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Original Article

Efficacy of the DEM test as a predictor of reading difficulty

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ABSTRACT

Purpose: This study aimed to evaluate the relationship between the DEM test and reading speed, its diagnostic accuracy (sensitivity and specificity), and its usefulness as a screening tool for reading difficulties. We also examined how reading speed is associated with other optometric measures.

Methods: A retrospective study was conducted involving children aged 7 and 8 years. Reading speed was assessed using the PROLEC test. The optometric evaluation included visual acuity, stereopsis, accommodative facility, near point of convergence, cover test, retinoscopy, and eye movements assessed with the DEM test. The standard DEM parameters were analyzed. In addition, given the aim of the study, a new outcome variable was introduced: the total time, calculated as the sum of the vertical and adjusted horizontal times.

Results: A total of 48 children participated in the study. When both age groups were analyzed together, all DEM parameters showed significant correlations with reading speed (vertical time, $r = -0.52, p < 0.01$; adjusted horizontal time, $r = -0.63, p < 0.01$; ratio, $r = -0.48, p < 0.01$; and total time, $r = -0.58, p < 0.01$).

The best sensitivity−specificity combination for detecting below-age PROLEC scores was obtained using the adjusted horizontal time (whole sample: 80 %/45 %). AUC ranged from 0.59 (ratio) to 0.79 (total time). A significant association was also found between reading speed and accommodative function ($p = 0.02$).

Conclusion: The application of the DEM test for detecting reading difficulties should be approached with caution. Although DEM results show a correlation with reading speed and demonstrate high sensitivity, specificity remains low regardless of the DEM measure used.

Introduccion

Learning disorders have exhibited a growing trend in recent years, with an estimated prevalence of up to 31 %.[1] Among these, reading difficulties constitute one of the most critical challenges, as they directly hinder the acquisition of academic knowledge.[2] The identification of children with suspected reading difficulties is usually carried out by teachers, followed by a comprehensive assessment by educational specialists.

Reading assessments[3,4] require considerable time and resources to administer and mark, which can limit the early identification of children with reading difficulties. They include both quantitative and qualitative measures, with the latter being more subjective and dependent on the examiner. Although these differences may seem subtle, they can significantly affect the interpretation of results.[5–7]

Furthermore, there is no universally standardised test for this type of evaluation, and national consensus is often lacking. In Spain commonly used tests include the TALE-2 (Test de Análisis de Lectoescritura) and the PROLEC battery,[8] including PROLEC-R [4] for primary education and PROLEC-S for secondary education.

Multiple factors shape reading ability, influencing both speed and fluency. These include phonological awareness (PA), rapid automatised naming (RAN),[9] and visual function. Visual function encompasses specific skills such as oculomotor control, vergence, and the accommodative system, as well as the presence of uncorrected refractive errors, amblyopia, and strabismus. Understanding these visual components is essential, as deficits in any of them can significantly impact reading efficiency.[10–13]

Individuals with reading difficulties often show abnormal oculomotor control, including inaccurate saccades (both horizontal and vertical, sometimes corrected by regressions) or hypometric saccades.[2,14] Fixations may also be altered, occurring more frequently and lasting longer.[15]

The Developmental Eye Movement (DEM) test is the gold standard psychometric instrument for assessing the effectiveness of eye movements and RAN, both variables associated with reading performance, in

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school-aged children.[16] In recent years, it has been proposed that the DEM test could serve as a screening tool to differentiate between proficient and poor readers, given that it is quicker and simpler to administer than conventional reading difficulties assessments. However, the literature reveals some controversy on this topic. On the one hand, several studies have reported significant correlations between measures of reading ability and DEM test performance.[2,5,7,15,17] On the other hand, other studies have found no such association.[6,18]

Among other differences, such as sample characteristics, it is worth highlighting the differences in the DEM parameters considered across those studies (horizontal time vs. ratio in most cases), as well as the different reading tests used as the gold standard.

Therefore, the aim of this study is to evaluate the relationship between the DEM test and reading speed, as measured by the PROLEC test, its diagnostic accuracy (sensitivity and specificity), and its usefulness as a screening tool for reading difficulties. We also examined how reading speed is associated with other optometric measures.

Material and method

Subjects

A retrospective study was conducted including children aged 7 and 8 years who were screened at the Centre for Optometry and Vision Therapy (COTV, Alicante, Spain), a private optometric center, between 2020 and 2024. All clinical records from this period that met the inclusion criteria were included. Eligible participants had undergone a comprehensive visual examination and an assessment for reading difficulties, and had signed the COTV informed consent form. All examinations were performed by the same examiner. Approximately 100 clinical records were reviewed; however, no precise data were collected. No more than five clinical records were excluded due to lack of informed consent, and between five and ten were excluded due to missing optometric testing. Finally, between 30 and 40 clinical records were excluded because they did not have a reader assessment.

Children were excluded if they presented with amblyopia or strabismus, had prescribed refractive correction for less than two months, or showed any ocular pathology affecting the retina (e.g. retinoblastoma, retinal detachment), as well as any alteration in media transparency that could compromise visual function or its development. Moreover, patients should be in good general health, with no systemic pathology. To be included in the study, the health record had to contain a comprehensive optometric examination and a reading evaluation conducted on the same date and the children included are 7 and 8 years old and must be in the academic year corresponding to their age.

All patients were treated in compliance with the Declaration of Helsinki and the European Normative for data protection (2016/679 Regulation of the European Parliament and the Council of 27th of April 2016, General Data Protection Regulation), and the study received approval from the ethics committee of Vega Baja in Orihuela, Spain (PI-2025-046). This committee determined that the necessary requirements for the suitability of the protocol in relation to the study objectives are met, that the foreseeable risks and inconveniences for the study are justified, and that the procedure is adequate for obtaining informed consent.

Material and procedure

To assess reading ability, an objective measure of reading speed was employed as the primary variable, calculated based on the number of words read per minute in the reading subtest of the PROLEC battery.[3] In addition, based on PROLEC criteria, it was determined whether each child's reading speed was appropriate for their age.

The optometric assessment included the following tests: visual acuity, stereopsis (Randot Preschool Stereotest, Stereo Optical, Inc., Chicago, IL), accommodative facility (± 2.00 D flippers), near point of convergence, cover test, estimation of refractive error with retinoscopy (Beta 200 retinoscope, Heine), and assessment of eye movements using the DEM test, the latter being the primary optometric variable.

Table 1
Normative values for vertical and horizontal times, errors, and ratio in the DEM test.

Age	Vertical time	Horizontal time adjusted	Errors	Ratio
6.0-6.11	63.11 ± 16.59	98.26 ± 32.61	15.22 ± 11.49	1.58 ± 0.45
7.0-7.11	54.83 ± 9.20	87.94 ± 28.18	12.50 ± 12.91	1.60 ± 0.41
8.0-8.11	46.76 ± 7.89	57.76 ± 12.32	4.61 ± 6.91	1.24 ± 0.18
9.0-9.11	42.33 ± 8.20	51.13 ± 13.30	2.17 ± 4.10	1.21 ± 0.19
10.0-10.11	40.28 ± 7.43	47.64 ± 10.11	1.91 ± 2.68	1.19 ± 0.17
11.0-11.11	37.14 ± 5.42	42.62 ± 7.61	1.68 ± 2.34	1.15 ± 0.13
12.0-12.11	35.14 ± 5.87	39.35 ± 8.11	1.11 ± 1.17	1.12 ± 0.10
13.0-13.11	33.75 ± 6.53	37.56 ± 7.23	1.61 ± 2.15	1.12 ± 0.12

The DEM test comprises three sheets. Sheets A and B each consist of two vertical columns with 20 numbers. The child is instructed not to use their finger, but to rely only on their eyes. Sheet C contains 80 numbers arranged horizontally in several lines and spaced irregularly. During the test, the time taken in seconds by the child to read the numbers aloud as quickly as possible—without using a finger as a guide—was recorded for each sheet.

The first outcome measure from the DEM test, referred to as vertical time, reflects the total time required to read sheets A and B. The second measure, adjusted horizontal time, reflects the time taken to read sheet C, adjusted for errors of omission ("o", when a number is skipped) and addition ("a", when a number is added, repeated, or incorrectly named). The adjustment is carried out according to Eq. (1). Finally, the DEM test provides a third outcome: the ratio, calculated as the quotient of the adjusted horizontal time divided by the vertical time (Eq. (2)). The test provides age-normative reference values for each outcome (vertical time, adjusted horizontal time, and ratio), as shown in Table 1.[16]

$$\text{Adjusted horizontal time} = \text{time (s)} \times 80/(80 - o - a) \quad (1)$$

where o represents omission errors and a represents addition errors.

$$\text{Ratio} = \text{adjusted horizontal time (s)}/\text{vertical time (s)} \quad (2)$$

These three variables allow the identification and differentiation of oculomotor dysfunctions (alterations in horizontal saccades) and RAN deficits, the declared purpose of DEM test. Vertical time is primarily associated with RAN, whereas horizontal time reflects both RAN performance and horizontal saccadic control. Therefore, the ratio offers an index of saccadic eye movement efficiency in the context of rapid automatised naming.[16] DEM test classifies patients into the following typologies, validated for English[16] and confirmed for Spanish:[19]

- Type I: Normal adjusted horizontal time, vertical time, and ratio.
- Type II: Normal vertical time, increased adjusted horizontal time, and elevated ratio – indicative of oculomotor dysfunction.
- Type III: Increased vertical time and adjusted horizontal time, and normal ratio – suggestive of difficulties in automaticity.
- Type IV: Elevated adjusted horizontal time, vertical time, and ratio – indicative of combined oculomotor and automaticity deficits.[16]

For the stated aim of this study, the relationship between reading speed and adjusted horizontal time appears straightforward, regardless of whether the underlying difficulty is oculomotor or related to automaticity. Among all DEM outcomes, adjusted horizontal time is, a priori, the most promising predictor examined in this paper.

By contrast, the ratio is designed to distinguish between oculomotor efficiency and rapid automatized naming. Although it can be affected when reading speed is influenced by either RAN performance or oculomotor ability alone, it would remain stable if both functions are impaired to a similar extent. Therefore, the ratio is a priori not a strong standalone predictor of reading difficulties.

Table 2
Descriptive statistics for the main study variables, including mean, standard deviation, and range. Correlations with reading speed are also presented for each age group. Rho de Spearman.

Measured Parameter	Mean ± DE	Range (min-max)	Corr. (words/min) R (p-value)	CI 95 %
Children from 7 years old				
Visual Acuity	0.93 ± 0.14	0.4 – 1	−0.08 (0.70)	0.87 to 0.98
Stereopsis (“)	106.67 ± 244.28	40 – 1200	−0.38 (0.07)	30.51 to 209.82
FAM (cycles/min)	6.94 ± 3.01	0 – 13	−0.13 (0.55)	5.66 to 8.21
PPC (cm)	3.56 ± 4.51	0 – 15	−0.06 (0.69)	1.65 to 5.47
Cover test (Dp)	4.46 ± 3.17	0 – 12	−0.20 (0.36)	3.11 to5.80
Vertical time (s)	61.78 ± 12.90	47.29 – 97.48	**−0.59 (<0.01)**	55.96 to 68.80
Addition errors	1.45 ± 2.50	0 – 10	−0.14 (0.54)	0.28 to 2.62
Omission errors	13.65 ± 9.09	0 – 31	−0.30 (0.20)	9.39 to 17.90
Adjusted Horizontal Time (s)	83.13 ± 43.61	0 – 155.29	**−0.63 (<0.01)**	88.72 to 110.79
Ratio	1.64 ± 0.46	1.02 – 3.12	0.04 (0.87)	1.43 to 1.86
Total time (S)	144.91 ± 48.37	47.66 – 225.37	**−0.64 (<0.01)**	147.73 to 176.54
Reading speed (words/min)	59.67 ± 26.35	14 – 103	-	45.43 to 70.66
Children from 8 years old				
Visual Acuity	0.93 ± 0.15	0.4 – 1	0.02 (0.46)	0.87 to 1.00
Stereopsis (“)	146.96 ± 332.74	40 – 1200	0.18 (0.47)	30.71 to 2090.84
FAM (cycles/min)	12.26 ±3.85	3 – 18	0.13 (0.20)	10.60 to 13.93
PPC (cm)	2.91 ± 2.74	0 – 7	0.03 (0.45)	1.73 to 4.10
Cover test (Dp)	2.26 ± 5.34	−10 – 12	0.07 (0.37)	−0.05 to 4.56
Vertical time (s)	53.59 ± 10.46	35.15 – 80.10	−0.41 (0.05)	49.07 to 58.11
Addition errors	0.48 ± 1.44	0 – 5	−0.51 (0.15)	−0.14 to 1.10
Omission errors	4.87 ± 5.47	0 – 20	−0.33 (0.12)	2.50 to 7.23
Adjusted Horizontal Time (s)	66.94 ± 16.75	41.94 – 106.67	**−0.51 (0.01)**	59.70 to 74.19
Ratio	1.27 ± 0.35	0.90 – 2.20	0.06 (0.96)	1.12 to 1.42
Total time (S)	120.53 ± 22.38	77.09 – 162.37	**−0.59 (<0.01)**	110.86 to 130.21
Reading speed (words/min)	87.17 ± 28.43	50 – 145	-	74.88 to 99.46
All children				
Visual Acuity	0.93 ± 0.14	0.4 – 1	0.13 (0.36)	0.89 to 0.97
Stereopsis (“)	126.38 ± 288.45	40 – 1200	0.06 (0.96)	41.069 to 211.07
FAM (cycles/min)	7.39 ± 4.34	0 – 18	**0.33 (0.02)**	8.26 to 10.82
PPC (cm)	3.61 ± 3.73	0 – 15	0.05 (0.62)	2.15 to 4.39
Cover test (Dp)	4.41 ± 4.46	−10 – 12	−0.07 (0.51)	2.07 to 4.69
Vertical time(s)	57.77 ± 12.36	35.15 – 97.48	**−0.52 (<0.01)**	53.76 to 61.60
Addition errors	0.93 ± 2.04	0 – 10	**−0.36 (0.02)**	0.30 to 1.56
Omission errors	8.95 ± 8.53	0 – 31	**−0.48 (<0.01)**	6.32 to 11.58
Adjusted Horizontal Time (s)	82.21 ± 25.94	41.94 – 155.29	**−0.63 (<0.01)**	74.22 to 90.19
Ratio	1.45 ± 0.44	0.90 – 3.12	**−0.48 (<0.01)**	1.31 to 1.58
Total time (S)	132.99 ± 39.51	47,66 – 225.37	**−0.58 (<0.01)**	129.89 to 150.24
Reading speed (words/min)	73.13 ± 30.44	14 – 145	-	64.05 to 83.20

Vertical time is primarily associated with RAN performance according to DEM guidelines. Therefore, is a priori a good predictor of reading difficulties only rooted in naming automaticity.

Given that both adjusted horizontal time and vertical time are a priori good predictors of reading speed, we evaluated whether combining them could yield an even stronger predictor than either measure alone. We refer to this combined metric as total time.

Statistical analysis

The sample size was calculated considering an alpha error and a beta error of 0.20. A total of 94 patients were needed to calculate sensitivity, 24 patients for specificity, and 40 patients for the ROC curve (with 11 cases and 30 controls).

Data were recorded in an Excel spreadsheet (Microsoft Office 2016) and subsequently analysed using SPSS version 26.0 (IBM, USA). Data were analysed in aggregate and separated by age. The Kolmogorov −Smirnov test was applied to assess the distribution of the sample, with a significance level of $p < 0.05$, indicating a non-parametric distribution.

For the descriptive analysis, the mean, standard deviation, and range (minimum−maximum) were reported. Given the non-parametric nature of the sample, Spearman’s rho correlation coefficient was calculated to examine the relationship between reading speed and the values obtained in the optometric assessment, including errors made in the DEM test and the variable defined as *total time*. A logistic regression model was performed with all variables based on Wald’s criterion to determine the associations of the studied variables with PROLEC outcomes by means of correlation coefficients and odds ratios.

Additionally, contingency tables were constructed to evaluate the sensitivity, specificity, positive predictive value, negative predictive value, overall predictive value, positive likelihood ratio, negative likelihood ratio of various optometric tests in relation to reading speed. In addition, ROC curves were generated for tests demonstrating higher sensitivity values to determine whether further improvements in sensitivity could be achieved. Finally, the data were standardised using the *z*-score [20] to enable graphical comparison.

Results

A total of 48 children aged 7 and 8 years were included in the study. Of these, 25 were girls (52.08 %) and 23 were boys (47.92 %). The 7-year-old group comprised 25 children (14 girls and 11 boys), while the 8-year-old group included 23 children (11 girls and 12 boys). Refractive errors were present in 22 % of 7-year-olds and in 26 % of 8-year-olds. Five 7-year-olds and five 8-year-olds did not have reading speeds appropriate for their age.

Table 2 shows the descriptive statistics (mean, standard deviation, minimum, and maximum) for each group individually and combined, across all measured variables. The final column displays the correlation between the optometric variables and reading speed, which was considered the primary outcome measure for assessing the children’s reading performance. Except for the DEM test, the only optometric variable that showed a statistically significant correlation with reading speed was accommodative flexibility when data from both groups were analysed together ($r = 0.33$; $p = 0.02$).

Correlation of the DEM test with reading speed

Statistically significant negative correlations were observed in the 7-year-old group between reading speed and vertical time ($r = -0.59$; $p < 0.01$) and adjusted horizontal time ($r = -0.63$; $p < 0.01$). The correlation for total time was similar to that of the adjusted horizontal time ($r = -0.64$; $p < 0.01$). Among the 8-year-olds, a statistically significant correlation was found only between reading speed and adjusted horizontal time ($r = -0.51$; $p = 0.01$), and between reading speed and total time ($r = -0.59$; $p < 0.01$).

Similarly, when data from both age groups are analysed together, a consistent negative correlation is observed between reading speed and all parameters derived from the DEM test namely, vertical time ($r = -0.52$; $p < 0.01$), addition errors ($r = -0.36$; $p = 0.02$), omission errors ($r = -0.48$; $p < 0.01$), adjusted horizontal time ($r = -0.63$; $p < 0.01$), ratio ($r = -0.48$; $p < 0.01$), and total time ($r = -0.58$; $p < 0.01$).

These correlations are showed in Fig. 1, which plots the reading speed according to PROLEC on the vertical axis against the DEM test results on the horizontal axis adjusted horizontal time, vertical time and total time. To facilitate the understanding of the graph, the results of the DEM test are normalised according to Z-score, taking mean and variance of the whole sample. The 8-year-old group, in orange, appears next to the 7-year-old group, in blue. The z-score normalised times of the total population are centred on zero after this normalisation.

A negative correlation is observed in all cases: higher reading speed is associated with shorter times on all DEM test measures. As expected, the 8-year-old group demonstrates faster reading speeds and lower DEM times compared to the 7-year-old group. Many participants were within $\pm$ 2 standard deviations according to the Z-score normalization.

Finally, the graph includes the linear regression lines of the full sample, the 7-year-old group and the 8-year-old group for all three times measures. The correlation coefficient of these linear regressions is consistently worse for the 8-year-old group compared to the 7-year-old group. In any case, it can once again be observed that the best fit with reading speed is achieved when considering total time ($r = -0.779$ for the full sample; -0.812 for 7 years old; -0.607 for 8 years old), followed by horizontal time ($r = -0.716$ for the full sample; -0.689 for 7 years old; -0.488 for 8 years old), while vertical time shows the weakest association ($r = 0.601$ for the full sample; -0.638 for 7 years old; -0.425 for 8 years old). The logistic regression model based on Wald's rejects all factors except total vertical time, horizontal time, and total DEM test time. In the next step, it considers that the factors are redundant, as the total time is the sum of the vertical and horizontal times, and decides that the factor related to screening performed with PROLEC is the total time, with a significance of less than 0.01 and an odd ratio of 1.04. If Wald's logistic regression model was applied to 7-year-old children, the result is very similar, with an odds ratio of 1.2. However, in 8-year-old children, no factor is considered statistically significant.

Sensitivity and specificity of the DEM test in the detection of reading difficulties

Table 3 shows the sensitivity and specificity results of the DEM test in relation to reading speed, the primary outcome measure assessed using the PROLEC. By comparing the proportion of children whose reading speed falls below the expected threshold for their age with the established cut-off times for various DEM test parameters, sensitivity and specificity values were obtained. These results indicate acceptable sensitivity for all variables except the ratio (vertical time 80 to 100 % depending on which group is considered; horizontal time 80 % in any grouping; ratio 40 to 60 % depending on grouping; total time 100 % in any grouping), although specificity was low (vertical time 22 to 47 %; horizontal time 33 to 58 %; ratio 42 to 73 %; total time 28 to 52 %).

Furthermore, Fig. 2 presents the ROC curves for the different time-based measures of the DEM test, along with the corresponding area under the curve (AUC) values for each parameter (vertical time: 0.673; horizontal time: 0.733; ratio: 0.591; total time: 0.789). Once again, total time demonstrates the highest discriminative capacity.

Discussion

Previous studies have reported inconsistent findings regarding the capacity of the DEM test to serve as a predictor of reading difficulties.[2,5–7,17]

In the present study, the PROLEC test was employed as test for assessing reading ability. The comparison between the outcomes of this test and those obtained from the DEM test, along with various optometric assessments, aimed to evaluate whether a faster and more objective alternative for identifying reading difficulties is feasible. This approach seeks to address the inconsistencies reported in previous studies.[5–7]

Correlation of the DEM test with reading speed

The results of this study, as presented in Table 2 and Fig. 1, indicate that DEM test times—specifically vertical time, adjusted horizontal time, and ratio—are correlated with reading speed. The strongest correlation was observed for adjusted horizontal time, while the ratio demonstrated a weaker association.

These findings are consistent with those reported by Ayton et al.[5] who found statistically significant correlations between Burt's reading tests and all DEM subtests. Similar conclusions were drawn by Wood et al. [6] who employed the NAPLAN test to assess reading ability, and by Hopkins et al.[7] who used the standardised Progressive Achievement Tests in Reading and Mathematics (PAT-R and PAT-M). Notably, in all three studies, as in the present one, the highest correlation was observed with adjusted horizontal time.

However, in the study conducted by Vernet et al.,[15] which employed the Alouette reading test in a cohort of 6-year-old children, a higher correlation was observed between reading speed and vertical time, despite significant correlations across all DEM subtests. The authors attributed this finding to the young age of the participants, whose oculomotor development was still immature. As horizontal saccadic control had not yet fully developed, the vertical subtest—which primarily involves visual processing and attentional demands—appeared to be a more representative indicator of reading readiness. This interpretation is consistent with the present findings and those of the aforementioned studies, which excluded 6-year-olds from their samples, as the reading process is not yet fully consolidated at that age.

Furthermore, there are clear differences between the various reading tests. The NAPLAN test (used by Wood et al.) includes tests on reading, writing, spelling, grammar, punctuation and numeracy, making it much longer than the Alouette test (used by Vernet et al.), which consists of a 3-minute reading test. This text contains 265 meaningless words whose overall and syntactic meaning is incorrect or improbable. It contains improbable or irregular words and also contains spelling traps with silent letters. The test used by Ayton et al. is an oral test of 110 words with increasing difficulty. However, the PAT-R test (used by Hopkins) used in Australia assesses reading comprehension, spelling and vocabulary, and is timed. Multiple-choice questions are also included after reading the texts. Observing the various tests used to classify children's reading abilities motivated the adoption of a simple and objective criterion: age-appropriate reading speed.

Besides, other factors such as age, language, and even the social and economic context of the school may influence results, it is perhaps in the reading assessment section where the most obvious differences are perceived.

It is important to note that the ratio demonstrated the weakest correlation with reading speed, as evidenced by the results of this study and those previously cited.[6,7,15,18] Alterations in the ratio from standard values are expected if either RAN performance or oculomotor ability is impaired, but not if both are affected to a similar degree. Therefore, ratio

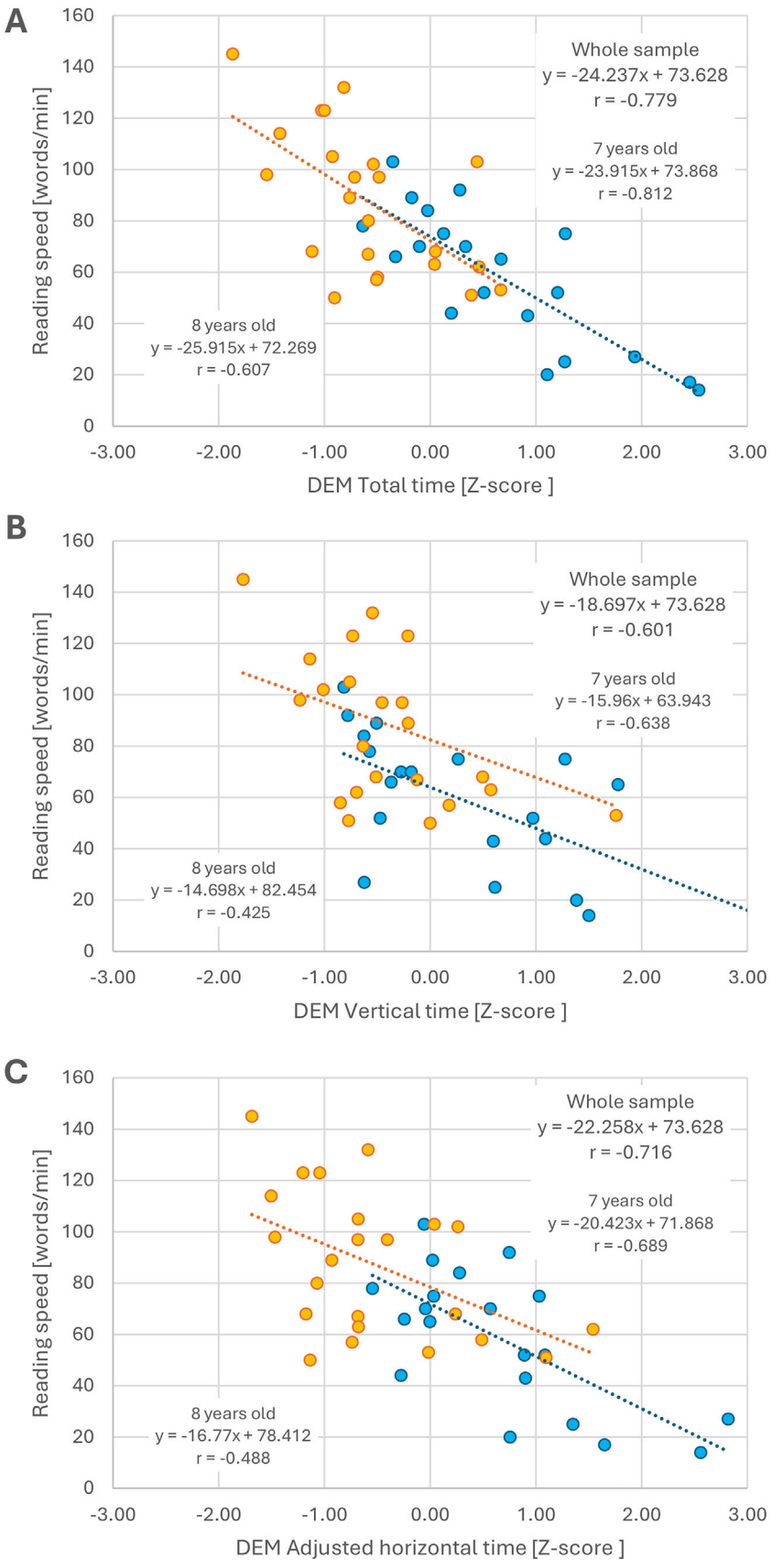

Fig. 1. Graphical representation of DEM z-scores (total time, vertical time, and adjusted horizontal time) versus PROLEC reading speed for each participant. Participants aged 7 years are represented in blue, and those aged 8 years in orange. Regression lines are shown for both age groups. Regression equations and correlation coefficients were calculated for each group as well as for the entire sample. (A) Total time. (B) Vertical time. (C) Adjusted horizontal time.

Table 3
Sensitivity and specificity of each of the DEM test variables and total time considering reading speed as a diagnostic criterion measured with PROLEC test.

DEM vs PROLEC	Sensitivity	Specificity	PPV	NPV	OPV	PLR	NLR
Children from 7 years old							
Vertical time	80 %	47.37 %	28.57 %	90 %	54.42 %	1.51	0.43
Adjusted Horizontal Time	80 %	57.63 %	33.33 %	91.67 %	62.50 %	1.90	0.35
Total time	100 %	52.6 %	35.71 %	100 %	62.5 %	2.13	0
Ratio	60 %	42.10 %	21.43 %	80.00 %	45.83 %	1.03	0.95
Children from 8 years old							
Vertical time	100 %	22.22 %	26.31 %	100 %	39.13 %	1.28	0
Adjusted Horizontal Time	80 %	33.33 %	25 %	85.71 %	43.48 %	1.19	0.60
Total time	100 %	27.80 %	27.78 %	100 %	43.48 %	1.39	0
Ratio	40 %	72.78 %	28.57 %	81.25 %	61.25 %	1.48	0.82
All children							
Vertical time	90 %	35.13 %	27.27 %	92.86 %	46.81 %	1.38	0.29
Adjusted Horizontal Time	80 %	45.94 %	28.57 %	89.48 %	53.19 %	1.48	0.43
Total time	100 %	40.50 %	31.25 %	100 %	53.19 %	1.69	0
Ratio	50 %	56.86 %	23.81 %	80.77 %	55.32 %	1.16	0.88

PPV: positive predictive value; NPV: negative predictive value; OPV: overall predictive value; PLR: positive likelihood ratio; NLR: negative likelihood ratio. Good values for the positive likelihood ratio would be greater than 5 and less than 0.2 for the negative likelihood ratio.

is not a good reading difficulties predictor, as it might fail in the worst-case scenario.

We calculated the total time to assess whether combining corrected horizontal time and vertical time could provide a stronger predictor than either one alone. Notably, total time yielded the strongest correlation with reading speed across both age groups and for the overall sample, as shown in Table 2 and illustrated in Fig. 1. Furthermore, this parameter has been shown to be the most significant factor in the logistic regression model, although this effect disappears in 8-year-old children (as it happens with all DEM parameters). This result may be related to the consolidation of the reading process. Moreover, as explained below, the ROC analysis shows the same trend, supporting that the superior performance of total time is not merely a statistical artifact.

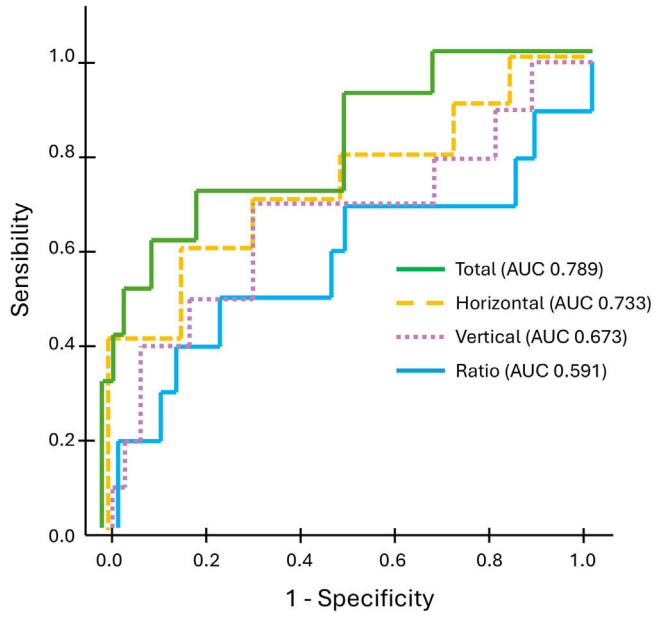

Fig. 2. ROC curves for the different DEM test outcomes as potential screening measures for the detection of reading difficulties (specificity vs sensibility): ratio (solid blue line), vertical time (dotted purple line), adjusted horizontal time (dashed orange line), and total time (solid green line). The area under the curve (AUC) is shown for each parameter.

Sensitivity and specificity of the DEM test in the detection of reading difficulties

Sensitivity and specificity values are generally considered acceptable when they exceed 75 %.[21] Although sensitivity values in this study were relatively high (see Table 3), specificity values were consistently low - below 60 % across all variables and age groups -. Analysis of the ROC curve revealed that the area under the curve (AUC) was lowest for the ratio, followed by vertical time, adjusted horizontal time, and total time. These results support the relevance of using the combined value of adjusted horizontal and vertical times when evaluating reading speed, and further highlight the limited utility of the ratio in reading-related assessments. However, ROC curve analysis did not yield a cut-off point that achieved a sensitivity greater than 80 % with acceptable specificity. These results limit the usefulness of any DEM variable for the diagnosis of reading difficulties on its own. On the other hand, the good sensitivity observed for total time or adjusted horizontal time allows their use as a pre-screening tool to identify children who require more comprehensive assessment.

The low specificity of all DEM variables analyzed in this study may lead to an overestimation of the prevalence of reading difficulties, at least when PROLEC is used as the reference test. One possible explanation is that PROLEC itself might exhibit limited sensitivity, as it was primarily designed to evaluate the underlying causes of reading disorders rather than to function as a screening tool for identifying reading difficulties. Consequently, its diagnostic sensitivity could be less than optimal. However, current evidence is not sufficient to substantiate this possibility.

New approaches are needed to improve the results obtained. Combining the DEM test with other visual or cognitive measures may help increase specificity. Recent technological advances—particularly eye-tracking—enable more detailed analysis of eye movements, allowing for the discrimination of fixations and saccades, and allowing the analysis of oculomotor efficiency independently of RAN. This technology may also facilitate the identification of the underlying cause of reading difficulties, whether oculomotor in origin or related to deficits in automaticity.[2,22]

Relationship between reading speed and accommodation

Analysis of the clinical variables revealed a statistically significant correlation between reading speed and accommodative facility ($p = 0.02$) when data from both age groups were combined. This finding is consistent with previous studies reporting that children with reading difficulties often exhibit reduced accommodative facility.[23,24]

However, these results contrast with those of Evans et al.[25] who found no significant association between these variables. One possible explanation for this relationship is that blurrier visual stimuli may require longer fixation times, thereby contributing to slower reading speeds; nonetheless, the two conditions do not necessarily coexist.[26]

Limitations of the study

This study presents several limitations that should be taken into account when interpreting the findings. First, the sample size was relatively small and drawn from a single clinical setting, which may limit the generalization of the results to broader populations. In this study, the sample size is insufficient for calculating sensitivity, although it has been included to show all the data, for which the sample size is adequate. Additionally, as a retrospective study, it was not possible to control all potential confounding variables that could influence reading speed, such as socioeconomic status or home reading environment.

Conclusions

The application of the DEM test for detecting reading difficulties should be approached with caution. Although DEM results show a correlation with reading speed and demonstrate high sensitivity - particularly when using the adjusted horizontal time or a newly proposed parameter, the sum of adjusted horizontal and vertical times - specificity remains low regardless of the DEM measure used. Based on these findings, its use is justified only as a pre-screening tool to identify children who require more comprehensive assessment. The search for rapid and reliable tests for early detection of reading difficulties and the identification of the key variables affecting reading skills remains an ongoing challenge.

Declaration of competing interest

The authors declare they have no known competing financial interests or personal relationships that may have influenced the work reported in this paper. This manuscript has not been presented at any meeting or congress. No funding was received for this work.

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