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THE EFFICACY OF OPTOMETRIC VISION TRAINING FOR ALTERING EYE MOVEMENT PATTERNS--A LITERATURE REVIEW

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ABSTRACT

It has been shown that people who exhibit inadequate reading performance often have deficient eye movement skills. Inefficient readers may demonstrate poor fixations, regressions, saccades or any combination of these factors. Can eye movements be altered or improved by instituting a program of visual training? Will reading performance increase as a result of more efficient eye movement patterns? It is the intent of this review to explore these relationships and to show that there is indeed a correlation between eye movements and reading performance. This review examines and asks several questions: (1) Where should the focus of a remedial effort be focused for those persons exhibiting poor reading ability and concurrently demonstrating inefficient eye movement skills? (2) What are the possible causes of deficient eye movements and/or reading ability? (3) Background physiological information about eye movements and their recording systems are presented. (4) Several studies dealing with the modification of eye movements are reviewed. (5) Finally, concluding remarks are offered as to what inferences and conclusions can be drawn from the available literature.

KEY WORDS

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INTRODUCTION

There exists widespread belief in the optometric community that eye movements and their patterns exhibited while reading can be enhanced by visual training. However, there are a significant number of educators, psychologists, medical professionals and even optometrists who have expressed doubts in the perceptual-motor system's ability to be altered via perceptual-motor training. The majority of the ophthalmological community has been especially critical of behavioral optometry's approach to eye movements and eye movement enhancement. Erratic ocular motor functioning (e.g. fixation or regressions measured on an ophthalmograph) are *symptoms*, or even *effects*, of a reading problem according to the ophthalmological perspective. In short, they are the symptoms, not the causes, of reading difficulties and inefficiencies.[45,51,52,53] If this, then, is true, previously deficient eye movements should become more efficient as a result of reading remediation alone. Behavioral optometry views poor or inefficient eye movements as either being a *cause* or a contributor to a reading problem. It then follows that optometric vision training combined with reading remediation should improve poor eye movement skills and possibly even reading "ability." Many siding with the behavioral optometry opinion feel efficient eye movements are fundamental for sound reading. And that to achieve full potential, both vision therapy and reading remediation must be administered. In short, much confusion exists as to the appropriate treatment of inefficient eye movement skills so often exhibited by poor readers. For behavioral optometry to convince other disciplines that optometric vision training can play a key role in the remediation of a reading problem, more compelling evidence is needed.

In an attempt to more closely examine how deficient eye movements affect reading performance, it becomes necessary to look at those individuals exhibiting "poor" reading skills. "Poor" reading skills have been defined several different ways. First, there are those who perform poorly on standardized reading tests and who report complaints of reading slow and laboriously. Second, there are individuals who perform average or better than average on standardized reading tests, yet they, too, report an inability to read rapidly and still maintain the level of comprehension they exhibit on a standardized reading test.[1] Both groups may present with symptoms while reading such as tiring easily, developing headaches shortly after beginning reading, "tearing" after prolonged reading, confusing similar letters or words, seeing double, loosing their place, increasing difficulty in reading as the letter size decreases and slow copying material from a blackboard. These individuals also tend to concentrate poorly, take frequent breaks from reading or they may opt for complete aversion from all reading or nearpoint tasks.[14,15,23] Cytoarchitectonic, neuropsychologic, neurophysiologic and radiologic research is beginning to show a possible causal relationship between anomalous neural structure with in the language zones of the left hemisphere and reading disorders. It has been hypothesized that visual information is processed by two separate pathways: a Magnocellular (M-Cell) pathway, which processes information about "coarse" form carried by lower spatial frequencies and a Parvocellular (P-Cell) pathway, which processes information about "local detail" carried by higher spatial frequencies. There also appears to be a *sequence* to the flow of visual information processed by these two pathways. This underscores the importance of the *temporal* order at which visual information flows along the retinogeniculocortical pathways. If this normal order or flow is disrupted by altering the relative contributions of the two pathways or in the speeds at which each processes its visual information, visual deficits would be expected--possibly in the form of a reading disorder.[74,75]

Research on developmental reading disabilities has not elucidated the etiologic factors that underlie this cognitive disorder. It is thought that "just as there are varieties of acquired reading disability caused by lesions in different areas of the brain, there are varieties of developmental reading deficits." At least two subgroups can be characterized via a neuropsychogical assessment: auditory-linguistic dyslexia and visual-spatial dyslexia. Auditory-linguistic dyslexics, which greatly outnumber those with visual-spatial deficits, show no evidence of eye movement disorders, either during reading or while performing nonreading tasks. Visual-spatial dyslexics, however, do show a number of eye movement anomalies (such as faulty oculomotor scanning strategies during reading), but these anomalies "probably result from poor visual-spatial programming of saccadic eye movements rather then from impairments in the motor mechanisms that trigger ocular movement."[74]

In addition to developmental or neurological etiologies affecting eye movements and/or reading skill, a disturbance within the accommodative-convergence system(s) has also been postulated. Oculomotor signs seen in these individuals may include high exo phoria at near, a receded NPC, hyperopia, anisometropia, aniseikonia, fusional vergence deficiency, a large "lag" of accommodation or rather, poor accommodative accuracy and an inability to suppress the occipital alpha rhythm during visual information processing.[2,3,8,14,16,18,19,23,25,27] It is thought that no single oculomotor function consistently relates to poor reading ability at a statistically significant level. It is also unknown whether poor performance in one oculomotor function can be compensated for by superior performance in another. However, it appears as though problems in the area of vision, as they relate to reading ability, often result from a disturbance in the accommodative-convergence relationship.[8,13] However, it is neither the scope, nor the aim, of this review to examine accommodative-convergence or refractive anomalies as they relate to reading ability. Rather, we wish to examine studies performed on subjects who demonstrate deficient visual information processing, possibly the result of inefficient eye movement patterns. An effective way to explore this is to look at eye movements exhibited while reading.

Reading involves four primary eye movement components: fixations, regressions, saccades and rate of reading with adequate comprehension. And from these components, duration of fixation and span of recognition may be calculated. A reader extracts information from the material being read during a fixation, which are reflexive movements that position the image of a stationary target upon the fovea and consume approximately 90% of time spent reading. The perceptual span of the fovea is small, approximately five to eight characters per fixation--this is referred to as a *semantic span*. However, useful information, word length, for example, may include 12 to 15 characters per fixation. As a result, most readers "see" more than one word per fixation. This indicates a portion of the characters fall in the parafoveal region. In English speaking and reading countries, these parafoveal characters are to the right of fixation. To the left of fixation, studies have shown a maximum of four characters of useful information are taken in per fixation. This asymmetry to the right implies that most of the useful information is transmitted first to the left hemisphere from the extended right visual field. It is thought by several investigators that this asymmetric shift is determined by attentional factors that develop as a result of the direction of reading and the principal direction of eye movements while reading. The duration of fixation in the majority of readers is influenced, and gradually decreases, with age--most of this reduction takes place by the fourth grade. Other factors shown to influence the duration of fixation are the difficulty of the text and the comprehension required during the reading task. Poor readers often demonstrate an excessive amount of fixations, regardless of the difficulty of the material being read. In contrast skilled readers most often exhibit fewer fixations than do non-skilled readers.[1,23,27]

A "fixation maintenance system" helps to hold the position of an object of interest in a stable position on retinal foveal receptors. This is so the object can be viewed by the foveal area having the highest visual acuity without a fading of the visual image--the Troxler Phenomena. Yet, stable fixation on a visual target is not associated with a lack of eye movement. There are three innate eye movements within this "fixation maintenance system": a series of residual, small angle slow drifts; microsaccades; and high frequency tremors. Slow drifts are a monocular phenomenon with amplitudes up to six minutes of arc. Superimposed over the slow drifts are high frequency tremors, having frequencies of thirty to eighty Hz and amplitudes of ten to thirty seconds of arc. The etiology and exact function of these high frequency tremors is unknown and can only be detected with very fine recording devices. Microsaccades, which are binocularly correlated, having amplitudes of up to twenty minutes of arc, tend to be a corrective type of movement that returns the individual's attention to the optimal point of foveal fixation following a slow drift. Microsaccades and slow drifts occur depending upon both the attention and perceptual factors exerted by an individual.[60,62,63,64,65,66]

Each fixation is separated by a saccade, which brings a new portion of the page into the foveal region for analysis and information processing. Saccades are considered to be high-velocity (up to 400 degrees per second), all-or-none, learned eye movements that develop at an early age. The stimulus for the initiation of a horizontal saccade is the difference in retinal position between the fovea and the image of an intended target. This is presumed to be mediated by the fronto-mesencephalic pathway. The neural pathway is from the posterior end of the middle frontal gyrus (Area #8) to the conjugate gaze centers in the midbrain and on to the third, fourth and sixth cranial nerve nuclei, which innervate the six extraocular muscles of the eye. In addition to these frontal eye fields, the superior colliculus, the cerebellum and the pontine reticular formation are involved with saccadic eye movements. Whereas the frontal eye fields compute the size of a saccade, it is the cerebellum, which computes target position and integrates this with visual and vestibular information, that determines the precision of a saccade.[1,36,55,64]

While reading, a single saccade takes approximately 20 msec. However, during this time visual information is not presented to the brain continually, but in short intervals that correspond to the saccadic eye movements. This oscillation of visual information received during a saccade, reduces blur or illusory movement of the visual scene. Research indicates that the threshold for perceiving visual information is raised during a saccade and for a short time before and after a saccade. The perception begins approximately 20 msec prior to a saccade and lasts for 75 msec afterward. Thus, little, if any, visual information is acquired during this time. Saccades may range in size from two to sixty degrees, depending upon the stimulus location in the frontal eye fields. The average length of a saccade is seven to ten characters in a good reader and is substantially reduced in the learning disabled, where problematic saccades show up as letter and word reversals; loss of place; skipped lines; omitted or inserted words; or the need for a motor reinforcement such as a finger following the material or a compensatory head movement.[2,9,23]

Regressions are the *right to left* eye movements used while reading to verify a textual element, to re-examine a word that was previously inadequately perceived or they may be merely poor oculomotor habits. In normal readers, they consume from ten to twenty percent of the total reading time--it is when regressions consume in excess of twenty percent of total reading time that reading becomes inefficient. "Reading-disabled" individuals often exhibit a higher number of regressions than do normal readers. Studies also show that as the difficulty of the material being read increases, the number of regressions do as well.[1,12]

Table 1 illustrates eye movement norms compiled by E.A. Taylor in 1942 from over 5000 recordings.

Table 1. Eye movement norms by grade level.

	1st	2nd	3rd	4th	5th	6th	Junior High	High School	College
Fixation per 100 words	240	200	170	136	118	105	95	83	75
Regressions per 100 words	55	45	37	30	26	23	18	15	11
Average Span of Recognition (Words per Fixation)	0.42	0.50	0.59	0.73	0.85	0.95	1.05	1.21	340
Rate of Comprehension (Words per Minute)	75	100	138	180	216	235	255	296	340

In an attempt to more closely assess eye movement patterns used while reading, several objective eye movement recording systems are used. Electro-oculography (EOG) is the most commonly used method of recording eye movements. A small, corneo-retinal electrical potential of approximately 1mV is present, with the cornea being more positively charged with respect to the posterior pole. Active skin electrodes are placed at the inner and outer canthi to record horizontal movements and above and below the eye to record vertical movements. As the cornea moves in the direction of one pair of electrodes, it records a positive change in electrical potential--the amplitude of which is proportional to the amplitude of the eye movement. The other electrode records a negative change in electrical potential of equal amplitude. Differential amplifiers increase the size of the potential changes and the electrical signals resulting from changes in eye position are displayed on a polygraph. EOG recording has several advantages: it uses relatively inexpensive equipment, is comfortable for the patient and glasses can be worn throughout the testing. It also has a relatively large range of accurate recording, with a linear relationship between potential changes and amplitude of eye movements up to approximately thirty-five degrees in both of the horizontal directions. Potential limitations with monocular EOG recordings result from asymmetric signals between movements in the nasal and temporal direction in the orbit. In a subject with a prominent nose bridge, the nasal skin electrode is farther from the corneo-retinal dipole than is the temporal electrode. This results in a smaller potential change for movements from primary gaze into the nasal field. Also, in most subjects EOG is not reliable for recording vertical eye movements because of electrical "artifacts" caused by eyelid movements.[36]

Infra-red scleral reflection techniques record eye movements by monitoring the position of the corneal limbus. A small infra-red light source mounted on a spectacle frame illuminates the anterior surface of the eye. The light is reflected and two infra-red sensitive photoelectric cells intercept the reflected light. To record horizontal eye movements the cells are placed so their receptive fields are located near the nasal and temporal limbus. The amount of light received by the cells is proportional to the voltage that is generated. As the eye moves, the cell in the direction of the movement receives less illumination since the infra-red light is absorbed by the iris. The other cell receives more illumination from light reflected off of the sclera. The amplitude of the potential change from the cells is proportional to that of the movement of the eye. This eye movement recording system can accurately record very small eye movements and have very little "noise." Primary drawbacks are that the linear range for horizontal movement is limited to approximately +/- fifteen degrees, which is sufficient to accurately record pursuits and saccades, but may be insufficient to record large amplitude nystagmus cycles of vestibular and optokinetic nystagmus. Also, vertical movements cannot be recorded easily and accurately, as the upper lid contributes to the electrical signal. Both the Eye Trac and the Visagraph are based on this recording system.[36,79]

Scleral search coil techniques are among the most sensitive, accurate and noise-free methods of measuring eye movements. In humans a fine wire is embedded in a large diameter soft contact lens annulus that fits flush to the surface of the globe, peripheral to the cornea. The subject's eye is centered within a large cube with pairs of horizontal and vertical coils. A magnetic field is generated by the large coils and movement of the scleral "search coil" on the eye generates a small current in the search coil that is proportional to the movement of the eye. This type of system can record eye movements as small a twenty minutes of arc, has very little noise and has a linear range of approximately +/- thirty to thirty-five degrees horizontally and vertically. This system can also accurately record vertical movements. Drawbacks include the relatively high cost and patient discomfort.[36]

The Purkinje-image tracker electronically tracks the position of the Purkinje-images that are formed by light illuminating the eye. The changes in the position of the images are proportional to movement of the globe. This system is "probably" the most sensitive and accurate technique of those previously discussed for tracking both horizontal and vertical eye movements. Drawbacks include the high cost of the system and the large amount of recording equipment that surrounds the subject, making presentation of visual stimuli and rotation of the subject in vestibular testing difficult. This method is "perhaps" most appropriately used for recording eye movements of limited amplitude.[36]

Subjective, indirect methods of evaluating eye movements are the Pierce Saccade Test and the NYSOA King-Devick Saccade Test. The Pierce Saccade Test was designed to evaluate an individual's gross saccadic eye movement development according to age expectancies. It consists of three subtests, each of which is a series of two laterally displaced numbers. The individual being tested is the asked to vocalize, as rapidly as possible, these laterally displaced numbers. Each of the three subtests is timed and the number of errors is recorded. For each subtest, the examiner can calculate the corrected score using the following formula:

$$\text{Corrected time score} = \frac{30}{30 - \text{errors}} \times \text{Time in seconds}$$

The total of the three corrected scores is determined and compared with the norms for the Pierce Saccade Test to judge the patient's chronological age equivalent. However, the saccades used on the Pierce test are gross and are not necessarily representative of saccades used while reading.[55,76]

The NYSOA King-Devick Saccade Test is a test of fine saccades, derived from the King-Devick Saccade Test, itself a modification of the Pierce Saccade Test. It consists of three norm-referenced tests in which an individual is asked to vocalize, as rapidly as possible, a series of forty horizontally arranged numbers on each test. The underlying assumption in both the Pierce and NYSOA King-Devick

Saccade Tests is the faster the individual completes the test, the more efficient and accurate the oculomotor performance. Conversely, slow performance indicates oculomotor inefficiency. Although this may indeed be the case, this interpretation tends to be an over-simplification. With the introduction of a visual-verbal variable (similar to the process of oral reading) present in both of these tests, interferences other than eye movement dysfunction can significantly influence the interpretation of such a saccadic test. Factors such as sustained visual attention, number recognition and retrieval, visual-verbal integration time, hesitation time between spoken names and vocalization time are a few of the associated factors that can influence the assumptions which underlie these two saccade tests.[76]

The Developmental Eye Movement test (DEM), a new visual-verbal automaticity saccade test, attempts to factor out the consequences of automaticity on oculomotor performance. To do this the DEM incorporates two vertical subtests consisting of forty numbers arranged into two vertical columns of equal length. A third subtest is comprised of eighty numbers arranged in a horizontal array of sixteen rows with five numbers in each. The first and fifth numbers of each row are in the same horizontal position as the preceding row. The spacing between the internal three numbers is random, thus making the DEM horizontal subtest more representative of saccades used while reading.[76]

METHODS

Of the seventy-eight articles, chapters, texts and symposiums read in preparation for this review, six studies were selected for an in-depth review and evaluation. These studies were chosen because they most accurately matched the central theme of this paper: "Can eye movement patterns be altered as a result of a program of visual training?" Specific research design criteria we looked for included:

(A). Were populations of subjects selected randomly?

(B). Were matched control groups used in conjunction with the population of subjects receiving visual training?

(C). Were the researchers, data collectors, and trainers "blind" with respect to who received visual training and who did not?

(D). Were appropriate eye movement recording device used to monitor pre- and post-training testing?

(E). If a short reading passage was read while eye movements were monitored by an electronic recording device, was a the same or a different passage read following training on re-test?

(F). How many subjects were included in the selected sample? A minimum of seven subjects per group is generally required for meaningful statistical conclusions and generalizations to be drawn.[79]

(G). What was the pre-training reading ability and/or eye movement efficiency status of the selected sample?

(H). How long was the program of visual training and what did it involve?

(I). What was the length and frequency of each training session?

(J). Why were the subject samples selected for inclusion in the study?

(K). What was the age and sex of the studied population?

(L). How were "poor" eye movements defined?

(M). How were "improved" eye movements defined?

RESULTS

In a study of achieving readers, Solan[1] tested nine “achieving” high school, college, graduate and professional school students who presented with the complaint of reading slow and laboriously. The subjects were then administered the Iowa Silent Reading Test (ISRT), which measures vocabulary and reading comprehension. All of the subjects would be recognized as proficient readers according to the averages of their comprehension and vocabulary scores on the ISRT, which were at the 56th percentile or better based on college preparatory norms. The nine subjects were then administered a high school/college and a fifth grade reading level test with the Eye-Trac.

Each subject was required to answer at least seven out of ten post-test comprehension questions in order to "pass" the test and render if valid. The results of the eye movement recordings and ISRT scores for the nine subjects are in Table 2.

Table 2. Eye Movement recordings and ISRT scores for nine subjects.

Subject	Grade	Selection	Fixations (per 100 words)		Regressions (per 100 words)		Span of Recognition (words per fixation		Rate of Reading w.p.m.	
			R	G	R	G	R	G	R	G
DP	12	College	98	7	25	5	1.02	7	160	4
		5	101	6	25	5	1.00	6	160	4
JW	College	College	108	6	25	5	0.93	6	170	4
		5	140	4	27	5	0.71	4	143	3
JF	College	College	97	8	18	8	1.03	8	153	3
		5	96	8	21	6	1.04	8	161	4
WD	College	College	137	4	31	4	0.73	4	143	3
		5	148	4	34	4	0.68	4	136	3
GD	College	College	90	9	13	HS	1.11	9	218	5
		5	98	7	10	Coll	1.02	7	197	4
CD	10	HS	147	3	34	3	0.68	3	96	3
		5	135	4	45	1	0.74	4	133	3
AP	College	College	108	6	10	Coll	0.93	6	194	4
		5	130	4	20	5	0.77	4	156	4
HZ	College	College	86	10	21	6	1.16	10	240	6
		5	94	8	27	5	1.06	8	245	7
MH	College	College	100	7	28	5	1.00	7	171	4
		5	107	6	32	4	0.93	6	150	4
Mean		College	108	6	23	6	0.92	6	172	4
		5	116	5	27	5	0.86	5	165	4

Of the nine subjects chosen originally, three--subjects 1, 3, and 9--were trained in an effort to enhance eye movement efficiency. Solan chose not to use a matched control group stating, "the average age of the group (>21 years) permitted the use of each subject as his/her own control. Based on previous clinical experiences, the probability of significant spontaneous improvement of reading efficiency taking place in each of the nine subjects within a period of few months is indeed remote." The three subjects were trained on an individual, one trainer to one subject, basis. After the training program, the three subjects again were tested with the Eye Trac. The results of the eye movement recordings using 100 word high school/ college reading selections before and after training are found in Table 3.

Table 3. Results of training three subjects: individual and average findings.

	Fixations (per 100 words)		Regressions (per 100 words)		Span of Recognition (words per fixation)		Rate of Reading (w.p.m.)		Comprehension (%)
Subject	R	G	R	G	R	G	R	G	
#1									
Before	98	7	25	5	1.02	7	160	4	80
After	60	Coll	10	Coll	1.67	Coll	343	Coll	90
#2									
Before	97	8	18	8	1.03	8	153	3	100
After	51	Coll	6	Coll	1.96	Coll	370	Coll	100
#3									
Before	100	7	28	5	1.00	7	171	4	100
After	56	Coll	13	Coll	1.79	Coll	338	Coll	100

	Average Improvement Before		After		Change
	R	G	R	G	
Fixations (per 100 words)	98	7	56	Coll	-42%
Regressions (per 100 words)	24	5	10	Coll	-58%
Span of Recognition (words per fixation)	1.02	7	1.81	Coll	+80%
Rate of Reading (w.p.m.)	161	4	300	Coll	+117%

The results of Solan's experiment do show a marked improvement in eye movement skills and reading skills as measured by the Eye Trac. However, several factors make the results suspect. First, the fact that a control group was not included and tested along with the three trained subjects, renders the post-training test results suspect to improvement by repeated measurement with the Eye Trac, i.e. a practice effect. Second, the author fails to report if measurements were obtained by researchers "blind" to whether subjects were in the control or experimental groups. Put another way, was the person who performed the training also the person who measured pre- and post-training eye movements via the Eye Trac? If so, the trainer/tester knew the subjects "should improve" and this, in turn, may be reflected in the post-training Eye Trac improvements. Third, we are not told whether a different high school/college level Eye Trac reading passage was used to test pre- and post-training eye movements. If the same 100 word selection was used, this, too, may partially explain the improvement in eye movements and reading ability. Fourth, the number of subjects used in this study is a very small number by which to assume the same improvement in eye movements and reading ability in all "achieving" readers in this age group. The author also fails to disclose why the three subjects trained were chosen from the original nine subjects. Was the choice random or was there some common aspect of these three that would allow them to achieve a greater improvement in eye movements and reading ability? Finally, Solan does not disclose the length of treatment, the number and length of each training session.

Broxterman and Stebbins[22] ask the following questions: 1) Can eye movements be improved by using visual training? 2) Do improved eye movement patterns result in reading improvement? and 3) Is there a relationship between visual-motor performance and reading efficiency? To do so they selected students enrolled in elementary school, who ranged in age from nine to twelve years. The "classroom teachers" of these subjects were given a checklist of characteristics believed to be present in those with poor visual function. This checklist was formulated by the American Optical Association Committee on Visual Problems of School Children. If fifteen or more of the thirty-two items were checked, the students underwent further screenings, which included a cover test, a convergence-divergence test, a visual tracking test (both monocular and binocular), a grasp-regrasp test, an eye dominancy test and a stereopsis test. The subjects who demonstrated problem in performing two or more of these screening tasks were invited to participate in the study. A group of twenty subjects, ten of which were trained and ten of which were used as a control, were randomly drawn from those invited to participate in the study. All twenty subjects were evaluated pre-training with the Eye Trac, MKM Biopter Test, which tests "binocular errors" made while the eyes are used together and the Woodcock Reading Test, which measures errors made in word identification ass a subject reads a list of selected words until five consecutive errors are made. The ten subjects in the control group were given no visual training between the pre- and post-training tests. The remaining ten subjects received a nine week visual training program, involving "individual training" three days per week for ten minutes per session. The training was conducted by one trainer to insure consistency among the ten subjects. At the end of the nine week period, all twenty subjects were again tested with the Eye Trac, MKM Biopter Test and the Woodcock Reading Test. A six week post-training "retention test" was done using only the Woodcock Word Identification test. The results are shown below in Table 4.

Table 4. Descriptive Statistic Means.

Variable	Experimental Means Pre	Post	Retest	Control Means Pre	Post	Retest
Eye Track Camera						
Fixations	93.80	102.20	X	116.40	111.90	X
Regressions	39.40	21.80	X	47.30	37.10	X
Span of Recognition	1.16	1.01	X	0.87	0.94	X
Duration of Fixation	51.10	45.40	X	49.70	52.00	X
MKM Biopter						
Mono. Errors-Left	14.60	6.40	X	13.50	18.60	X
Mono. Errors-Right	15.20	7.00	X	11.30	16.40	X
Bino. Errors	33.40	11.60	X	26.60	33.30	X
Woodcock Reading Test						
Raw Score	96.50	105.40	107.80	88.30	89.20	92.50
Mastery Score	165.50	175.70	177.90	156.60	157.50	161.30
Easy Read. Score	3.55	4.15	4.46	2.93	2.97	3.17
Read Grade Score	4.23	5.13	5.40	3.30	3.35	3.64
Failure Read. Level	5.20	6.43	7.10	3.78	3.88	4.28

Variable	Experimental Std. Deviations Pre	Post	Retest	Control Std. Deviations Pre	Post	Retest
Eye Track Camera						
Fixations	29.77	17.63	X	21.11	28.10	X
Regressions	18.20	6.12	X	20.45	21.33	X
Span of Recognition	0.39	0.19	X	0.15	0.22	X
Duration of Fixation	0.15	0.10	X	0.09	0.12	X
MKM Biopter						
Mono. Errors-Left	9.65	5.44	X	9.33	11.22	X
Mono. Errors-Right	12.15	6.76	X	4.16	10.40	X
Bino. Errors	15.32	9.35	X	15.01	19.06	X
Woodcock Reading Test						
Raw Score	27.15	24.76	27.49	12.50	13.09	18.37
Mastery Score	30.75	27.72	31.07	14.32	15.02	20.93
Easy Read. Score	1.28	1.59	1.92	0.46	0.51	0.76
Read Grade Score	1.75	2.16	2.74	0.57	0.63	0.96
Failure Read. Level	2.47	3.38	4.00	0.78	0.84	0.13

From these results, Broxterman and Stebbins concluded that "eye movements of children with minor visual motor dysfunctions are improved by visual training" and that "training of eye movement patterns using a visual training program result in fewer regressions."

The authors do not report: (1) If the same person who performed the training was involved in the pre- and post-training testing of the subjects or if the "tester" was aware of which subjects were in the control and experimental groups. This, again, is the principal of "blind" data collectors. (2) Whether different Eye Trac reading passages were used pre- and post-training testing, the age level of the selected passage nor if reading comprehension was tested after the administration of the Eye Trac. (3) Which, if any, statistical analysis was used to evaluate the raw data.

Heath, Cook and O'Dell[41] selected sixty-eight second and third grade students from a suburban, middle-class background. The subjects were first administered one form of the Metropolitan Reading Test (MRT) and the ocular-pursuit subtest of the Purdue Motor Survey. Children scoring below the 40th percentile on the reading test and in the "deficient" range on the ocular-motor tracking examination were randomly assigned to one of four groups: Group 1 received the Bender "proprioceptively-involved" facilitating exercises; Group 2 was assigned exercises utilizing a motor approach, but with no proprioceptive feedback except from that of the eyes themselves; Group 3 received non-motoric, perceptual exercises; Group 4 was the control and received no assigned exercises or training. The training was designed to improve "ocular control." At the end of ten weeks, all of the groups were administered an alternative form of the MRT, the ocular-pursuit tracking test as well as an eye tracking recording by the Biometric Reading Eye II. For post-training analysis a t-test was used to compare gains made between the four groups. The level required for significance was .05. The comparison results are listed in Table 5.

Table 5. Group 1 compared to groups 2, 3, and 4: Pursuit Gains (t-test).

Group	Mean	Standard Deviation	One-Tailed Probability	
1	3.71	3.84		
2	.95	3.49	.015	s
1	3.71	3.84		
3	-.22	1.79	.0005	s
1	3.71	3.84		
4	-.33	2.61	.0005	s

s = significance level

Table 6. Group 1 compared to groups 2, 3, and 4: Convergence Gains (t-test).

Group	Mean	Standard Deviation	One-Tailed Probability	
1	2.19	4.64		
2	-.80	4.02	.017	s
1	2.19	4.64		
3	.22	7.65	.195	s
1	2.19	4.64		
4	-3.67	3.70	.0005	s

s = significance level

Table 7. Group 1 compared to groups 2, 3, and 4: Metropolitan Gains (t-test).

Group	Mean	Standard Deviation	One-Tailed Probability	
1	4.30	5.20		
2	3.66	4.45	.340	ns
1	4.30	5.20		
3	1.18	4.96	.069	ns
1	4.30	5.20		
4	.99	4.04	.033	s

ns = not significant
s = significance level

Table 8. Group 1 compared to groups 2, 3, and 4: Post-Program Biometric Scores (t-test).

Group	Mean	Standard Deviation	One-Tailed Probability	
1	73.80	19.05		
2	80.67	22.07	.155	ns
1	73.80	19.05		
3	85.11	21.10	.082	ns
1	73.80	19.05		
4	101.46	28.71	.002	s

ns = not significant
s = significance level
Lower scores indicate proficiency

Although gains were made in all of the tested areas with respect to the control group (Group 4), several details must not be overlooked. The authors fail to report who administered the pre- and post-training tests. This does not allow the reviewer to see if the study was performed in a "blind" fashion. The authors also fail to report how many training sessions were involved and the length of time spent at each session. An additional test that would have been extremely beneficial in comparing pre-training eye movements to post-training eye movements is if the Biometric Reading Eye II were used prior to training. We, however, are not told why this was not administered. The authors state that "these results support the premise that ocular control can be improved, and that the Bender program is superior in improving it when compared to other techniques studied." This claim may in fact, or in part, be true. However, because several of the previously cited factors were either neglected to be done or were not reported in the article, the reader cannot assume the optimistic view that Heath, Cook and O'Dell share.

In their study exploring the potential of using videocassettes to alter saccadic eye movements, Fujimoto, Christensen and Griffin[71] selected a population of thirty-two six to twelve year olds. The subjects were patients at the Optometric center of Fullerton at the Southern California College of Optometry. The invitation to participate in this study was extended to those six to twelve year olds who exhibited poor saccadic performance shown during a vision efficiency evaluation within the Vision Therapy Center. Poor saccadic ability being defined as a qualitative score of 1+ or 2+ (failing) on saccades, based on a 4+ system.[73] The subjects were then divided into three groups: one receiving videocassette saccadic training (ten subjects), a second receiving a standard saccadic training procedure (nine subjects) and a third group, the control (thirteen subjects), receiving no training. The videocassette and standard groups then underwent a saccadic training program, conducted by senior optometry students under faculty supervision, for fifteen minutes per week for a time period ranging from one to four weeks (the mode being three weeks). All subjects' saccadic ability were tested prior to and following training using the Pierce Saccade Test to see if there was a change in saccadic ability as a result of training. The control group received post-testing after three weeks. The results of the Pierce Saccadic Tests are listed in Table 9.

Table 9. **Standard Condition Data.** The corrected scores on the Pierce Saccade Test (PST) for standard group subjects on the pre- and post tests are shown. The difference in corrected scores for pre- and post test performance is expressed as CS. The amount of time spent on saccadic therapy in weeks (wks) is listed.

	Subject Initials	Chronological age (years) CA (years)	Sex	Corrected score pre-test	Corrected score post-test	^CS	Time (weeks)
1.	MB	11.91	M	98	88	10	4
2.	MB	11.83	M	74	67	7	3
3.	AA	10.42	M	106	94	12	4
4.	MA	9.75	M	139	116	23	3
5.	JB	9.33	M	107	99	8	4
6.	CB	7.75	M	120	109	11	4
7.	FB	7.67	M	193	171	22	4
8.	TA	8.17	F	66	62	4	4
9.	EC	9.42	M	97	73	24	3

Table 10. **Video Data.** The corrected scores on the Pierce Saccade Test (PST) for video group subjects on the pre- and post tests are shown. The amount of time spent on saccadic therapy is listed per week (wks).

	Subject Initials	Chronological age (years) CA (years)	Sex	Corrected score pre-test	Corrected score post-test	^CS	Time (weeks)
1.	SM	12.83	M	101	73	28	3
2.	MM	12.00	M	84	76	8	3
3.	PM	10.67	M	67	63	4	3
4.	KB	9.50	M	88	97	-9	3
5.	LF	9.08	M	122	107	15	3
6.	KG	8.42	M	89	84	5	3
7.	MB	8.25	M	93	79	14	3
8.	BF	8.25	M	129	111	18	3
9.	RO	7.83	F	162	137	25	2
10.	MF	8.92	M	109	99	10	1

Table 11. **Control data**

	Subject Initials	Chronological age (years) CA (years)	Sex	Corrected score pre-test	Corrected score post-test	^CS	Time (weeks)
1.	EA	8.92	M	57	66	-9	3
2.	JC	8.50	F	143	101	42	3
3.	JG	8.67	M	72	60	12	3
4.	HH	8.67	F	89	117	-28	3
5.	RJ	9.25	M	76	82	-6	3
6.	GM	8.75	M	112	123	-11	3
7.	EM	8.75	F	92	89	3	3
8.	JM	8.67	M	72	87	-15	3
9.	TR	9.25	M	110	90	20	3
10.	MR	9.25	M	67	74	-7	3
11.	AS	9.42	F	98	99	-1	3
12.	TS	9.17	M	78	61	17	3
13.	MW	9.42	F	94	94	0	3

Table 12. **Summary statistics** for the evaluation of therapeutic outcomes.

Groups	n	Mean CS (seconds)	Standard deviation
Video	10	11.80	10.8
Standard	9	13.44	7.55
Control	13	1.31	18.0

The mean improvement of both the video and the standard training groups was significantly greater than zero ($p=.0036$ and .0062 respectively). The control group change was not significant ($p=.7976$). A two tailed *t*-test revealed improvements in the videocassette and standard groups greater than that of the control group at a .05 level.

In a review of this study, several questions are not addressed. First, the saccadic eye movements were judged *qualitatively* by an examiner for inclusion of subjects into the study. This raises the question of potential examiner biases' and/or inaccurate, imprecise judgements as well as inconsistency among the examiners. Put another way, did all of the examiners grade similar saccadic performance consistently? Another limitation of this study is that the Pierce Saccade Test was administered by the students who performed the saccadic training, thus breaching the "blindness" of the study. Also, the fact that the training was performed by several different trainers, introduces the problem of the subjects being trained, instructed and influenced in an inconsistent manner. Other weaknesses include the relatively small sample size used.

In his article "Deficient Eye Movement Patterns in Achieving High School Students: Three Case Histories," Solan[23] analyzes case histories of three "achieving" high school students who were experiencing a visual functional disorder. Case #1 is R.T., an eighteen year old male who reported that after 45 minutes of reading, his eyes tire, which made it difficult for him to visually sustain a task. There was no evidence of pathology in either eye. However, the patient was mildly myopic, who was correctable to 20/20. Further testing revealed convergence insufficiency, and slow, laborious accommodation. Eye movement skills as shown by the Eye Trac showed a reading pattern comparable to that of a grade four student. The results of the ISRT (Advanced), based on college preparatory norms, revealed R.T.'s reading vocabulary was slightly above the median, while reading comprehension was slightly below the median. A vision training program, in combination with individual reading instruction, was instituted one hour per week for six months with the exception of holidays and a brief period when he was recuperating from an athletic injury. The training regimen stressed improving binocular fusion, accommodative facility and eye movements. After seventeen weeks of training R.T. reported he could read for longer periods of time with better comprehension. Visual testing revealed the convergence insufficiency had been corrected. Upon administration of another form of the ISRT, R.T. showed an improvement of 16% in Total Reading (50th to the 66th percentile). Corresponding growth also occurred in vocabulary and reading comprehension subtests. The maturation of R.T.'s eye movements were "especially impressive" (see Table 13).

Table 13. **Case 1: R.T.** Eye Movement Photography

	Before Training		After Training	
	Raw Score	Grade Score	Raw Score	Grade Score
Fixations-per 100 words	153	4+	82	High School
Regressions-per 100 words	25	5	1	College
Span of Recognition--words per fixation	.65	4+	1.22	High School
Rate of Comprehension-words per minute	143	3+	256	8
Comprehension	70%	X	90%	X
Selection Level	X	High School	X	High School

Case #2, R.K., a sixteen year old male who maintained a "B" average in school but who could comfortably read or study for only thirty minutes at a time. Visual acuity was 20/20 in each eye at both near and far distances without correction. There was no evidence of pathology in either eye. Testing showed convergence and divergence reserves were low and accommodative facility was sluggish. An eye movement recording was administered on R.K. prior to training--the results are found in Table 14 below:

Table 14. **Case 2: R.K.** Eye Movement Photography

	Before Training		After Training	
	Raw Score	Grade Score	Raw Score	Grade Score
Fixations-per 100 words	100	6+	81	High School
Regressions-per 100 words	17	Junior High School	12	High School
Span of Recognition--words per fixation	1.00	6+	1.24	High School
Rate of Comprehension-words per minute	198	4+	270	9
Comprehension	80%	X	90%	X
Selection Level	X	High School	X	High School

Level III of the ISRT was administered to R.K. Based on grade ten college preparatory norms, his Total Reading performance was "just about average" for this age group. A program of visual training and individual reading instruction was instituted. After eighteen visual training visits and an equal number of reading instruction sessions, all areas of visual function had improved. R.K. also reported he was now able to read more comfortably for longer periods with "good" comprehension. A maturation of R.K.'s eye movement efficiency was also noted (see Table 14). Following retest of the ISRT, Level III, reading vocabulary improved from the 42nd to the 76th percentile. Comprehension improved from the 58th to the 95th percentile.

Case #3 is D.H., a seventeen year old female who presented with complaints that her reading rate was slow and that her attention and comprehension were poor when reading. Her grades in high school showed her to be performing near the top of her large, class. Examination yielded no evidence of pathology and glasses for distance were not indicated. D.H. exhibited significant exo phoria, suggesting the presence of a binocular dysfunction. Further testing showed that both convergence and divergence reserves were low at all distances and that accommodation at near was sluggish. Eye movement recording measured reading skills of a second grade child when reading from a second grade selection (see Table 15). There was also a very large disparity between her performance on the vocabulary portion (92nd percentile) of the ISRT (Level III based on college preparatory norms) and the reading comprehension (47th percentile) subtests. Following ten one hour sessions of visual training, in combination with ten one hour sessions of individual instruction in reading efficiency, D.H. made significant improvement in her binocular functioning. This enabled her to read more comfortably for longer periods without her eyes tiring. However, the most dramatic improvements occurred in the maturation of her eye movements (see Table 15).

Table 15. **Case 3: D.H.** Eye Movement Photography

	Before Training		After Training	
	Raw Score	Grade Score	Raw Score	Grade Score
Fixations-per 100 words	198	2	47	College +
Regressions-per 100 words	40	2	8	College +
Span of Recognition--words per fixation	.51	2	2.13	College +
Rate of Comprehension- words per minute	113	2	533	College +
Comprehension	80%	X	90%	X
Selection Level	X	High School	X	High School

The improvement in the number of fixations and regressions and the improvement in the rate of comprehension "are remarkable!" The results of the post-training ISRT were identical to the initial testing, although an alternative, but equally difficult, form was used. Solan states "had she begun treatment earlier in the school year and completed sixteen to twenty weeks of training, it is probable that her reading comprehension score with the ISRT would also have shown a significant gain."

These three case histories all show a dramatic improvement of eye movement efficiency as measured by the Eye Trac. However, it was not stated in any of the case histories if the material being read by the subject while the eyes were being monitored was the same or different pre- and post-testing. If it were the same, the subject would undoubtedly exhibit more efficient eye movement patterns. It was also not noted if the person monitoring these eye movements was "blind" to the fact that the subjects had underwent a visual training program, specifically designed to improve eye movements. Also, all three cases had, in combination with a visual training program, "individual reading instruction." It was not reported exactly what this entailed. However, it, too, may have had a synergistic effect on eye movement efficiency. This may simply be adding another variable to be factored out as to what actually is causing the improved eye movements. Solan does not report why these three subjects were chosen. Were they a random, representative sample of the cases he works with who exhibit similar signs and symptoms? Or were these three subjects outstanding examples of successfully altering eye movements and reading efficiency?

Young, et. al.,[7] worked with a population of thirteen students attending the Stephen F. Austin Learning Center. All subjects were identified by a screening test to have problems with fusion, stereopsis or lateral posture. The eye movement skills of each student was tested prior to training using the Eye Trac. Reading passages were selected for each student that represented at a "recreational level" with a comprehension level of 70% or greater. A six week training regimen ensued, consisting of fifteen minutes of training per day for four days per week. This program was administered by a student teacher. Following the six week program, the subjects were again tested on the Eye Trac. The pre- and post-training Eye Trac data are seen in Table 16.

Table 16. Changes resulting from six weeks of eye exercises and reading instruction.

Factors	Pre-test Mean (per 100 word sample)	Post-test Mean	Difference In Mean
Number of Fixations	319.4	245.3	74.1*
Number of Regressions	46.9	24.8	22.1*
Number of Drifts (OD)	10.1	8.9	1.2
Number of Seconds of Drift (OD)	8.9	5.3	3.6
Number of Seconds OVC (OD)	9.6	0.6	9.0
Number of Drifts (OS)	6.8	8.5	+1.7
Number of Seconds of Drift (OS)	5.7	6.5	+0.8
Number of Seconds OVC (OS)	21.5	1.8	19.7*
Number of Blinks	3.1	5.7	+2.6
Total Reading Time (in seconds)	127.8	98.6	29.2
Total Fixation Time	34.9	39.5	+4.6*

* Statistically significant at .05.

Young, et. al. did not report whether the person monitoring the Eye Trac was "blind" to which subjects had undertaken the program of visual training. It is also noteworthy that the reading level used with the Eye Trac is not reported for each subject--it is stated as a "recreational reading level." Similarly, it is not stated whether the same or a different "recreational" reading passage was used in pre- and post-training assessment. Because a control group was not used the improved eye movement patterns may have been the result of possible examiner bias and/or "practice effect." It would also be interesting to note if the reported gains in eye movement efficiency were long-standing, and that they did or did not deteriorate over time.

DISCUSSION

In summary of the various studies reviewed, most of the researchers do a reasonable job of defining the testing procedures; the methods of data collection; the inclusion criteria for participation in the study; the sex, age and achievement level of the population studied; and the end-training results and data. However, the majority of the authors neglect to state whether the researchers were "blind" with respect to who received training and who did not and/or if a different reading passage was used pre- and post-training testing. Other commonly overlooked research design principles include lack of a control group and the use of a relatively small number of subjects. A reviewer of these studies must ask the question " Do the weaknesses of the studies' outweigh the strengths and invalidate the results?" The answer to this question may be "yes, but only in part." The fact remains that all of the studies reviewed in this paper report that a behavior was altered--eye movements were changed in a more desirable direction. And in many cases, these new, more efficient eye movements resulted in an increased reading performance as measured by a standardized reading test or as recorded by an objective eye movement recording device while reading a passage. The fact that all of the studies reviewed have inherent flaws simply make the reviewer sceptical as to what actually changed the reported eye movement pattern. Was it the program of vision training? Was it due to a practice effect exhibited by the subject? Was the apparent altered behavior simply the outcome of the researchers' expectations? These are a few of the possibilities that come to mind as one examines these studies. In short, until the basic research design principles previously cited are instituted under carefully controlled clinical trials, many educators, psychologists, ophthalmologists and even a number of optometrists will fail to acknowledge the fact that optometric visual training may in fact be a very important *part* of the remediation of a reading problem. Two members of the behavioral/developmental optometry community, Carlson and Greenspoon[49], state: "If 'developmental vision specialists' would spend the necessary time to determine under controlled clinical conditions what *does* or *does not* work and *under which conditions*, rather that making exaggerated claims, acceptance by other professions would be immediate." We both fully agree with statement and hope that this review of literature will contribute to the stimulation of some fine research in the very near future.

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BIBLIOGRAPHY

1. Solan, H. Eye Movement Problems in Achieving Readers: An Update. American Journal of Optometry and Physiological Optics. December, 1985. 62:812-819.

2. Ciuffreda, K; Bahill, A; Kenyon, R; Stark, L. Eye Movements during Reading: Case Reports. American Journal of Optometry and Physiological Optics. August, 1976. 53:389-395.

3. Kaplan, R; Dumont, C. A Reading Disability Case Report. Journal of Optometry and Vision Development. June, 1982. 13:20+.

4. Hiatt, R. Reading Problems and the Ophthalmologist. Annals of Ophthalmology. February, 1984. 16:116+.

5. Rosner, J; Rosner, J. The Clinical Management of Perceptual Skills Disorders in a Primary Care Practice. Journal of the American Optometric Association. January, 1986. 57:56-59.

6. Ludlam, W; Twaroski, C; Ludlam, D. Optometric Visual Training for Reading Disability--a Case Report. American Journal of Optometry and Physiological Optics. January, 1973. 50:58-66.

7. Young, B; Pollard, T; Paynter, S; Cox, R. Effect of Eye Exercises in Improving Control of Eye Movements During Reading. Texas Optometry. December, 1982:8-10.

8. Poynter, H; Schor, C; Haynes, H; Hirsch, J. Oculomotor Functions in Reading Disability. American Journal of Optometry and Physiological Optics. February, 1982. 59:116-127.

9. Lane, K. Chapter One: Vision Processing and Reading. OEP Curriculum II. January, 1985. 57:5-10.

10. Lane, K. Chapter Two: Vision Processing and Reading. OEP Curriculum II. February, 1985. 57:57-62.

11. Lane, K. Chapter Three: Vision Processing and Reading. OEP Curriculum II. March, 1985. 57:51-58.

12. Petri, J; Anderson, M. Eye and Head Movements in Reading-Disabled and Normal Children. American Journal of Occupational Therapy. December, 1980. 34:801-808.

13. Abrams, J. The Psychologist-Educator Views the Relationship of Vision to Reading and Related Learning Disabilities. Journal of Learning Disabilities. December, 1981. 14:565-567.

14. Atzmon, D. Positive Effect of Improving Relative Fusional Vergence on Reading and Learning Disabilities. Binocular Vision. October, 1985. 1:39-43.

15. Tannenbaum, R. Call for Optometrists' Participation for Treating Learning Disorders. Optometric Times. August, 1984. 2:9+.

16. Ludlam, W. Visual Training, the Alpha Activation Cycle and Reading. Journal of the American Optometric Association. January, 1979. 50:111-115.

17. Griffin, J. Saccadic Eye Movements--Recommended Testing and Training Procedures. Optometric Monthly. July, 1981: pgs. 27-28.

18. Grosvenor, T. A Problem Orientated Approach to Optometric Practice Part 5--the History: Reading or Learning Problems. Optometric Monthly. July, 1981: pgs.16-18.

19. Suchoff, I. Research on the Relationship Between Reading and Vision--What Does It Mean. Journal of Learning Disabilities. December, 1981. 14:573-576.

20. Fitzmaurice, K. Reading Efficiency of Visually Impaired Students--Review of Pilot Program. Australian Orthoptic Journal. January, 1985. 22:57-59.

21. Bedwell, C; Grant, R; McKeown, J. Visual and Ocular Control Anomalies in Relation to Reading Difficulty. British Journal of Educational Psychology. 1980. 50:61-70.

22. Stebbins, A; Broxterman, J. The Significance of Visual Training in the Treatment of Reading Disabilities. Kansas Optometric Journal. May-June, 1982. 50:16-18.

23. Solan, H. Deficient Eye Movement Patterns in Achieving High School Students: Three Case Histories. Journal of Learning Disabilities. February, 1985. 18:66-70.

24. Fitzmaurice, K; Keast, J. The Effect of a Reading Efficiency Program on Visually Impaired Tertiary Students--A Pilot Study. Australian Orthoptic Journal. May, 1984. 22:33-37.

25. Simons, H. Meta-Analysis of Vision and Reading. American Journal of Optometry and Physiological Optics. December, 1988.

26. Grisham, D. Validity and Reliability of the Visagraph Reading Eye Movement System. Vision and Reading: An Optometric Update. p. 4.

27. Taylor, E. The Fundamental Reading Skill. Second Edition. Springfield, Illinois: Charles C. Thomas. 1966.

28. Birnbaum, P. Binocular Co-ordination as a Factor in Reading Achievement. American Journal of Optometric Association. 39:48-56.

29. Spache, G. Diagnosis and Correcting Reading Difficulties. New York: Allyn and Baum.

30. Solan, H. The Improvements of Reading Efficiency: A Study of Sixty-three Achieving High School Students. Journal Read. Spec. 1967. 7:8-13.

31. McIntyre, C; Murray, M; Blackwell, M. Visual Search in Learning Disabled and Hyperactive Boys. Journal of Learning Disabilities. March, 1981. 14:156-158.

32. Enderle, J. Observations on Pilot Neurosensory Control Performance During Saccadic Eye Movements. Aviation, Space and Environmental Medicine. April, 1988. 59:309-313.

33. Keogh, B. Optometric Vision Training Programs for Children with Learning Disabilities: Review of Issues and Research. Journal of Learning Disabilities. April, 1974. 7:36-46+.

34. Francke, A. The Marsden Ball. OEP Curriculum II--Introduction to Optometric Visual Training. October, 1988. 61:9-13.

35. Francke, A. Variation of Thumb Pursuits. OEP Curriculum II--Introduction to Optometric Visual Training. June, 1988. 60:327-332.

36. Yee, R. Eye Movement Recording as a Clinical Tool. American Academy of Ophthalmology. March, 1983. 90:211-221.

37. Rotberg, M. Biofeedback for Ophthalmologic Disorders. Survey of Ophthalmology. May-June, 1983. 27:381-386.

38. Kaplan, M. Eye Movements and Respiratory Function. OEP Curriculum II--Visual Training. June, 1988. 60:341-344.

39. Pierce, J. Is There a Relationship Between Vision Therapy and Academic Achievement? June, 1977: pgs. 48-63.

40. Bross, M; Milton, J. Effect of Monocular Occulusion on Rotary Pursuit Performace. Perceptual and Motor Skills. 1987. 65:796-798.

41. Heath, E; Cook, P; O'Dell, N. Eye Exercises and Reading Efficiency. Academic Therapy. Summer, 1976. 11:435-445.

42. Peters, H. The Influence of Orthoptic Training on Reading Ability, Part II. American Journal of Optometry and Archives of the American Academy of Optometry. 1942. 19:152-176.

43. Olson, H; Mitchell, C; Westberg, W. The Relationship Between Vision Training and Reading and Academic Improvement. American Journal of Optometry and Archives of the American Academy of Optometry. January, 1953. 30:3-13.

44. Balliet, R; Nakayama, K. Training Voluntary Torsion. Investigative Ophthalmology. April, 1978. 17:303-314.

45. Goldberg, H; Arnott, W. Ocular Motility in Learning Disabilities. Journal of Learning Disabilities. March, 1970. 3:160-162.

46. Krippner, S. On Research in Visual Training and Reading Disability. Journal of Learning Disabilities. February, 1971. 4:66-67.

47. Lyons, C; Lyons, E. The Power of Optometric Vision Training. Journal of the American Optometric Association. August, 1967. 38:654-660.

48. Solan, H. The Treatment and Management of Children with Learning Disabilities. Springfield, Illinois. CS Thomas. 1982.

49. Carlson, P; Greenspoon, M. The Uses and Abuses of Visual Training for Children with Perceptual-Motor Learning Problems. American Journal of Optometry. 1968. 45:161-169.

50. Maples, W; Ficklin, T. Comparison of Eye Movement Skills Between Above Average and Below Average Readers. Journal of Behavioral Optometry. 1990. 1:87-91.

51. Dunlop, E. The Role of Strabismus in Reading Problems. American Orthoptic Journal. 1966. 16:44-49.

52. Keeney, A. Dyslexia and Associated Diseases as Seen by the Ophthalmologist and the Orthoptist. American Orthoptic Journal. 1968. 18:98-102.

53. Norn, M; Rindziunski, E; Skydsgaard, H. Ophthalmologic and Orthoptic Examinations of Dyslectics. Acta Ophthalmology. 1969. 47:147-159.

54. Hoffman, L; Rouse, M. Referral Recommendations for Binocular Function and/or Developmental Perceptual Deficiencies. Journal of the American Optometric Association. Februay, 1980. 51:119-125.

55. Griffin, J. Binocular Anomalies--Procedures for Vision Therapy. New York, New York. Professional Press Books/Fairchild Publications. Second Edition. 1988.

56. Buzzelli, A. Vergence Facility: Developmental Trends in a School Age Population. American Journal of Optometry and Physiological Optics. May, 1986. 63:351-354.

57. Atzmon, D; Shulamit, H. Positive Effect of Improving Fusional Amplitudes on Reading and Learning Disabilities. Reprinted from Proceedings of the Fifth Meeting ISA V--Rome, 1986.

58. Nakayama, S; Makasone, R; Rouse, M. Effectiveness of Audio-Visual Instruction and an Aid to Saccadic Training. SCCO Thesis. 1982.

59. Alleman, K; Bescoby, W. Ocular Motility Training and Its Relationship to Reading Readiness and Achievement. SCCO Thesis. 1980.

60. Yarbus, A. Eye Movements and Vision. New York. Plenum Press. 1967.

61. St. Cyr, G; Fender, D. The Interplay of Drifts and Flicks in Binocular Fixation. Vision Research. 1969. 9:245.

62. Barlow, H. Eye Movements During Fixation. J. Physiol. 1952. 116:290.

63. Fiorentini, A; Ercules, A. Involuntary Eye Movements During Attempted Monocular Fixation. Atti Fond. Giorgio Ronchi. 1966. 21:199.

64. Steinman, R; et.al. Voluntary Control of Microsaccades During Maintained Monocular Fixation. Science. 1967. 155:1577.

65. Moses, R; Hart, W. Adler's Physiology of the Eye. St. Louis, Missouri. CV Mosby Company. 1987.

66. Cornsweet, T. Determination of the Stimuli for Involuntary Drifts and Saccadic Eye Movements. Journal Opt Soc Am. 1956. 46:987.

67. Larson, S. Comparison of Saccadic Eye Movements Made by Musicians When Reading Music Versus Text. Journal of Behavioral Optometry. 1990. 1:143.

68. Borish, I. Clinical Refraction. New York, New York. Professional Press. Third Edition. 1980.

69. Cline, D; Hofstetter, H; Griffin, J. Dictionary of Visual Science. Radnor, Pennsylvania. Chilton Book Company. Third Edition. 1980.

70. King, A; Devick, S. ICO Senior Research Study. 1976.

71. Fujimoto, D; Christensen, E; Griffin, J. An Investigation in Use of Videocassette Techniques for Enhancement of Saccadic Eye Movements. Journal of the American Optometric Association. April, 1985. 56:304-308.

72. Cohen, A; et. al. The Efficacy of Optometric Vision Therapy. Journal of the American Optometric Association. February, 1988. 59:95-105.

73. Hoffman, L; Rouse, M. Referral Recommendations for Binocular Function and/or Developmental Perceptual Deficiencies. Journal of the American Optometric Association. February, 1980. 51:119-125.

74. Rayner, K. Eye Movements in Reading: Perceptual and Language Processes. New York, New York. Academic Press. 1983.

75. Bassi, C; Lehmkuhly, S. Clinical Implications of Parallel Visual Pathways. Journal of the American Optometric Association. February, 1990. 61:98-110.

76. Garzia, R; Richman, J; Nicholson, S; Gaines, C. A New Visual-Verbal Saccade Test: the Developmental Eye Movement Test (DEM). Journal of the American Optometric Association. February, 1990. 61:124-135.

77. Cox, R; West, W. Fundamentals of Research for Health Professionals. Laurel, Maryland. RAMSCO Publishing. 1982.

78. Goldstein, G. A Clinician's Guide to Research Design. Chicago, Illinois. Nelson-Hall Publishers. 1980.

79. Yolton, R. Personal Communication. January, 1990.