Research Article

Effects of Computerized Vision Therapy on Developmental Eye Movement Test Test Performance in Children with Poor Reading Skills: A Pre-Post Study

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Running Title: Computerized Vision Therapy & DEM Test in Poor Readers

Abstract

Background: Reading difficulties in school-aged children are frequently associated with oculomotor deficits, including prolonged fixation durations, increased saccade frequency, and

frequent refixations. Given the critical role of eye movements in fluent reading, early diagnosis and targeted intervention are essential to mitigate adverse academic, social, and economic outcomes. This study aimed to evaluate pre-post changes in Developmental Eye Movement test (DEM) test performance following a structured oculomotor training program, delivered via the Sanet Vision Integrator(SVI) system, in Iranian primary school children with reading difficulties.
Material and Methods:This single-group, pre- and post-intervention study included children recruited from primary schools in Shiraz, Iran.Training sessions of 30 minutes, incorporating saccadic and tracking exercises, were conducted three times weekly. Outcomes were assessed before and after the intervention using the DEM test.
Results: Thirty-two children aged 7–12 years with abnormal DEM scores and teacher-reported reading weaknesses participated in a 12-week intervention program. Paired t-tests revealed statistically significant improvements in vertical time, adjusted horizontal time, ratio and total errors following the intervention (all $p < 0.001$), with post-treatmentt means closley approximating age-mached normative value across all age groups.
Conclusion: Oculomotor training using the SVI system was associated with improved DEM test performance in children with reading difficulties. However, the absence of a control group limits causal interpretation, as improvements may reflect practice effects, maturation, or non-specific factors. Randomized controlled trials with standardized reading assessments are needed to determine whether such training produces functional reading improvements.
Keywords: Developmental Eye Movement test, oculomotor training, reading, vision therapy, saccade

Introduction

Reading difficulties affect approximately 5–17% of school-aged children worldwide, representing a major challenge for academic achievement and daily functioning (1-4). These difficulties are often accompanied by oculomotor deficits, including increased saccade frequency, prolonged fixation durations, and frequent refixations, all of which compromise reading fluency (5, 6). However, the nature of relationship between oculomotor deficits and reading difficulties remains debated. While some studies suggest that inefficient eye movement control may contribute to reduced reading fluency, others argue that oculomotor irregularities may instead reflect secondary adaptations to linguistic or attentional deficits rather than a primary causal factor (7, 8). This ongoing controversy highlights the need for cautious interpretation and further investigation.

In Persian script, saccadic movements typically proceed from right to left, with return sweeps initiating fixation on subsequent lines. This rightward reading direction underscores the critical importance of oculomotor control in achieving reading fluency among Persian-speaking populations (9, 10). Accordingly, examining eye movement behavior in this linguistic context may provide additional insight into the interaction between visual and cognitive processes in reading.

The Developmental Eye Movement (DEM) test is a widely used clinical instrument for assessing rapid automatized naming (RAN) and visual-verbal processing efficiency (11-13) . Although the DEM does not directly measure saccadic accuracy, it provides valuable information regarding horizontal scanning ability and naming speed, and has been proposed as a screening tool for children with learning and reading difficulties (11, 14). Despite its established utility, evidence regarding the application of the DEM in evaluating vision therapy outcomes remains limited (15).

The sanet vision integrator (SVI) system was selected in this study as a structured, clinically practical platform for delivering oculomotor training. Its use was based on the assumption that repeated, guided saccadic and visual tracking exercises may help improve oculomotor efficiency, which has been associated with reading performance in previous studies (16, 17).

To date, only two studies have examined the DEM as a pre- and post-treatment measure, and that investigations were conducted in the context of concussion rehabilitation (15, 18). No research has systematically investigated its application in children with reading weakness, particularly in Persian-speaking populations. Furthermore, few studies have explored the therapeutic effects of oculomotor rehabilitation exercises on reading disorders, representing a critical gap in the literature (19, 20).

The present study aimed to evaluate changes in DEM test performance following oculomotor training in Iranian primary school children with reading difficulties. We hypothesized that systematic oculomotor training would be associated with significant improvements in DEM parameters, particularly in error reduction and time-based measures, thereby providing preliminary evidence that may guide future research**,** while acknowledging that the uncontrolled design precludes causal inference (17, 21, 22).

Method and Procedure of the Study

This prospective, quasi-experimental, pre–post intervention study was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.RETECH.REC.1402.877) and conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from the parents or legal guardians of all participating children. A total of 35 children were initially recruited by convenience sampling from primary schools in Shiraz, Iran. Pretherapy standardized testing and vision therapy was performed in the Spring of 2023, and post-therapy testing was done in the summer of 2023. Potential participants were identified based on teacher reports of academic and reading weaknesses, combined with abnormal DEM performance (23). Inclusion criteria were as follows: Age between 7 and 12 years, normal distance and near visual acuity (≥20/25), absence of strabismus or binocular vision disorders, DEM scores falling at least one standard deviation below age-matched norms, or below the 15th percentile, according to the Persian-adapted DEM normative data presented in Table 3. Exclusion criteria included: diagnosed learning disabilities or developmental disorders, attention-deficit/hyperactivity disorder (ADHD), cocurrent participation in reading intervention programs, use of psychoactive medications.

Preliminary assessments of far and near visual acuity, cover testing, and stereoacuity evaluation were performed to confirm the absence of binocular vision disorders. Three children were excluded: two due to binocular vision abnormalities and one due to accommodative spasm. The final sample comprised 32 children (15 males, 17 females) with a mean age of 8.97 ± 1.46 years.

The DEM test was administered by a trained examiner following standardized protocols (24). A Persian-adapted version of the DEM (with numerals converted from English to Persian) was used. Testing was conducted in a quiet, distraction-free environment, with children seated comfortably and holding the test card at a typical reading distance while wearing their habitual spectacle correction. A stopwatch was used to ensure accurate timing, and all time values were recorded to two decimal places, and recorded all errors on the test blank. Following the explanation of the test, timing commenced at the onset of the child's reading of the numbers and stopped upon the final digit being called out. The child was instructed to read test cards A, B, and C as rapidly as possible without the use of his fingers. As specified in the manual, the vertical time is defined as the total number of seconds required to read cards A and B. The horizontal time is defined as the time, in seconds, required to read card C.

The DEM test comprises one pre-test card and three test cards (216 × 279 mm each). Pre-test card contained ten single-digit numbers spaced evenly apart, . Cards A and B contained 40 numerals arranged in two vertical columns of 20 digits each, assessing vertical number-naming automaticity. The third card, labeled C, contained 80 numbers arranged in 16 horizontal rows of five digits each, with randomized spacing between intermediate numbers, requiring precise saccadic eye movements for fluent number reading (24). Four outcome measures were derived from the DEM test: Vertical Time, reflecting automaticity in number naming and verbal fluency. Horizontal Score, indicating horizontal scanning and saccadic efficiency (25-27). Adjusted Horizontal Time: Calculated as (80 − [Omissions + Additions]) × (Time for Card C ÷ 80). Ratio: Adjusted horizontal time divided by vertical time, serving as an index of relative oculomotor efficiency. Total Errors: Sum of transposition, substitution, omission, and addition errors.

Interpretation of results followed established criteria: if both vertical and horizontal times were slow but the ratio remained normal, the issue was attributed to automaticity deficits. When both times were slow and the ratio was elevated, deficits were identified in both automaticity and eye movement control. If vertical time was within normal range while horizontal time was slow or the ratio was high, the deficit was considered to stem solely from eye movement dysfunction.

The DEM test has been widely used in children and has shown acceptable validity for screening visual-verbal automaticity and saccadic efficiency, as well as good test-retest reliability in prior studies (28, 29). The normative data for the DEM test (mean ± SD by age) for Persian-speaking children are presented in Table 3, which served as the reference for identifying participants with abnormal scores. This study did not control for potential confounding variables, including participants' age, cognitive ability.These factors are known to influence performance on the DEM test independent of oculomotor function.

Statistical analysis

The sample size was calculated a priori using the standard formula for paired comparisons in a quasi-experimental pre-test/post-test design (30).

$$n = \left[\frac{\left(z_{1-\alpha/2} + z_{1-\beta} \right) \times \sigma}{\mu_1 - \mu_2} \right]^2$$

Assuming a two-tailed Type I error rate (α = 0.05), statistical power of 80% (β = 0.20), and a medium effect size (Cohen's d = 0.5) based on Cohen's conventions for behavioral research, the required sample size was determined to be 32 participants. To account for potential attrition, 35 children were initially recruited.This choice is consistent with previous vision-science and oculomotor intervention studies, which frequently rely on moderate sample sizes when evaluating pre–post changes in children (20, 31). Participants were recruited using convenience sampling, and data analysis was conducted using SPSS version 25.

Intervention Phase and Vision Therapy Protocol

All participants underwent vision therapy at the Soroosh Optometry and Vision Therapy Center under the supervision of a licensed optometrist. The intervention consisted of 30-minute sessions conducted three times weekly for 12 weeks (total of 36 sessions), delivered using the SVI system (HTS, Inc., USA).

The SVI is a clinical software platform that provides vision therapy exercises via a touchscreen interface with visual and auditory feedback (32). Adjustable parameters include target contrast, size, and position and display duration. Each training level was considered mastered when the participant achieved >80% accuracy on two consecutive sessions. Upon mastery, task difficulty was increased according to the built-in SVI progression algorithm, which sequentially reduces target display duration, increases target speed, and reduces target contrast.

Training was divided into two levels. Level 1 involved touch-based tasks requiring sequential selection of visual targets on the 50-inch touchscreen monitor. Level 2 focused on verbal response training, requiring rapid and accurate naming of letters, numbers, and words without physical interaction. Accuracy and reaction time were recorded automatically by the SVI system. Progression from Level 1 to Level 2 occurred when a participant achieved a predefined accuracy criterion of >80% correct responses across two consecutive sessions. Within each level, display duration was incrementally reduced as performance improved, requiring progressively faster saccadic responses. Target contrast, size, and position were adjusted by the supervising optometrist based on individual performance scores recorded by the software at each session.

The tracking component consisted of four progressive levels. Tracking 1 provided pre-designed pursuit exercises. Tracking 2 allowed user-defined smooth pursuit paths. Tracking 3 integrated pursuit and saccadic elements through sequential target appearance at multiple screen points. Tracking 4 combined all previous features.

Attendance was recorded for each session. A licensed optometrist supervised all sessions and verified task execution visually. The SVI system automatically logged completion times and accuracy scores. At the beginning of each session, natural behavior was observed before recommendations for more effective execution were provided. Auditory feedback consisted of a positive chime for correct responses and a low-tone beep for incorrect responses. No additional reinforcement was provided. Advancement to a higher level required meeting the accuracy threshold on two successive sessions, if performance fell below 70% at any level, the difficulty was reduced for the subsequent session. Attendance and task completion were recorded at every session. Participants who missed a session were rescheduled within the same week where possible, any participant missing more than three sessions in total was flagged for protocol review. After 12 weeks of training, the DEM test was re-administered by a separate examiner to minimize bias.

Descriptive statistics (means and standard deviations) were calculated for all DEM parameters at baseline and post-intervention. Normality of the paired differences was assessed using the Shapiro-Wilk test. The results indicated approximate normality for horizontal time ($p = 0.291$), ratio ($p = 0.465$), and total error ($p = 0.936$). Although vertical time ($p = 0.022$) and adjusted horizontal time ($p = 0.026$) showed slight deviations from normality, with a sample size of 32 participants, the paired t-test is considered robust to modest violations of normality.

Paired-sample t-tests were used to compare pre- and post-treatment scores. Effect sizes (Cohen's d) were calculated as Mean Difference divided by SD of Differences and interpreted according to Cohen's conventions. As a robustness check, nonparametric Wilcoxon signed-rank tests were also conducted. The results were consistent with the paired t-tests, showing significant improvements for all DEM parameters ($p < 0.001$ for all) (33). Statistical significance was set at $p < 0.05$ for all analyses.

Results

Thirty-two participants completed the 12-week SVI therapy protocol. Their data were included in the final analysis. The mean (SD) age of subjects was 8.97 (±1.46) years.

Demographic Information

The demographic distribution of participants by gender and age group is presented in Table 1. The sample comprised 17 females (53.1%) and 15 males (46.9%). Eight participants were in the 7.0–7.11 years age group, six in the 8.0–8.11 group, ten in the 9.0–9.11 group, five in the 10.0–10.11 group, and three in the 12.0–12.11 group.

Table 1: Distribution of participants by gender and age Group

	Gender		Total
Age	**Male**	**Female**	
7-7.11	4	4	8
8-8.11	3	3	6
9-9.11	4	6	10
10-10.11	2	3	5
12-12.11	2	1	3
Total	15	17	32

Table 2 presents the mean DEM scores pre- and post-intervention, stratified by age group. Substantial reductions in all DEM parameters were observed following the 12-week training program.

Table 2: Mean and standard deviation of DEM test scores before and after treatment

	Age Group (years)	**Index**	**Vertical time (seconds)**	**Horizontal Time (seconds)**	**Adjusted Horizontal Test(seconds)**	**Ratio**	**Total error (n)**
Before vision therapy	7-7,11	mean	85.64	145.95	171.50	2.04	27.25
		sd	19.34	42.58	60.15	0.66	7.09
	8-8,11	mean	59.84	90.00	108.01	1.83	27.00
		sd	8.02	30.07	21.49	0.46	9.57
	9-9,11	mean	58.16	105.25	118.54	2.06	24.50
		sd	13.48	31.84	31.44	0.46	9.42
	10-10,11	mean	49.46	96.71	107.64	2.16	25.00
		sd	14.23	45.72	38.51	0.38	6.12
	12-12,11	mean	42.85	50.56	56.03	1.31	14.00
		sd	5.22	1.64	4.76	0.13	3.61
	total	mean	62.55	106.11	122.24	1.96	24.75
		sd	19.65	43.50	49.99	0.52	8.45
after vision therapy	7-7,11	mean	67.92	96.94	104.82	1.60	18.13
		sd	12.28	27.09	25.80	0.31	7.38
	8-8,11	mean	51.87	74.45	77.99	1.53	14.17
		sd	8.75	14.96	10.83	0.30	11.21
	9-9,11	mean	50.38	83.50	83.84	1.67	7.90
		sd	12.79	27.67	27.02	0.37	5.47

10-10,11	mean	43.17	64.79	64.72	1.48	6.80
	sd	7.91	16.49	18.22	0.25	4.82
12-12,11	mean	36.85	46.11	46.07	1.43	3.00
	sd	3.30	7.77	6.36	0.29	2.65
total	mean	52.86	78.73	81.64	1.57	11.00
	sd	14.26	26.34	27.17	0.31	8.48

Note: DEM = Developmental Eye Movement, SD = Standard Deviation, Ratio = Adjusted Horizontal Time / Vertical Time. Age groups are presented as years–years,months (e.g., 7–7,11 indicates ages 7 years 0 months to 7 years 11 months). Adjusted Horizontal Time is calculated as (Horizontal Time × 80) / (number of horizontal numbers), as per the standard DEM test manual. Total Error represents the sum of transposition, substitution, omission, and addition errors across test card C, n = number of errors

As shown in Table 2, the time values across all indicators decreased substantially following the intervention. The mean vertical time decreased from 62.55 (SD ± 19.65) seconds prior to training to 52.86 (SD ± 14.26) seconds after training. Similarly, the adjusted horizontal time showed a notable decrease from a pre-VT mean of 122.24 (SD ± 49.99) seconds to a post-VT mean of 81.64 (SD ± 27.17) seconds. The ratio also decreased following intervention, from a pre-VT mean of 1.96 (SD ± 0.52) to a post-VT mean of 1.57 (SD ± 0.31). Finally, a substantial decline was observed in the error rate, which decreased from a mean of 24.75 (SD ± 8.45) before training to 11.00 (SD ± 8.48) after vision therapy.

Table 3 presents the normative data for the DEM test in Persian-speaking children, providing reference values for comparison with the study sample. The results indicated a consistent decrease in all measured parameters with increasing age, with younger children showing the highest vertical and adjusted horizontal times, ratios, and errors.

Table 3: DEM norms by age for Persian-speaking children

Age		Vertical time	Adjusted horizontal time	Ratio	errors
7-7.11	mean	69.2702	104.2082	1.5386	19.0000
	sd	14.42100	21.79607	.34009	8.95742
8-8.11	mean	54.7213	77.5546	1.4341	15.6667
	sd	10.39285	17.36891	.28129	8.66106
9-9.11	mean	47.1303	65.5138	1.4114	13.6333
	sd	8.64474	14.71718	.31989	8.76867
10-10.11	mean	44.9313	54.3507	1.2229	7.4417
	sd	8.16318	10.62255	.20906	6.07903
11-11.11	mean	39.1611	46.7970	1.1986	6.1667
	sd	5.50202	9.10688	.18511	5.08637
12-12.11	mean	36.3051	41.0072	1.1420	4.4833
	sd	5.48969	7.51995	.22964	4.52070
total	mean	48.5866	64.9052	1.3246	11.0653
	sd	14.35130	25.67847	.30274	8.98724

Note: DEM=Developmental Eye Movement, SD=Standard Deviation, Ratio = Adjusted horizontal time divided by vertical time. Age groups are presented as years–years,months (e.g., 7–7.11 indicates ages 7 years 0 months to 7 years 11 months). Adjusted horizontal time is calculated as (Horizontal time × 80) / (number of horizontal numbers), as per the standard DEM test manual. Total error represents the sum of transposition, substitution, omission, and addition errors across test card C.

Comparison of parameters Pre- and Post-Treatment

To evaluate the differences in timing and scoring parameters before and after the intervention, paired-sample t-tests were performed. The results are presented in Table 4.

Table 4: Paired t test results for pre and post treatment scores

Parameter	Mean Difference	SD of Differences	SD of mean Differences	df	t-value	95% CI (Lower)	95% CI (Upper)	Cohen's d	p-value
Vertical time (seconds)	9.90	8.72	1.54	31	6.42	6.76	13.05	1.14	<0.001
Horizontal time (seconds)	27.37	26.52	4.70	31	5.84	17.81	36.93	1.03	<0.001
Adjusted horizontal time (seconds)	40.78	30.86	5.46	31	7.48	29.66	51.91	1.32	<0.001
Ratio	0.38	0.45	0.08	31	4.83	0.22	0.55	0.84	<0.001
Total error (n)	13.75	8.03	1.42	31	9.68	10.85	16.65	1.71	<0.001

Note: SD = Standard Deviation, SD of differences = Standard Deviation of the Differences, CI = Confidence Interval, df = degrees of freedom. Mean Difference = Before vision therapy minus After vision therapy. Cohen's d was calculated as Mean Difference divided by SD of differences (0.2 = small, 0.5 = medium, 0.8 = large effect).Ratio = Adjusted Horizontal Time / Vertical Time. Adjusted Horizontal Time is calculated as (Horizontal Time × 80) / (number of horizontal numbers) per DEM test manual. Total Error represents the Sum of transposition, substitution, omission, and addition errors across test C card. A positive Mean Difference indicates improvement after vision therapy.

As shown in Table 4, all mean differences were positive, indicating that scores before treatment were higher (worse) than after treatment**.** The effect sizes (Cohen's d) were large for all outcome measures, ranging from 0.84 (ratio) to 1.71 (total error), indicating clinically meaningful improvements following the intervention.The paired t-tests demonstrated statistically significant improvements across all DEM parameters, for vertical (mean difference = 9.90 s, $t=6.42$, $df=31$, $p< 0.001$), adjusted horizontal time (mean difference = 40.78 s, $t=7.48$, $df=31$, $p< 0.001$) , ratio (mean difference = 0.38, $t=4.83$, $df=31$, $p< 0.001$) and errors (mean difference = 13.75, $t=9.68$, $df=31$, $p< 0.001$).

Figure 1 illustrates the mean values for vertical time (A), adjusted horizontal time (B), total errors (C), and ratio (D) before and after the 3-month vision therapy program. The noticeable downward trends across all parameters are consistent with pre-post improvements following the intervention.

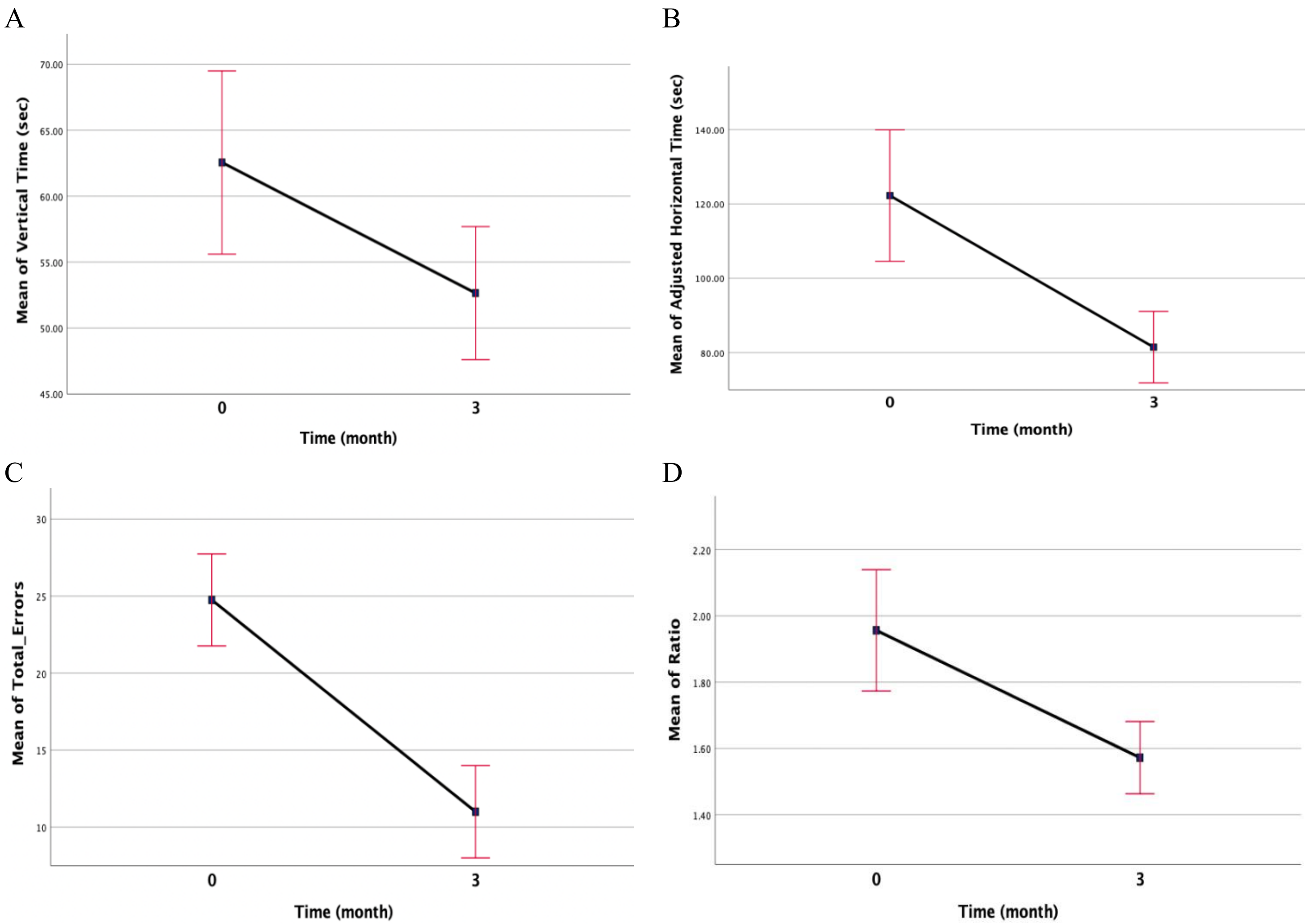

Figure 1: Mean Vertical time (A), Adjusted Horizontal time (B), Total Errors (C), and Ratio (D) pre- and post-vision therapy

Discussion

This study found that a 12-week program of computerized oculomotor training using the Sanet Vision Integrator system was associated with significant pre-post improvements in DEM test performance in primary school children with reading difficulties. Post-treatment results revealed consistent improvements across all DEM parameters, including reductions in vertical and horizontal times, adjusted horizontal scores, ratio values, and total errors. However, it is important to clarify what the DEM test measures. The DEM is not a direct measure of saccadic accuracy or isolated oculomotor control. Rather, it is a composite measure substantially influenced by RAN, visual-verbal processing speed, attention, and task familiarity (25, 28, 34). Therefore, improvements in DEM performance cannot be uniquely attributed to changes in oculomotor function, they likly also reflect enhanced naming speed, attentional control, or general processing efficiency.

From a neurophysiological perspective, improvements in vertical time likely reflect training-induced neural plasticity within the left hemisphere reading network, particularly the visual word form area and angular gyrus, which enhance visual word decoding efficiency. Repeated oculomotor and naming practice may strengthen synaptic connections within frontoparietal attentional networks, facilitating more efficient top-down control of visual scanning (35). This form of experience-dependent neuroplasticity has been documented following structured reading and visual training programs in children, supporting the plausibility of similar mechanisms in the present context (36). Additionally, the repetitive naming of single-digit numbers strengthens the phonological loop and syllable-level processing, accelerating the mapping between orthographic symbols and their verbal outputs (37, 38). Rapid automatized naming abilities in childhood represent a robust predictor of later reading achievement, operating independently of phonological awareness, verbal comprehension, and reading skills (39).

Notably, in comparison to the established DEM norms for Persian-speaking populations presented in Table 3, the present findings reveal clinically meaningful normalization of vertical time across all age groups (7–12 years) following intervention. Whereas mean vertical time values exceeded the normal threshold (>1 SD above age-matched norms) prior to treatment, post-intervention measures fell within or even surpassed the average range for the general population.

The observed improvement in vertical time appears to stem from the synergistic effects of two customized SVI protocols. The Tracking Level 4 program requires vertical saccadic movements to acquire targets at specific positions, incorporating adjustable speed, size, and contrast alongside multisensory feedback. When combined with the Level 2 saccadic verbal naming module, which targets rapid automatized naming speeds, this training addresses the visual-verbal processing speed underlying DEM vertical time.

The significant reduction in horizontal time following intervention was associated with improved performance on this measure, which reflects a combination of horizontal scanning efficiency, naming speed, and attentional factors. At the neural level, improvements in horizontal scanning may involve strengthened connectivity within the posterior parietal cortex and frontal eye fields, regions critically involved in the programming and execution of voluntary saccadic movements (40). Attention-related gains may further contribute through enhanced recruitment of the superior parietal lobule, which coordinates spatial attention during sequential visual scanning tasks (41). Unlike vertical time, which primarily measures verbal processing, horizontal time is more heavily influenced by oculomotor demands, including, saccadic precision, and the capacity to execute accurate return sweeps during reading-like tasks (42, 43). Nevertheless, even horizontal time is not a pure measure of saccadic function, as it also requires rapid verbal naming of each digit. Therefore, while the observed improvements in horizontal time are consistent with enhanced scanning efficiency, they may also reflect improved naming speed or attentional focus.

The SVI saccadic training modules (Levels 1-2), featuring progressively shorter target display durations and sequential target acquisition tasks, directly address the combined oculomotor and naming demands assessed by DEM horizontal time. Level 1 fosters rapid saccadic accuracy and fixation stability through touchscreen interaction, while Level 2 accelerates automatic verbalization under time pressure (44). This improvement would be expected to result in increased reading speed, reduced fixation durations on words, and enhanced reading fluency. Previous research has demonstrated that individuals with slower horizontal time tend to exhibit more reading errors, such as losing their place or omitting words (42). The existing literature have also confirmed significant correlations between saccadic deficits and reading dysfunction, and further showed that targeted training can enhance the speed and accuracy of saccadic movements (16, 45, 46). However, because reading performance was not directly measured in the present study, we cannot determine whether the observed DEM improvements correspond to actual gains in reading rate, accuracy, or comprehension.

The DEM ratio is designed to differentiate between poor saccadic function and poor ability to rapidly name numbers (34). A ratio approaching or exceeding 1.0 indicates disproportionately slow horizontal scanning relative to vertical naming performance, suggesting impaired saccadic efficiency, fixation instability, or poor line-switching ability rather than merely reduced automatized naming speed (43, 47).

Following the three-month SVI intervention, significant normalization of the DEM ratio was observed, with values decreasing from pathological ranges toward normal limits across all age cohorts. Normalization of the DEM ratio is associated with faster reading speeds, while elevated ratios correlate with poorer reading performance (48). Nevertheless, as reading was not directly measured in the present study, these associations remain theoretical rather than empirically demonstrated in our sample.

The substantial reduction in error scores is particularly noteworthy. DEM errors, comprising omission and addition errors during horizontal card performance, primarily reflect visuo-attentional processing and reading accuracy rather than pure oculomotor precision (29). The reduction in omission and addition errors is consistent with enhanced top-down attentional control mediated by the dorsolateral prefrontal cortex, which suppresses task-irrelevant responses and maintains goal-directed visual search(49). Furthermore, repeated engagement of sustained attention during SVI training may promote neuroplastic changes within the anterior cingulate cortex and prefrontal-parietal networks, regions associated with error monitoring and attentional regulation (50). The SVI Level 2 saccadic verbal training, combined with the tracking modules' auditory feedback, may have contributed to these reductions by building automaticity in alphanumeric recognition while reinforcing sustained attention and error monitoring (51, 52). Children with fewer DEM errors have been shown to exhibit superior reading skills and academic outcomes (53).

It should be noted that the neurophysiological mechanisms discussed above including, training-induced neuroplasticity, frontoparietal network reorganization, and prefrontal attentional modulation were not directly assessed in the present study. These mechanistic interpretations are therefore speculative.

The observed reductions in horizontal and vertical times, together with fewer total errors, highlight clinically meaningful improvements in DEM performance and rapid automatized naming. Before intervention, the pattern of longer horizontal times compared to vertical times reflected relatively poorer horizontal scanning efficiency compared to vertical naming speed, consistent with previous reports on children with reading difficulties (12, 25, 26). Our findings confirm that horizontal scanning skills are particularly vulnerable in this population (13, 54, 55). Similar results have been reported in children with learning disabilities, where horizontal times consistently exceeded vertical times regardless of binocular vision status (13, 54, 56).

DEM errors are linked to dysfunction of the magnocellular pathway, which is essential for visual attention and word recognition during reading (57). The improvements in horizontal and ratio scores observed in our study are consistent with earlier reports that targeted visual training can improve accuracy, speed, and comprehension in children with reading difficulties (58-62).

In addition to the statistical improvements, qualitative observations from parents and teachers were collected. They reported that children read faster and more smoothly, with fewer errors, less frustration, and reduced line skipping (63). However, these reports are subjective and were not obtained under masked conditions. Therefore, they are susceptible to expectancy and desirability biases and cannot serve as conclusive evidence of reading improvement.

The novelty of the present study lies in its first-time application of the DEM test to evaluate the DEM performance in Persian-speaking children with reading difficulties. This unique contribution expands the evidence base by demonstrating the applicability of DEM-based assessment and therapy outcomes in a non-English speaking context (6, 62, 64).

The strengths of our study include the use of the DEM test before and after vision therapy, implemented via the Sanet Vision Integrator system. The diversity of digital targets in terms of size, shape, contrast, and positioning effectively motivated participants to continue treatment. All therapy sessions were conducted under the supervision of optometrists, and pre- and post-treatment evaluations were performed by separate optometrists to minimize bias.

Several limitations should be acknowledged. The uncontrolled pre-post design and the absence of a randomized control group reduces the ability to isolate the specific effects of vision therapy from potential test-retest practice effects, regression to the mean, attention effects or natural maturation. The DEM is a composite measure influenced by RAN, attention, and processing speed, not a direct measure of oculomotor control. The relatively modest sample size limits generalizability. The intervention focused primarily on saccadic and pursuit training, excluding convergence exercises and other visual functions that may contribute to reading performance (6, 62). Visual attention was not directly measured, although the exercises required sustained attentional engagement (65, 66). Finally, qualitative reports from parents and teachers were based on subjective observations rather than standardized assessments such as reading rate, accuracy, comprehension.

Future research should employ larger samples, randomized controlled designs, longer follow-up periods, and comprehensive measures of visual attention, binocular function, and comprehensive, standardized measures of reading performance to strengthen the evidence base (67).

The clinical implications of the present findings should be interpreted with consideration of the uncontrolled pre-post design and the absence of direct reading measures. Nevertheless, the improvements in DEM parameters particularly the normalization of vertical and horizontal times across all age groups suggest that SVI-based vision therapy is a feasible intervention that may be associated with short-term improvements in rapid automatized naming and visual-verbal processing speed in children with reading difficulties (58-61, 68). These preliminary findings, together with qualitative reports from parents and teachers of smoother and faster reading, provide a rationale for future randomized controlled trials to rigorously evaluate the efficacy of this approach.

Conclusion

The present study demonstrated that Iranian primary school children with reading difficulties showed significant pre-post improvements in DEM test performance following a 12-week SVI-based vision therapy program, including reductions in vertical and horizontal times, ratio values, and error scores. However, due to the uncontrolled pre-post design, these improvements cannot be attributed solely to the intervention. Alternative explanations include normal developmental maturation, practice/retest effects (learning effect on the DEM), regression to the mean given selection for abnormal baseline scores, and nonspecific attention effects. Therefore, future randomized controlled trials are needed to confirme the clinical effectiveness of targeted visual training in addressing core visual deficits underlying reading problems.

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Conflict of interest
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