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Developmental eye movement test results of Hebrew-speaking children with cross-linguistic comparisons

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Abstract

Introduction and Purpose: The developmental eye movement (DEM) test is designed to assess saccadic eye movements and visual-verbal automaticity in children. This study aimed to assess whether there is a need for independent DEM Hebrew norms and to compare DEM results for Hebrew-speaking children with eight other language norms.

Methods: The DEM test was administered to 224 Hebrew-speaking children aged 6–13 years who met the inclusion criteria and read the numbers in Hebrew. Test C of the DEM was performed twice, once from right (R) to left (L) and once from L to R, in random order. Age group and language comparisons, including vertical and horizontal reading speeds, errors and horizontal/vertical (H/V) ratios in both directions were analysed.

Results: The participants were almost evenly distributed between the sexes (46.8% female). Statistically significant differences were found between age groups (6–9 and 10–13 years) for vertical and horizontal reading speeds and H/V ratios in both directions ($p < 0.001$). Older children, as compared to younger children, exhibited faster vertical and horizontal times, with fewer errors, as well as lower ratios ($p < 0.001$). No significant difference was noted between reading directions for horizontal time and H/V ratio within both age groups (6–9 year olds: $p = 0.27$ and $p = 0.06$; 10–13 year olds: $p = 0.89$ and $p = 0.49$, respectively). Comparison of DEM norms across languages showed significant differences, with post-hoc analysis revealing specific language-related variations. DEM results for Hebrew-speaking children had similar outcomes to both original English and French values.

Conclusions: This study compared DEM results of Hebrew-speaking children and scores across nine languages. DEM test values for Hebrew-speaking children aligned with norms from other languages, particularly the French and original English norms, with consistent ratio scores. It is recommended for practitioners who test Hebrew-speaking children to continue using the original English norms and to enable the children to read using their preferred reading direction.

KEYWORDS
children, developmental eye movement (DEM) test, eye movements, Hebrew, languages, saccades

INTRODUCTION

Reading requires the eyes to make fast, precise movements separated by short pauses to allow high-resolution visual information to be received from the text.[1] These eye movements, known as saccades, are associated with perception, visual processing, memory and attention during reading.[2] In order to understand the complex visual motor and

cognitive processes required for efficient reading, various tests have been developed.

The developmental eye movement (DEM) test is designed to assess saccadic eye movements and visual-verbal automaticity in children in a reading-like condition. It was introduced in 1987 and is widely used by optometrists.[3] The DEM is easy to administer and assesses speed and accuracy of ocular movements in children.[4] Although widely used, previous studies have found that the DEM outcomes do not correlate directly with specific parameters of ocular movements. However, it was concluded that the DEM test outcomes were correlated with reading and reading development, and thus may serve a diagnostic role in clinical practice.[5,6]

In a previous study, the horizontal adjusted time in the DEM, rather than the DEM ratio, demonstrated the strongest association with Visagraph outcome measures.[7] However, this study did not find a significant relationship between the DEM findings and reading rate. In contrast, other research has shown that poor readers exhibit deficient horizontal scanning, as assessed by the DEM, which correlates with slower reading speed.[8] This suggests the utility of the DEM as a screening tool for identifying poor reading skills in school children at an early stage. Additionally, further studies have supported the DEM as a valuable tool for assessing oculomotor behaviour in dyslexic children during reading.[9]

The original DEM test norms were established from 556 English-speaking American school children aged from 6 to 13 years.[4] Researchers have hypothesised that children from non-English-speaking countries might have varying reading speeds necessitating the establishment of appropriate datasets. Several studies have been published for different languages with mixed results. For example, Mandarin Chinese,[10] Italian,[11] Spanish,[12,13] Portuguese,[14] Cantonese Chinese[15] and Latvian[16] studies found significantly different norms than English, suggesting language-specific norms be used for those populations. Comparing the English and French DEM norms revealed no differences, leading to the conclusion that French clinicians could use the original English norms,[17] while one of the Spanish norms similarly found mean reference values closely aligned with the English norms.[13] In Hebrew, DEM norms have yet to be compared with other languages.

A complicating factor related to developing DEM age-expected norms is the issue of reading direction in different languages. In most languages, children are taught to read from left to right. However, in some languages such as Arabic, Hebrew, Persian and Kurdish, children read from right to left. Investigators have explored whether this variable of direction might affect the norms. A study with Arabic-speaking children reported that right-to-left reading speed was faster with fewer reading errors than left-to-right reading.[18] In a previous publication, we found that reading direction for Hebrew-speaking children was significantly different for horizontal reading speed on the DEM test, with a directional preference of right to left in children under 10 years of age.[19]

Key points

- First time comparison of the developmental eye movement test results for Hebrew-speaking children with the norms of eight other languages.
- Developmental eye movement test values for Hebrew-speaking children aligned with norms from other languages, particularly the French and original English norms, with consistent ratio scores.
- It is recommended for practitioners who test Hebrew-speaking children to continue to use the English norms and to enable the children to read using their preferred reading direction.

Currently, there has not been an investigation regarding whether it is appropriate to use the original normative data of DEM that were developed for English-speaking children for children who speak only Hebrew. This investigation was designed to compare DEM results of Hebrew-speaking children to other language norms and to assess whether there is a need for independent Hebrew DEM norms.

METHODS

Participants

The study included 224 healthy children, aged 6–13 years, whose mother tongue is Hebrew. Children included in the study had minimum near visual acuity of Jaeger 1 (6/7.5) at 40 cm, no strabismus (verified by cover test), stereoacuity (Randot test) of ≤60 s of arc and a near point of convergence of ≤6 cm. The DEM test was performed twice, once from right (R) to left (L) and once from L to R, randomly ordered. This study was approved by the IRB committee at Hadassah Academic College (#480). The parents of the participants signed the informed consent form after receiving an explanation on study aims and methods. All data were coded and analysed anonymously.

Procedure

The children were instructed to recite in Hebrew the numbers on Test Plates A and B vertically, as quickly and accurately as possible, without using a finger for support. The examiner recorded the time taken with a stopwatch and any errors made while reading the 80 numbers, with the vertical score serving as a baseline measure of the child's automaticity in number calling.[3]

Subsequently, the children were tested with Card C. Card C consists of the same 80 numbers as Cards A + B; however, they are arranged horizontally, resembling a paragraph of text. The examiner recorded the time with a stopwatch and kept track of errors (addition, subtraction, substitution and transposition) during this task. The ratio score, calculated by dividing the adjusted horizontal time (AHT) by the vertical baseline, assessed the child's speed in horizontal number calling.

Sample size

Based on the mean and SD of horizontal time from the mid-range aged children (9 years old) in English-speakers (51.13 ± 13.30 s)[3] versus Spanish-speakers (54.54 ± 11.60 s)[3] with $\alpha = 0.05$ and power of 80% the required total sample size is 212 children (computed by statulator.com; ©Statulator 2023, on November 15, 2023).

Statistical analysis

Data normality was approved by the Kolmogorov–Smirnov test. When analysing subgroups of age, nonparametric tests were used due to small samples within each subgroup. Continuous variables such as vertical time, horizontal time, number of errors and horizontal/vertical (H/V) ratio were presented as means with standard deviation and analysed using Mann–Whitney *U* test when comparing between groups and by Wilcoxon test for comparisons within groups. Analysis of these parameters by sex and age groups was performed by Chi-square test. In comparison of vertical and horizontal reading times among different languages, a one-way ANOVA test was used and post-hoc Tukey–Kramer was employed for multiple comparison test. A statistically significant result was considered as $p < 0.05$ in a two-tailed test. The analysis was performed using SPSS software (ibm.com).

Power analysis

A study including 224 patients yielded a power of 95% with $\alpha = 0.05$ and effect size of 0.23 (calculated by G*Power calculator version 3.1.9.7, psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower).

RESULTS

A total of 224 children (47% female) with a mean age of 9.7 ± 1.9 years, ranging from 6.0 to 13.8 years were included. Means of vertical and horizontal reading speeds, errors and H/V ratios of all study participants are presented in Table 1.

TABLE 1 Basic characteristics and developmental eye movement (DEM) mean results of study population.

Parameter	Mean ± SD
N	224
Female, *N* (%)	105 (47)
Mean age ± SD (Y)	9.6 ± 1.9
Age range (Y)	6.0–13.8
Vertical (s)	45.56 ± 12.19
Error vertical	0.65 ± 2.72
Horizontal left to right (s)	60.85 ± 23.52
Error horizontal left to right	4.13 ± 5.61
Ratio H/V left to right	1.32 ± 0.25
Horizontal right to left (S)	59.77 ± 22.52
Error horizontal right to left	4.07 ± 5.19
Ratio H/V right to left	1.31 ± 0.29

Abbreviations: H/V, horizontal/vertical; SD, standard deviation; Y, years.

TABLE 2 Comparison of developmental eye movement (DEM) scores by age groups.

DEM test parameter	6–9 years (*n* = 127); Mean ± SD	10–13 years (*n* = 97); Mean ± SD	*p*-Value[a]
Vertical (s)	50.58 ± 12.45	39.00 ± 8.07	<0.001
Error vertical	0.96 ± 3.46	0.21 ± 0.70	0.01
Horizontal left to right (s)	70.45 ± 25.17	48.28 ± 13.14	<0.001
Error horizontal left to right	5.81 ± 6.46	2.01 ± 3.28	<0.001
Ratio H/V left to right	1.39 ± 0.27	1.22 ± 0.17	<0.001
Horizontal right to left (s)	68.63 ± 24.49	48.17 ± 12.23	<0.001
Error horizontal right to left	5.88 ± 5.88	1.67 ± 2.64	<0.001
Ratio H/V right to left	1.38 ± 0.32	1.20 ± 0.19	<0.001

Abbreviation: H/V, horizontal/vertical.

[a]Analysed by Mann–Whitney *U* test.

Table 2 compares the vertical and horizontal reading speeds in both directions (R–L and L–R), errors and H/V ratios for the 6–9 and 10–13 year age groups. The comparison between the older and younger children in this study follows a previous publication and was repeated here due to the larger sample size.[19] Statistically significant differences were found between age groups for vertical and horizontal reading speeds and H/V ratios in both directions ($p < 0.001$). Older children, compared with the younger age group, exhibited faster vertical (39.00 ± 8.07 vs. 50.58 ± 12.45, respectively) and horizontal times (48.28 ± 13.14 vs. 70.45 ± 25.17, respectively), with fewer errors vertically (0.21 ± 0.70 vs. 0.96 ± 3.46, respectively) and horizontally (2.01 ± 3.28 vs. 5.81 ± 6.46, respectively), as well as lower ratios (1.22 ± 0.17 vs. 1.39 ± 0.27, respectively; $p < 0.001$).

No statistically significant difference was noted between reading directions (R–L vs. L–R) for horizontal time and H/V ratio for all study participants as well as for both

TABLE 3 Comparison of reading direction in developmental eye movement (DEM) test by intra-age groups.

DEM test parameter	All children (n = 224); time (s); mean ± SD	*p*-Value[a]	6–9 years (*n* = 127);	*p*-Value[a]	10–13 years (*n* = 97); time (s); mean ± SD	*p*-Value[a]
Horizontal left to right	60.85 ± 23.52	0.27	70.45 ± 25.17	0.14	48.28 ± 13.14	0.89
Horizontal right to left	59.77 ± 22.52		68.63 ± 24.49		48.17 ± 12.23	
Error horizontal left to right	4.13 ± 5.61	0.86	5.81 ± 6.46	0.50	2.01 ± 3.28	0.26
Error horizontal right to left	4.07 ± 5.19		5.88 ± 5.88		1.67 ± 2.64	
Ratio H/V left to right	1.32 ± 0.24	0.06	1.39 ± 0.27	0.06	1.22 ± 0.17	0.47
Ratio H/V right to left	1.31 ± 0.29		1.38 ± 0.32		1.20 ± 0.19	

Abbreviation: H/V, horizontal/vertical.

[a]Analysed by Wilcoxon test.

age groups; thus, comparisons to different languages were analysed using the standard L–R direction (Table 3).

Moreover, no difference was found in distribution of sexes between younger and older children ($p = 0.91$). DEM parameter scores were not found to be statistically significant different when divided by sex for vertical (p=0.88), horizontal (p=0.80), errors (p=0.26) and ratio (p=0.35).

Table 4 presents a comparison of DEM scores across various languages, including Hebrew, English, Spanish, Cantonese, Mandarin, Portuguese, Italian, French and Latvian. The data are categorised by age and measures four parameters: vertical time, horizontal time, error rates and the H/V ratio. Children speaking English, Portuguese, Italian and Hebrew included those 6.0–13.11 years of age, while those speaking Mandarin and French included up to 12.11 years of age and Spanish and Cantonese up to 11.11 years. The data on the Latvian-speaking children included only the ratio outcomes in children ages 6.0–13.11 years. Comparison of DEM norms across languages showed statistically significant differences, with post-hoc analysis revealing specific language-related variations.

Vertical and horizontal times tended to decrease as age increased across all language groups, reflecting improved performance with age. Across different age groups (6.0–13.11 years), significant differences in vertical and horizontal times were observed among children speaking different languages. Cantonese children consistently had the shortest times across all age groups, while Spanish children, especially those aged 6.0–6.11 years, had the longest times. Cantonese and Mandarin children generally showed lower ratios, whereas Spanish-speaking children exhibited higher ratios.

DISCUSSION

The original DEM norms were developed in English and are extensively validated.[3,6] The main purpose of this study was to determine if these original norms can be used with children whose primary language is Hebrew. These results indicate that there are significant similarities between the Hebrew results and the original English norms. Vertical time norms across all ages are equivalent between the English and Hebrew values. The horizontal time, errors and ratio of the Hebrew results were most similar to the English and French norms when compared with the other languages.

In the current study, the H/V ratios of the Hebrew-speaking children were found to be comparable with the established English norms, suggesting similar challenges in horizontal reading despite the differences in reading direction between the two languages. A previous study on the directional effect in the DEM test indicated that younger Hebrew-speaking children tended to prefer reading numbers from R to L.[19] However, no such preference was observed in the present study. This discrepancy may be attributed to the larger sample size and the inclusion of children from diverse educational backgrounds, with 28% of participants being Ultra-Orthodox, compared to 67% in the earlier study. In Ultra-Orthodox schools, there is a strong emphasis on Hebrew reading, while English and mathematics are often not introduced at the early stages of education. Future research on directionality preferences in Arabic-speaking children, who also read from right to left, could provide further insight into the influence of reading direction on young children's performance.

A secondary aim of this study was to compare data from Hebrew-speaking children with norms previously published in English, Spanish, Cantonese, Mandarin, Portuguese, Italian, French and Latvian-speaking children. There were two Spanish studies reporting DEM norms,[12,13] and we chose to include the one with the larger sample size in the analysis.

Hebrew-speaking children exhibited significant differences compared with other language groups. For ages 6.0–7.11 years, they had higher vertical and horizontal times compared with Cantonese and Mandarin children, resulting in similar H/V ratios. Spanish children in this age group had the slowest times but made fewer errors than English speakers, possibly due to an emphasis on accuracy, with Hebrew-speaking children's error rates being similar to those of Spanish speakers. In ages 8–9.11 years, Hebrew speakers had significantly higher vertical and horizontal times compared to Mandarin and Cantonese speakers and more errors than Mandarin and Portuguese speakers. This

TABLE 4 Comparison of developmental eye movement (DEM) scores among Hebrew, English, Spanish, Chinese (Cantonese), Chinese (Mandarin), Portuguese, Italian, French and Latvian studies.

Age group (Y)	Time (s); mean ± SD	Hebrew (*a*)	English[3] (*b*)	Spanish[12] (*c*)	Cantonese[15] (*d*)	Mandarin[10] (*e*)	Portuguese[14] (*f*)	Italian[11] (*g*)	French[17] (*h*)	Latvian[16] (*i*)	*p*-Value[a]
6.0–6.11	*N*	13	52	224	53	238	78	65	32	NA	
	Vertical	59.13 ± 13.88$_{(c)}$	63.11 ± 15.59$_{(c,d)}$	86.30 ± 23.02$_{(d,e,f,g,h)}$	50.98 ± 13.16$_{(e,f,g)}$	62.84 ± 17.97$_{(f,g)}$	72.44 ± 17.49	72.29 ± 20.99	62.29 ± 13.51	NA	<0.001
	Horizontal	77.87 ± 23.46$_{(c,f,g)}$	98.26 ± 32.61$_{(c,d)}$	146.90 ± 41.60$_{(d,e,f,g)}$	71.27 ± 18.45$_{(e,f,g,h)}$	86.67 ± 34.10$_{(f,g)}$	107.99 ± 24.49	108.12 ± 30.49	99.20 ± 23.77	NA	<0.001
	Error	7.69 ± 7.88$_{(b)}$	15.22 ± 11.49$_{(c,d,e,f)}$	7.70 ± 4.43$_{(h)}$	9.66 ± 7.51$_{(g)}$	7.17 ± 8.22$_{(g,h)}$	8.41 ± 6.97$_{(g)}$	14.9 ± 8.3	13.0 ± 11.15	NA	<0.001
	Ratio	1.36 ± 0.36$_{(c)}$	1.58 ± 0.45$_{(e)}$	1.67 ± 0.37$_{(d,e)}$	1.41 ± 0.25	1.38 ± 0.28$_{(f,g,h)}$	1.53 ± 0.34	1.53 ± 0.29	1.60 ± 0.31	NA	<0.001
7.0–7.11	*N*	36	75	227	63	183	92	196	42	141	
	Vertical	54.13 ± 13.69$_{(d)}$	54.83 ± 9.20$_{(d)}$	58.27 ± 13.04$_{(d,e,g,h)}$	43.34 ± 8.82	50.48 ± 9.72$_{(f)}$	60.39 ± 14.48$_{(g,h)}$	52.74 ± 10.17	51.83 ± 9.38	NA	<0.001
	Horizontal	76.90 ± 22.03$_{(d)}$	87.94 ± 28.18$_{(d,e,g,h)}$	81.38 ± 26.91$_{(d,e,f,g)}$	57.14 ± 14.21$_{(f,g,h)}$	65.86 ± 15.26$_{(f,g)}$	81.47 ± 21.48	75.01 ± 19.33	73.38 ± 15.27	NA	<0.001
	Error	8.55 ± 7.84$_{(e)}$	12.50 ± 12.91$_{(c,d,e,f,g,h)}$	6.97 ± 6.41$_{(e)}$	5.59 ± 6.72	4.26 ± 6.19$_{(g)}$	5.00 ± 5.84$_{(g)}$	7.9 ± 7.6	6.88 ± 5.96	NA	<0.001
	Ratio	1.44 ± 0.25$_{(c)}$	1.60 ± 0.41$_{(d,e,f,g,h)}$	1.70 ± 0.29$_{(d,e,f,g,h,i)}$	1.32 ± 0.16$_{(i)}$	1.31 ± 0.22$_{(g,i)}$	1.36 ± 0.24$_{(i)}$	1.43 ± 0.25	1.42 ± 0.18	1.49 ± 0.27	<0.001
8.0–8.11	*N*	36	93	240	54	195	90	200	43	114	
	Vertical	48.49 ± 10.83$_{(d)}$	46.76 ± 7.89$_{(d,f)}$	49.60 ± 9.65$_{(d,e)}$	38.50 ± 7.99$_{(e,f,g,h)}$	43.64 ± 9.14$_{(f,h)}$	50.97 ± 10.61$_{(g)}$	45.77 ± 9.68	50.15 ± 6.99	NA	<0.001
	Horizontal	69.31 ± 28.52$_{(b,d,e,g)}$	57.73 ± 12.32$_{(c,d,f,h)}$	68.30 ± 19.57$_{(d,e,g)}$	47.55 ± 10.60$_{(f,g,h)}$	52.76 ± 12.74$_{(f,g,h)}$	65.67 ± 17.62	59.91 ± 14.87	67.13 ± 13.62	NA	<0.001
	Error	5.60 ± 5.35$_{(e,f)}$	4.61 ± 6.91$_{(e,f)}$	5.55 ± 5.97$_{(e,f,g)}$	3.96 ± 3.74	1.86 ± 3.18$_{(g,h)}$	2.33 ± 3.31$_{(h)}$	4.0 ± 4.6	6.44 ± 6.79	NA	<0.001
	Ratio	1.41 ± 0.28$_{(b,d,e)}$	1.24 ± 0.18$_{(c,i)}$	1.40 ± 0.31$_{(d,e,f,g)}$	1.24 ± 0.15$_{(i)}$	1.21 ± 0.20$_{(g,i)}$	1.30 ± 0.27$_{(i)}$	1.31 ± 0.20$_{(i)}$	1.33 ± 0.18	1.45 ± 0.35	<0.001
9.0–9.11	*N*	42	84	238	50	156	65	188	50	178	
	Vertical	46.67 ± 10.29$_{(c,d,e,g)}$	42.33 ± 8.20$_{(d,e,f)}$	42.37 ± 7.46$_{(d,e,f)}$	36.53 ± 6.61$_{(f,g,h)}$	37.18 ± 7.76$_{(f,g,h)}$	48.10 ± 10.45$_{(g)}$	41.98 ± 7.89	44.66 ± 9.92	NA	<0.001
	Horizontal	63.60 ± 23.95$_{(b,c,d,e,g)}$	51.13 ± 13.30$_{(d,e,f,h)}$	54.54 ± 11.60$_{(d,e)}$	43.00 ± 7.83$_{(f,g,h)}$	43.03 ± 10.66$_{(f,g,h)}$	57.72 ± 12.11$_{(g)}$	52.04 ± 12.78$_{(h)}$	58.87 ± 15.91	NA	<0.001
	Error	2.97 ± 3.95	2.17 ± 4.10	1.69 ± 2.66$_{(h)}$	2.98 ± 3.28	1.45 ± 3.83$_{(h)}$	1.72 ± 3.67	2.6 ± 3.8	3.58 ± 4.66	NA	<0.001
	Ratio	1.35 ± 0.24$_{(b,d,e,f,g)}$	1.21 ± 0.19$_{(c,i)}$	1.31 ± 0.22$_{(d,e,f,g)}$	1.18 ± 0.12$_{(i)}$	1.16 ± 0.18$_{(g,h,i)}$	1.22 ± 0.21$_{(i)}$	1.24 ± 0.18$_{(i)}$	1.30 ± 0.18	1.34 ± 0.22	<0.001
10.0–10.11	*N*	34	73	258	52	184	88	184	38	135	
	Vertical	42.20 ± 8.91$_{(d,e,g)}$	40.28 ± 4.73$_{(d,e,f)}$	40.19 ± 7.65$_{(d,e,f)}$	29.38 ± 6.00$_{(f,g,h)}$	32.33 ± 6.04$_{(f,g,h,g)}$	43.70 ± 9.85$_{(g)}$	38.13 ± 6.35	41.31 ± 5.79	NA	<0.001
	Horizontal	52.67 ± 12.03$_{(c,d,e,g)}$	47.64 ± 10.11$_{(d,e)}$	47.24 ± 10.37$_{(d,e)}$	33.69 ± 8.72$_{(f,g,h)}$	36.04 ± 6.98$_{(d,e,g)}$	49.30 ± 9.91$_{(g)}$	44.72 ± 8.08$_{(h)}$	50.98 ± 8.04	NA	<0.001
	Error	3.29 ± 3.84$_{(c,d,e,f)}$	1.91 ± 2.68$_{(c,e,f)}$	0.81 ± 1.76$_{(g,h)}$	1.56 ± 2.16	0.71 ± 1.48$_{(g,h)}$	0.76 ± 2.47$_{(g,h)}$	2.0 ± 2.6	2.21 ± 3.86	NA	<0.001
	Ratio	1.23 ± 0.14$_{(e)}$	1.19 ± 0.17$_{(i)}$	1.25 ± 0.16$_{(d,e,f,g)}$	1.14 ± 0.15$_{(i)}$	1.12 ± 0.13	1.14 ± 0.13$_{(i)}$	1.18 ± 0.12$_{(i)}$	1.23 ± 0.14	1.30 ± 0.29	<0.001
11.0–11.11	*N*	28	82	252	33	166	83	77	27	118	
	Vertical	39.19 ± 7.51$_{(d,e)}$	37.14 ± 5.42$_{(d,e)}$	36.16 ± 6.32$_{(d,e)}$	29.83 ± 5.36$_{(f,g,h)}$	30.35 ± 5.67$_{(f,g,h)}$	38.33 ± 5.51$_{(g)}$	35.06 ± 6.41	38.72 ± 8.20	NA	<0.001
	Horizontal	48.97 ± 14.32$_{(b,c,d,e,f,g)}$	42.62 ± 7.61$_{(d,e)}$	43.49 ± 10.04$_{(d,e,g)}$	32.87 ± 7.03$_{(f,g,h)}$	32.83 ± 6.48$_{(f,g,h)}$	42.98 ± 6.35	39.49 ± 8.44	43.94 ± 9.83	NA	<0.001
	Error	2.00 ± 3.57$_{(c,e,f)}$	1.68 ± 2.34$_{(c,e,f)}$	0.51 ± 1.68$_{(d,g,h)}$	1.70 ± 2.72$_{(e,f)}$	0.55 ± 1.51$_{(g,h)}$	0.45 ± 1.63$_{(g,h)}$	1.7 ± 2.0	2.14 ± 2.74	NA	<0.001
	Ratio	1.26 ± 0.22$_{(b,d,e,f,g,h)}$	1.15 ± 0.13$_{(i)}$	1.18 ± 0.15$_{(e,i)}$	1.10 ± 0.11$_{(i)}$	1.09 ± 0.14$_{(i)}$	1.13 ± 0.12$_{(i)}$	1.13 ± 0.12$_{(i)}$	1.13 ± 0.11$_{(i)}$	1.25 ± 0.18	<0.001
12.0–12.11	*N*	23	38	NA	NA	166	94	79	26	153	
	Vertical	36.36 ± 6.59$_{(e)}$	35.14 ± 5.87$_{(e)}$	NA	NA	28.06 ± 4.80$_{(f)}$	35.47 ± 5.57	31.55 ± 5.74	35.96 ± 6.16	NA	<0.001
	Horizontal	42.73 ± 11.71$_{(e)}$	39.35 ± 8.11$_{(e)}$	NA	NA	30.67 ± 5.56$_{(f)}$	39.29 ± 5.20	35.34 ± 6.47	41.91 ± 7.31	NA	<0.001

(Continues)

TABLE 4 (Continued)

Age group (Y)	Time (s); mean ± SD	Hebrew (*a*)	English[3] (*b*)	Spanish[12] (*c*)	Cantonese[15] (*d*)	Mandarin[10] (*e*)	Portuguese[14] (*f*)	Italian[11] (*g*)	French[17] (*h*)	Latvian[16] (*i*)	*p*-Value[a]
	Error	0.91 ± 1.85	1.11 ± 1.17	NA	NA	$0.51 \pm 1.34_{(g,h)}$	$0.43 \pm 1.36_{(g,h)}$	1.1 ± 1.8	1.61 ± 2.07	NA	<0.001
	Ratio	1.15 ± 0.17	$1.12 \pm 0.10_{(i)}$	NA	NA	$1.10 \pm 0.12_{(i)}$	$1.12 \pm 0.13_{(i)}$	$1.12 \pm 0.09_{(i)}$	1.17 ± 0.12	1.23 ± 0.17	<0.001
13.0–13.11	*N*	13	37	NA	NA	NA	87	85	NA	171	
	Vertical	$34.56 \pm 6.16_{(g)}$	$33.75 \pm 6.53_{(g)}$	NA	NA	NA	$34.13 \pm 4.81_{(g)}$	29.71 ± 4.58	NA	NA	<0.001
	Horizontal	$44.92 \pm 12.57_{(b,f,g)}$	$37.56 \pm 7.23_{(g)}$	NA	NA	NA	$37.46 \pm 6.10_{(g)}$	33.16 ± 6.57	NA	NA	<0.001
	Error	0.55 ± 1.16	$1.61 \pm 2.15_{(f)}$	NA	NA	NA	$0.48 \pm 1.70_{(g)}$	1.2 ± 1.9	NA	NA	<0.001
	Ratio	$1.20 \pm 0.09_{(f,i)}$	$1.12 \pm 0.12_{(i)}$	NA	NA	NA	$1.10 \pm 0.10_{(i)}$	$1.12 \pm 0.12_{(i)}$	NA	1.71 ± 0.14	<0.001

Note: Letters in parentheses indicate statistically significant result between pair of groups by post-hoc analysis ($p < 0.05$).

Abbreviations: H/V, horizontal/vertical; NA, not applicable.

[a]Analysed by one-way ANOVA and post-hoc Tukey–Kramer.

trend continued in ages 10–11.11 years, where Hebrew-speaking children had higher times and more errors than Cantonese, Mandarin, Italian and Spanish speakers, and their ratio was most similar to Latvian. In the oldest group (12–13.11 years), Hebrew-speaking children showed no significant differences in errors or ratios compared with English, Portuguese, Italian and Latvian children.

The differences between Cantonese and Mandarin-speaking children and others were highlighted by Xie et al.,[10] explaining that in China, children often begin reading earlier than their American counterparts. This explains the norms of the younger aged children. In older aged children, an additional explanation proposed that Chinese is an ideographic language, and numbers are easier to pronounce in Chinese than English. This also applies to Hebrew, where most numbers have several syllables that could lengthen the measured time. The ratios of all languages could theoretically be identical no matter how complex the language pronunciation.

Studies of DEM norms in Cantonese,[11] Portuguese[14] and Italian[15] consider the differences in language, educational systems and cultural practices as explanations for the variations across different languages.[11,14,15] Regardless of these differences, Moiroud reiterated the universal importance of the DEM test for judging the reading performance and speed of visual processing, particularly in children with reading disorders.[9] Spanish[13] and French[17] studies have concluded that their specific language DEM norms are similar to the original English values. French norms show similarities with Hebrew in terms of vertical and horizontal times, and the errors are somewhat comparable. The DEM results for Hebrew-speaking children align with other norms, particularly those for English and French.[17]

A limitation of this study is the relatively small sample size in the youngest and oldest age groups, which may affect the generalisability of the results for these age ranges. However, the overall sample size was sufficient based on the conducted power analysis. Specific DEM norms per age were not established; rather, only comparisons to other language results.

Based on the findings of this study, it is recommended that practitioners testing Hebrew-speaking children continue to use the English norms and allow children to read in the direction they are most comfortable with, ensuring their preferred reading orientation.

CONCLUSIONS

This study compared DEM results for Hebrew-speaking children with eight other languages. DEM test values for Hebrew-speaking children aligned with the norms from other languages, particularly the French and original English norms, with consistent ratio scores. It is recommended that practitioners who test Hebrew-speaking children continue to use the English norms and allow children to read using their preferred reading direction.

AUTHOR CONTRIBUTIONS

Hadas Ben-Eli: Conceptualization (equal); formal analysis (lead); methodology (equal); project administration (lead); validation (equal); writing – original draft (equal). **Hadas Blique:** Data curation (equal); investigation (equal); writing – review and editing (equal). **Mitchell Scheiman:** Conceptualization (equal); methodology (equal); supervision (equal); writing – review and editing (equal). **Rachel Eichler:** Conceptualization (equal); investigation (equal); methodology (equal); project administration (equal); supervision (lead); writing – original draft (equal).

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CONFLICT OF INTEREST STATEMENT

The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

CONSENT

A written parental consent for participation in the study was obtained for all participants.

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