (or sustained) systems. When reading, an image of the text is focused on the fovea. When the next saccade begins, that retinal image must be erased before the next fixation occurs. The sustained system ensures that the retinal image persists during the fixation. The transient system, however, is responsible for erasing that image before the next fixation occurs. These two subsystems must interact in visual processing: the transient response, occurring first, directs fixation to the location of the words on a page. The sustained response, occurring during the fixation, is responsible for extracting or seeing the details of letters, numbers, and symbols. If the retinal image of a word created during the sustained response persists during the eye movement (initiated by the transient system), it will interfere with the image created during the next fixation. Transient activity inhibits the sustained activity from persisting from one fixation to the next. If the retinal image is not completely erased, it will be faded, but superimposed on the image seen on the next fixation.

Clarity of vision on each fixation depends upon the interaction of the transient and sustained channels. A deficit in the timing between these two systems can result in severe reading disabilities. The child may see double images, blurred images, or words that appear to float around.<sup>12</sup> Recent electrophysiological studies have confirmed that children with reading disabilities have defects in the magnocellular neuroretinal pathways.<sup>11</sup>

### Symptomology

Numerous signs and symptoms are often reported in children with decreased eye tracking skills.<sup>13</sup> These students are frequently found to skip words and lines when reading. Smaller words tend to be skipped more frequently than larger words. Excessive head movements and even body movements are common during reading. Fingers are frequently used as a marker to help track. Reading skills often improve if a ruler or cardboard window is used as a marker to guide tracking. These children may have difficulty copying from board to paper or even from book to paper. They may appear to have a short attention span since they are unable to read for long

periods without visual confusion. Markedly decreased saccadic eye movement skills may even contribute to word and letter reversals when reading. Some children report that the words appear to float and move around when reading.

It can not be assumed, however, that children with this symptomology have a saccadic eye movement disorder. Conflicting evidence exists in the literature over the relationship between eye tracking and reading disabilities (dyslexia). Several investigators<sup>14-19</sup> have argued that some reading disorders are actually caused by decreased ocular motor control. Researchers have demonstrated that dyslexics display abnormal eye movements not only when reading for comprehension but also when tracking non-verbal targets such as progressive displayed lights.<sup>14</sup> Pavlidis<sup>15</sup> demonstrated that dyslexics have statistically decreased eye movement skills even when reading text they found easy to comprehend. He also demonstrated that eye movements of normal readers do not deteriorate as much as dyslexics when they read text that is difficult for their age.<sup>16</sup> Investigators have also demonstrated that if eye movements are eliminated by presenting the words one at a time on a computer screen, the dyslexic's comprehension skills increase significantly.<sup>19</sup>

Other investigators,<sup>20-23</sup> however, argue that the erratic eye movements in dyslexics merely reflect the child's inability to comprehend what is being read. They argue that dyslexia is a language-based disorder caused by the child's inability to decode and understand text. The reading-disabled child may fixate words for longer periods, fixate every letter of the word, and make more regressive eye movements in an attempt to decode unfamiliar text. The erratic eye movements displayed by these children are proposed to be an attempt to scan and decode unfamiliar text to gain comprehension. These investigators argue that when reading-disabled children are given text appropriate to their reading level, their saccadic eye movement skills appear normal for fixation length, frequency of regressions, and length of saccades.<sup>24</sup>

There may actually be a reconciliation between these two opposing views. Christenson and co-investigators<sup>25</sup> have classified dyslexics into two subgroups, dysphonetic and dyseidetic. The more

prominent dysphonetic group has an auditory linguistic deficit. This group typically has problems with decoding and phonetic spelling. Dysphonetics tend to have auditory perceptual problems and a higher performance IQ than a verbal IQ. When evaluated for eye tracking, the dysphonetic group may display decreased saccadic skills when tested with material requiring comprehension. As text material becomes more difficult, the dysphonetic may display increased fixation length, shorter saccades, and more regressive eye movements. However, if tracking is evaluated using non-verbal targets, such as those suggested by Maples,<sup>26</sup> saccadic skills may appear normal. If the child has adequate number recognition and verbalization skills, performance on saccadic eye tracking tests such as the King-Devick<sup>27</sup> Test may also appear normal.

On the other hand, the child with dyseidetic dyslexia displays various visual perceptual and spatial disorders. These children typically have higher verbal than performance IQ scores. The dyseidetic reader has decreased sight vocabulary skills, makes nonphonetic spelling errors, and has difficulty remembering the form of the word. This group may display eye tracking disorders not only when reading text but also when evaluated with tests that utilize non-verbal targets.

Although ocular motor deficiencies, such as decreased saccadic eye movements, may not be the cause of many reading disabilities, these visual problems may significantly contribute to a child's reading difficulties.<sup>25</sup> It is important that optometrists test and treat eye tracking difficulties regardless of whether this is the cause or simply a contributing factor to the child's overall academic difficulties. Hoffman<sup>28</sup> exemplified this point when he asked, "If a child has allergies and a learning disability, would it not be proper care to improve the allergic condition?" In the same sense that allergies can contribute to a child's learning problems, saccadic eye movement deficiencies, as well as other ocular motor dysfunctions, can contribute as well.

### TESTING SACCADIC EYE MOVEMENTS

#### King Devick Test

The NYSOA King Devick (K-D) Test,<sup>27,a</sup> which is based on the Pierce Saccade Test,<sup>29</sup> is frequently used to evaluate

saccadic eye movement skills. Three charts are presented to the patient. Each contains eight lines of five single digit numbers. The spacing between lines becomes closer and the numbers more randomly staggered as the patient progresses through the three charts. The child is asked to read aloud each page of numbers as quickly as possible. A score is calculated based on the time to complete each chart and the total number of errors made and is compared to the mean and standard deviation of the Test's developmental norms.

A criticism of the K-D Test is that it requires verbal processing and articulation skills similar to those required for reading. Presumably children with decreased number recognition, hesitation between number recognition and vocalization, decreased information retrieval skills, or decreased visual verbal integration skills will display decreased performance on the K-D Test even though their saccadic skills may be normal.<sup>30-32</sup> Oride<sup>33</sup> has questioned the test-retest reliability of the K-D Test since some children perform significantly better when the test is administered a second time.

The scoring methods utilized by the K-D Test have also been criticized. No scoring adjustments are made if a child skips or rereads digits or entire lines. For example, a child who skips two lines of numbers may appear to have a normal time score even though only 6 of the 8 lines were read.

If a child does have accurate number recognition skills, however, the K-D Test can provide valuable insight into the child's eye tracking ability. If the child scores at or above age level, it can be concluded that the saccadic eye movement skills are at least normal when reading numbers. The child could still, however, display decreased saccadic ability when reading more complicated materials. In addition to the time and error scores, observations of where the child holds the test, whether he/she uses a finger as a pointer to track, displays excessive head movements, or skips lines and digits all provide clinical clues into the child's tracking ability.

### Developmental Eye Movement Test

The Developmental Eye Movement test (DEM),<sup>a</sup> illustrated in Figure 1, also evaluates saccadic eye movements by as-

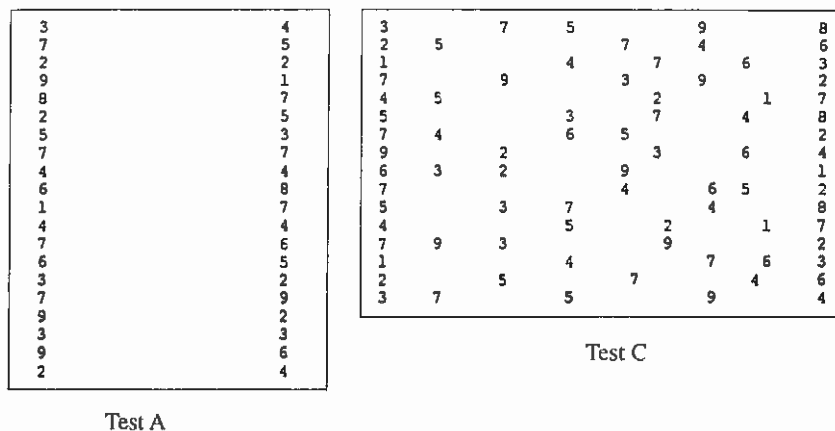


Figure 1. Test A and Test C from the Developmental Eye Movement test.

sessing the speed and accuracy in which a series of single digit numbers can be seen, recognized, and verbalized.<sup>31</sup> This test circumvents the visual verbal automaticity component, inherent in the NYSOA K-D Test, by comparing differences in the times scored with and without horizontal eye movements. The child is first timed while reading two test plates, each composed of two separated vertical columns of numbers. The Vertical Time Score is the sum of these two times. Next, the child reads the same quantity of numbers presented in a randomly spaced, horizontal array (16 rows of 5 randomly spaced single digit numbers).<sup>34</sup>

A formula is used to adjust the scores if lines or digits are reread or skipped. Scoring is based on the ratio of horizontal to vertical times and the number of errors. The Vertical Time Score indicates the automaticity of a child's number calling ability without saccadic eye movements. The Horizontal Time Score reflects both the automaticity of number calling and saccadic eye movement skill. Each score can be compared to the developmental norms and standard scores developed for the test. The ratio between the Vertical and Horizontal Time Scores provides a quantitative comparison of both scores at once. Four interpretations of the results are possible:

1. The child may display normal scores for both the Horizontal and Vertical Times resulting in a normal ratio. This would indicate a child with both normal number calling skills and normal saccadic skills.
2. The time scores for completing the Horizontal Test may be increased while the score for the Vertical Test is normal. In this case, the ratio would be

abnormally high. This type of performance is indicative of a child with an oculomotor dysfunction.

3. Increased time scores for both the Horizontal and Vertical Tests results in a normal ratio. This would indicate a child with difficulties in automaticity of number calling but not in ocular motility skills. The increased Horizontal Test time score, in the presence of a normal ratio between Horizontal and Vertical times, result from the increased time to recognize, interpret, and call out the numbers.
4. If the Horizontal and Vertical Test times are both abnormally high and the ratio is also high, the child can be diagnosed with deficiencies in both automaticity and eye tracking skills.

### Observational Saccades

Observational saccades are based on monitoring several aspects of the patient's behavior while specific eye movements are being made. During this evaluation, the practitioner assesses the child's ability to make accurate saccadic fixations, to move the eyes without head or body movement, without random motor overflow, to perform the task automatically with minimal effort, and to respond appropriately to the instructional set.<sup>35</sup> Numerous variables can cause both different observers and even the same observer over time to reach different conclusions about the status of a child's saccadic eye movements. Head movements, body posture, target characteristics, how the target is moved, instructional sets, and test distance are just a few of the variables that can affect the interpretation of saccadic skills.<sup>36</sup>

The Northeastern State University College Of Optometry (NSUCO) Oculomotor Test attempts to solve these prob-

lems by standardizing both the procedures and scoring criteria for observational saccades and pursuits.<sup>26</sup> The targets used for testing consist of 1/2 cm. colored gold and silver spheres attached to dowel rods (Wolff wands) or Disney type character targets attached to pencils. Since these targets do not involve letters, words, or numbers, no comprehension skills are involved for this task. Four parameters are evaluated. Ability (sustaining power), accuracy of the saccades, the degree of head movements, and the degree of body movements have been normed into standard scores for both age and grade levels. Each of the four areas is rated with a score of 1 to 5. Although the reliability of quantifying saccadic and pursuit eye movements by subjective observation might be questioned, recent studies indicate strong inter-rater and test-retest reliability.<sup>36</sup>

Using the criteria established for the NSUCO Oculomotor Test, Maples and Ficklin<sup>37</sup> found that the scores for observational saccades and pursuits were significantly higher for those children reading above grade level than those children reading below their grade level.

### Visagraph/Eye Trac

Several electronic devices have been marketed to measure eye tracking skills. These include the Eye Trac<sup>b</sup> and the Visagraph Eye Movement Recording System.<sup>5,c</sup> Neither of these devices are currently in production. The Eye Trac (Model 106) is a self-contained monitor and strip chart recorder. The subject is positioned in a chin/head rest and required to read selected test passages. Eye movements are evaluated by monitoring limbal reflectance. Analysis of the strip chart recordings can be time consuming, laborious, and left to the subjective interpretation of the clinician.

The Visagraph is a computerized (Apple II) instrument that monitors the subject's eye movements using infrared photocells. The subject must be properly aligned in the instrument for accurate recordings. Head and body movements must be minimized for recording alignment to be maintained. The Visagraph, however, uses computer software to objectively analyze the recordings. Subjective interpretation by the practitioner is minimal. The Visagraph automatically calculates several eye tracking components including fixations, regressions, directional at-

tack (left to right tendency), average span of recognition, average duration of fixation, reading rate with rereading, reading rate without rereading, grade equivalency, and relative eye movement efficiency. The actual eye movement recordings can also be printed and analyzed by the practitioner. Similar results can be obtained with the Eye Trac, but the measurements and calculations have to be made by hand.

Although the Visagraph is a useful diagnostic tool, it does have several limitations. Younger children (grade 3 and below) can be difficult to test. Once the child is aligned in the instrument, if head movements occur proper recording alignment is lost. Positioning can be very difficult with reading-disabled children, especially those with hyperactive behavior. The story to be read is presented on a computer screen while the subject is positioned in the Visagraph's recording hood in a somewhat awkward reading posture. Both of these conditions create an unnatural reading posture during testing.

When using the Visagraph, it is useful to list the major words found in the testing passages in vertical columns on a printed page. The child is asked to read these words aloud and questioned about their meaning. If unable to do so, the next lower grade level passage is tried. Testing on the Visagraph begins with a story in which the child can easily recognize and understand the words if previewed in vertical columns. If the child can read and recognize the words when presented vertically, but displays decreased saccadic skills when tracking the same words arranged horizontally, compromised saccadic skills should be suspected. It is also useful to compare the patient's eye tracking ability at this level to his/her tracking ability with grade level reading material.

### Diagnosing Deficient Saccadic Eye Movements

The final diagnosis should be based upon the child's performance on several of these tests. Observational saccades, for example, provide information about the child's ability to make accurate and sustained saccadic eye movements when no comprehension is involved. The DEM and K-D test evaluate saccades when only number recognition is required. The DEM can further differentiate between decreased tracking skills and decreased number automaticity. The Visagraph re-

cordings can expand this information by evaluating saccades, fixations, regressions, and the span of recognition when reading for comprehension is required. Interpreting the results of these tests also assumes that the child has normal accommodative, vergence, binocular control, acuities, and that refractive errors have been corrected. Deficiencies in any of these areas could result in decreased performance on the above tests even though saccadic eye movements were normal.

### Maturation and The Development of Saccadic Skills

When the preschool child looks back and forth between two targets separated by a few inches, head and neck movements are typically utilized to redirect gaze from one target to the next. Minimal eye movements are made. By age 4 or 5, head and body movements still support the task, but eye movements should now lead the activity. The 5-year-old, when instructed, should be able to partially or fully inhibit head movements and accomplish this activity by eye movements alone. By age 6 or 7, the child should be able to redirect gaze between non-verbal targets without head or body movement support.<sup>38,39</sup> The school-age child who uses head and body movements instead of saccadic eye movement skills to read, demonstrates immaturity and inefficient performance. The use of head and body movements rather than eye movements is disadvantageous for several reasons. Eye movements are finely controlled compared to the grosser movements accomplished by the head and neck. Eye movements, when properly controlled, tend to be faster, more accurate, and more efficient. Head movements require a greater expenditure of energy and are more subject to fatigue. Rapid head movements may also cause some degree of disorientation in space.<sup>35</sup> Since saccadic eye movements are a learned skill, using head movements as a substitute contributes to potential developmental delay in learning saccadic control.

Saccadic eye movement skill tends to improve with maturation and reading experience.<sup>3,26</sup> The data presented in Table 1<sup>3</sup> indicate that both the number of fixations and regressive eye movements tend to decrease with grade level. The span of recognition becomes wider<sup>7,8</sup> and the duration of fixation tends to become shorter. As expected, reading rate (words

Grade	1	2	3	4	5	6	7	8	9	10	11	12
Fixations per 100 words	224	174	155	139	129	120	114	109	105	101	96	94
Regressions per 100 words	52	40	35	31	28	25	23	21	20	19	18	17
Average Span of Recognition (in words)	.46	.57	.65	.72	.78	.83	.88	.92	.95	.99	1.04	1.06
Average Duration of Fixation (seconds)	.33	.30	.28	.27	.27	.27	.27	.27	.27	.26	.26	.25
Reading Rate (Words/Minute)	80	115	138	158	173	185	195	204	214	224	237	250

Table 1. Grade Level Norms For The Components of Saccadic Eye Movements

per minute) increases significantly with grade level. Beginning readers do not have the control over their eye movements that experienced readers do. Nor do they use their parafoveal vision effectively for ocular motor guidance. Since these components of eye tracking improve with learning and experience, it is axiomatic that children with decreased saccadic eye movements can be taught this skill with the appropriate remedial therapeutic techniques.

### Therapy

A review of the literature<sup>35,40-42</sup> reveals numerous techniques for improving saccadic eye movement skills. Many of these procedures are also used to enhance other aspects of a patient's visual motor performance. In clinical therapy programs, saccadic skills are seldomly treated in isolation. Therapy regimens often include procedures to enhance accommodation, vergence control, eye-hand coordination, posture, balance, visual motor integration, and visual perceptual skills. The discussion that follows, however, has isolated procedures that pertain specifically to enhancing eye tracking.

Eye movement therapy generally begins by developing strong binocular fixation, accommodative, and vergence control skills. Attempting eye movement therapy in the presence of unsteady central fixation skills will impede progress. Visual memory skills should also be at age level. The child should have tachistoscopic skills that meet criteria suggested by Solan et al.<sup>42-44</sup> Tachistoscopic skills reflect several areas of visual processing that are frequently associated with academic achievers. These include short term visual memory, central fixation, rehearsal prior to storing the target stimulus, encoding, accuracy and automaticity, and perceptual speed.

Saccadic therapy should begin with targets requiring minimal or no number, letter, or word recognition. As skill is gained, target complexity should be increased and target size should decrease. Depending upon the severity of the deficit, these procedures can be introduced monocularly before binocular training begins. All therapy procedures should strive to minimize or eliminate head and body movement. Using a finger as a marker for tracking during therapy should also be avoided. If the child has difficulty controlling head movements during therapy, balance a small, dry sponge or plastic block on the child's head. This technique can be utilized on most tracking activities, but eventually the child should master the task without the tactile reminder. Birnbaum<sup>35</sup> has criticized the use of a balanced sponge since it creates an unnatural head and neck posture during therapy. The efficacy of using visual therapy to develop saccadic eye movement skills is well documented in the literature.<sup>46-52</sup> There is general consensus that improving saccadic tracking skills per se may not improve reading or academic ability.

### Nearpoint of Convergence Rod or Brock String

Although this procedure is usually associated with binocular vision and antisuppression therapy, it can also be a valuable procedure for developing accurate fixation skills under binocular conditions. Three to five beads are spaced on a short rod or length of string. The patient is instructed to alternate fixation and focus from one bead to the next while maintaining awareness of physiological diplopia. The three bead convergence rod is illustrated in Figure 2.

### Prism Saccades<sup>53</sup>

A small target (colored circle or child's



Figure 2. Therapy procedure utilizing the Nearpoint Of Convergence Rod.

sticker) is placed on a chalkboard or blank wall at eye level. The child sits or stands 10 or 15 feet from the target. One eye is occluded and the child is instructed to fixate the target. A loose prism in the 10 to 15 diopter range is introduced before the fixating eye. The child is instructed to refixate the displaced target, point to it, and tell which direction the target appeared to jump (right, down, up and left, etc.). A flashlight pointer can be used as an alternative to pointing with the arm and hand. Training should begin by initially displacing the target in vertical directions, then horizontally, and finally obliquely. As skill is gained, gradually reduce the prism strength until the patient can no longer discern any target displacement. Depending upon the patient's age, 1 to 2 prism diopters is often the goal. This technique should then be repeated for the other eye. This procedure develops monocular saccadic ability as well as accurate spatial judgments.

### Wayne Saccadic Fixator (WSF)<sup>d</sup>

The WSF, displayed in Figure 3, is a computerized instrument consisting of a 29x29-inch board that contains thirty three 1/2 inch diameter light switches. A computer chip is preprogrammed to control the location and length of illumination for each light. When a light is illuminated, the patient must depress the lighted switch. The computer chip counts the number of lights scored and time to depress the light. Numerous visual skills can be enhanced with this device since eye-hand coordination, visual reaction time,



Figure 3. The Wayne Saccadic Fixator

saccadic eye movements, and peripheral awareness are required to maximize scoring ability. The instrument is preprogrammed with numerous routines for developing eye hand coordination and eye movement skills.

Preprogrammed procedure #51 is very applicable for the initial development of gross saccadic eye movements. The procedure illuminates only the 16 light switches in the outer circle (diameter of outer circle of lights = 28 inches). Each of these light switches has a letter next to it. The instrument is placed at eye level. The patient stands 3 to 5 feet from the WSF. To begin, the child simply looks at and points to each illuminated light with his extended arm and pointing finger. Next, the child is moved close enough to the instrument so that the light switches can be depressed when illuminated. The speed of presentation is set sufficiently slow so that the child has ample time to respond to each light. Finally, the child is moved 3 to 10 feet from the WSF. As the lights are illuminated, the patient is asked to call out the letter next to the light. Again, the initial display speed is set so that success is easily achieved.

Some patients tend to make excessive head and body movements while doing WSF activities. It is important for the optometrist to remind the patient not to move his/her head or body (except, of course, when light switches are to be depressed). Balancing a sponge on the patient's head while calling out the letters on WSF procedure #51 can be an effective measure for controlling excessive head movements.

In addition to developing large angle saccadic eye movements, the WSF also trains peripheral awareness, reaction time, and eye-hand coordination. Patients, especially children, find this instrument challenging and motivating to use.

### **Saccades in the Primary Meridians:**

This procedure begins by asking the patient to look back and forth between his/her two extended thumbs. Since the individual's own thumbs are used, the task creates kinesthetic feedback and facilitates awareness of position in space. It is important that no head or body movements are made to support the tracking task. The patient should be peripherally aware of the opposite thumb before the saccade is made. As skill is gained, substi-

tute non-verbal targets (cartoon characters, colored dots, etc) held by the therapist. Separation of the targets can be varied between 1 and 24 inches. This procedure should be practiced both while the child is seated and standing with equal weight on both feet. As skill is gained, this task can be practiced while maintaining balance on a balance board. A metronome can also be incorporated to create auditory integration and timing demands.

The final goal for this procedure requires the patient to rock back and forth on a balance board, in time to a beating metronome, while making accurate saccades between two targets (separated by 5 to 10 inches) held by the therapist.

### **Four Corner Fixations:**

For this procedure, four targets (various colored circles, X's on a chalkboard, or pictures/shapes on index cards) are placed at the corners of an imaginary square on a blank wall or chalkboard. A fifth target is placed at eye level in the center of the square. Target separation begins at 12 to 24 inches but should eventually be decreased to 2 to 3 inches. The patient is instructed to be peripherally aware of the next target before an eye movement is made. The subject stands or sits 3 to 5 feet from the targets.

Set a metronome at 60 beats per minute. The patient is instructed to fixate the center target for four beats, then switch fixation to one of the corner targets for four beats, then back to the center target. This task continues until all four corners have been fixated and is then repeated for a specified number of repetitions.

As skill is gained, ask the patient to repeat the above, but to call out the direction of the next corner to be fixated: for example, top right, bottom left, etc.

Motor and auditory integration can be introduced by instructing the patient to look at the corner target and call out the direction of this target on the first beat of the metronome, look at and point to the second corner target on the second beat, lower his/her arm and fixate the third corner on the third beat, and fixate the fourth corner target on the fourth beat. This cycle is repeated several times.

### **Central Peripheral Saccades<sup>39</sup> (Figure 4)**

This is a versatile activity that can be utilized to develop several visual skills, including saccadic eye movements, pe-



*Figure 4. Central Peripheral Saccades using a Hart Chart for fixation target.*

ripheral awareness, timing, and eye-hand coordination. A chalkboard, 2 wooden dowel pointers, 2 flashlights, and a metronome are needed. A fixation target is placed at eye level on the chalkboard. Several, various sized (3 to 4 inches) circles are drawn around and at varying distances from the central fixation target. The patient is instructed to grasp a dowel pointer with both hands and slowly move the pointer to the center of one of the circles while fixating the central target. The kinesthetic involvement provides additional feedback for performance accuracy as well as clues for spatial location of the target. The patient should be peripherally aware of the circle and the movement of the pointer as it approaches the peripheral target. Fixation should remain on the central target while the therapist observes the patient's eyes to ensure that no eye movements are being made. Once the pointer has been placed, the patient should then look at the tip of the pointer to determine the accuracy of its placement. At this level, peripheral awareness during central fixation is being developed.

To increase the level of difficulty, increase the number of circles, decrease circle diameter, or practice this procedure while maintaining balance on a balance board.

As skill is gained, replace the pointer with a flashlight held in each hand. Replace the central fixation target with a Hart Chart which is a grid of 10x10 letters. Figure 4 illustrates a patient using pointers and a Hart Chart while practicing the Central Peripheral Saccades procedure. The patient is instructed to read a letter on the chart and direct the beam of each flashlight on one of the peripheral circles. Both lights should be moved simultaneously when directed toward the circles. If difficult, begin with a single flashlight grasped with both hands. The sequence of reading a letter and redirecting the flashlights continues for a specified number of cycles.

Once mastered at this level, the entire procedure is practiced to the beat of a metronome and on a balance board. Body posture should be carefully monitored for this task. The child stands with equal weight on both feet; the head should be straight and level; no head or body movements should be made to accomplish this task other than the required arm movements. If a large chalkboard is not available, circular targets can be cut from index cards or construction paper and taped to a blank wall.

### Ann Arbor Letter Tracking Books<sup>e</sup>

This workbook contains "paragraphs" (6 to 8 lines) of random letter combinations arranged into nonsense words:

mox ziln chako evin nomud zeby thi pig  
zuth pirm nuroc dif stok nileg myt lof  
tixsot num raus zab tuin lugah marb

The first and last letter of each line can be read emphasizing the return sweep saccade. The first letter of each "word group" can be read. To increase difficulty further, instruct the patient to read the second letter of each letter group. Both of these activities should be timed. Progress can be monitored by noting improvements in completion times and reduction in errors. Improvements in training times reflects the increased speed and efficiency of saccadic performance. Difficulty levels can be increased by having these procedures practiced to the beat of a metronome.

Each paragraph of nonsense words in the Letter Tracking Workbook actually has the letters "a" through "z" embedded in alphabetical order. The final activity consists of instructing the patient to search for the letters of the alphabet in order in each paragraph. The child finds and circles each letter consecutively. Improvement is monitored by noting decreased errors and completion times.

The Ann Arbor Sentence Tracking, High Frequency Word Tracking, Limerick Tracking, and Thought Tracking Workbooks all provide variety and challenge for saccadic eye movement therapy.

### Computer Therapy

In addition to the therapy options discussed, I incorporate several computer programs, which I have developed for IBM compatible computers, into the patient's therapy regimen. The main menu screen for Visual Skills I<sup>1</sup> is depicted in Figure 5. This module contains eight pro-

cedures for developing saccadic eye movement skills.

I begin computer therapy with the Visual Fixation module. The patient is instructed to fixate the center of the screen as numbers are tachistoscopically presented at a predefined display speed between two screen brackets. The patient responds by pressing the space bar when the number 5 is randomly presented. The patient must correctly respond to the number 5 while it is displayed to receive a "correct" score. At this level of therapy, only visual fixation, attention, and reaction times are being developed. No eye movements are required to accomplish the task and comprehension involves only the recognition of the number 5. Task difficulty can also be increased by employing prism and lens flippers during the activity.

Therapy continues by developing visual memory skills through the tachistoscopic presentation of random number and letter sequences. Practice continues until the patient achieves age-appropriate performance as suggested by Solan.<sup>43-45</sup> Success in tachistoscopic therapy requires the patient to develop steady central fixation and visual sequential memory skills. Computer systems provide an excellent tool for tachistoscopic therapy since target size, type, color, and speed of presentation can be readily controlled by the therapist.

When the patient has gained appropriate fixation and tachistoscopic visual memory skills, therapy continues with the Span of Recognition program. The patient is now instructed to fixate the central screen as a 3 digit number is tachistoscopically presented. Each time the number is correctly identified, the two end digits are separated. If an incorrect response is made, the separation is reduced. This therapy again requires accurate fixation skills and peripheral target recognition. Eye movements are not utilized to accomplish this task.

Eye movement therapy begins with the Random Saccades module. In this program, a single digit number is presented at screen center between two brackets for a predetermined display time. A second number is then presented at a random peripheral location. The patient is instructed to use eye movements to look from the central number to the peripheral number and to press the space bar if the number 5 is displayed. The response must occur during the display time to receive a correct score. This activity continues at a prede-



Figure 5. Main Menu screen for Visual Skills I computer therapy program.

termined display rate for a specified training time. Saccadic eye movements, fixation skills, and visual reaction times must be integrated to achieve success in this module. Comprehension skills are minimized since only the number 5 must be recognized.

Saccadic eye movement therapy continues with the Number Saccades program. In this module, random, single digit numbers are tachistoscopically presented across the screen one line at a time. The child is instructed to track the numbers and to press the space bar on the keyboard each time the number 5 is presented. This task requires accurate saccadic eye movements but only minimal cognitive processing since only the shape "5" has to be recognized. The child does not have to say or even know the other numbers. The number of digits per line and the speed of presentation can be varied. Return sweep saccades can be enhanced by specifying only two numbers per line.

As skill is gained, therapy should continue with the Sequential Saccades module. A random, target sequence of 2 to 5 characters is generated and shown to the patient. This becomes the sequence the patient must recognize during the tracking task. Random sequences are then tachistoscopically presented across the monitor. The child utilizes eye movements to track each sequence. The patient is instructed to press the space bar each time the target sequence is displayed. This module requires pattern recognition, visual sequential memory and accurate saccadic eye movements to achieve success. This therapy creates ocular-motor and visual processing demands that are similar to those utilized for reading, yet no word recognition or comprehension skills are required.

The Word Saccades module requires a higher level of processing and tracking. In this module, a grade-appropriate word is randomly chosen as the target sequence. Random nonsense sequences, with the



same number of characters as the target word, are then tachistoscopically displayed across the screen. The patient is instructed to track each sequence and to press the space bar if the target word appears. This task requires a higher level of cognitive processing during tracking since the patient must decide if each displayed sequence is a word or merely a nonsense sequence. Although Figure 6 shows all sequences displayed at once, during therapy the sequences would be tachistoscopically displayed one at a time. Figure 7 displays a score screen for Word Saccades. The graph depicts the improvements in display speed that occurred during the ten therapy trials. The Number, Sequential, and Word Saccade therapy modules all have similar score and graphing options for charting therapy results.

Computer software can offer several advantages in vision therapy programs. Since children and adults both have a high interest in working at the computer, compliance is high and easily monitored. Computers allow easy control of target size, type, color, rate of movement, and display speeds. Scores, practice times, and results of therapy sessions can be printed and filed in patient records. Since many patients have IBM compatible computers at home, software can be loaned for home therapy sessions and printed results can be returned to the office for practitioner review. Compliance and progress for home therapy programs can be easily monitored.

Computers also provide a convenient tool for positive feedback during therapy. In the software discussed, for example, autopacing options make the task harder each time a correct response occurs and easier when an incorrect response is made. This type of feedback loop both challenges the patient and allows therapy to occur at an appropriate level of difficulty for each individual patient.

## Conclusions

Current research does not provide conclusive positive or negative support for a causal relationship between reading disabilities and decreased saccadic eye movement skills. Nevertheless, clinical testing frequently reveals many children with reading disorders who are unable to achieve age level scores when tracking non verbal targets. Many reading disabled children appear to have normal saccadic skills when tested in isolation, but fre-

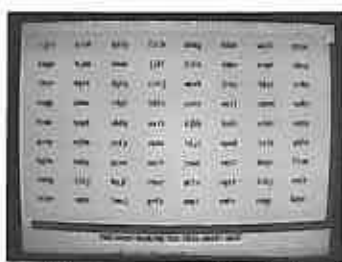


Figure 6. Therapy screen for the Word Saccades procedure in Visual Skills I.

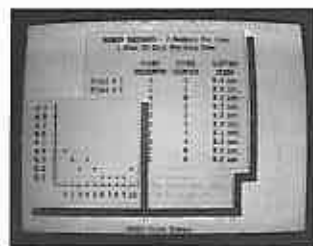


Figure 7. Score screen and graphical results for Word Saccades therapy session.

quently have difficulties when attempting to integrate eye tracking tasks with other oculomotor or gross motor skills. Furthermore, since saccadic eye movements are an integral part of the reading process, even those patients who are able to track non-verbal targets successfully, but whose saccadic ability deteriorates when linguistic symbols are used, should be identified and treated. Although this article has reviewed several therapeutic procedures for developing tracking skills, there are many equally effective clinical techniques that have not been discussed.

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### EDITORIAL continued from page 2

This is something that optometry has always known and on which it has based its reason for being. It is something that ophthalmology apparently didn't know—it needed a study to become aware of it—and points out the dangers of overspecialization. I believe there's a lesson here for optometry; it is the potential risk of placing such emphasis on any relatively new area of care, however seductive, so that the more conventional areas—refraction, low vision, vision therapy and contact lenses—gradually become relegated to a secondary role. We need to keep this in mind as new residency programs are planned, and we need to reassess all of our clinical educational programs to guard against a creeping deemphasis on preventative and rehabilitative eye care. Here's a case where we can learn from ophthalmology and not take the same road they followed, but are now planning to leave.

The sixth recommendation states that there should be further study and discussion on:

- How can the delivery of eye care by different providers be better integrated and coordinated to meet the needs of the public?
- How could the education and credentialing of eye care providers be better integrated in order to enhance the provision of care to the public?<sup>2</sup>(p.19)

The discussion under this recommendation points out the differences in education, modes of practice and interprofessional networking among the various disciplines engaged in ophthalmic practice. It points out that the lack of integration and coordination of training programs leads to a system of less than optimal patient care, with accompanying duplicative services and increased costs. An integrated educational system with a linked credentialing process is advocated.

Now, while these negatives are valid points, the proposed solution of a single, albeit integrated education system does raise some concerns. First, who would be the major planner and implementer of this system; who would be captain of the team? Further, would a single integrated educational system for opticians, optometric technicians and assistants, ophthalmic nurses, ophthalmologists and optometrists necessarily benefit the public? The argument can be made that nursing was previously dependent upon a similar system, but has found it necessary to increasingly distance itself from it. Further, a great benefit to the public has been two different systems of education between optometry and ophthalmology. It has provided a check and balance situation along with treatment options for patients that would probably be difficult to maintain under an integrated system. And, of course, there is the possibility that this is a velvet glove approach on the part of ophthalmology to establish a greater degree of control and limit the increasing independence of the other eye care professions.

Optometry has undergone profound changes in the past two decades. By contrast, ophthalmology has not. The RAND report signals the beginning of a metamorphosis. There are once again prevailing winds of change that will affect us. My advice to optometrists and optometry ... the price of independence is vigilance ... fasten your seat belts!

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