ORIGINAL INVESTIGATION

Assessing Variability in Reading Performance with the New Greek Standardized Reading Speed Texts (IReST)

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SIGNIFICANCE: This article evaluates the standardized Greek version of the International Reading Speed Texts (IReST) set, which enriches interlanguage comparisons and international clinical studies of reading performance. Moreover, it investigates how specific textual and subject-related characteristics modulate the variability of reading speed across texts and readers.

PURPOSE: The purpose of this study was to develop a standardized Greek version of the IReST set and investigate how specific textual and subject-related factors modulate the variability of reading speed across texts and readers.

METHODS: The English IReST texts were translated to Greek and matched for length, content, and linguistic difficulty. The Greek IReSTs were presented at a distance of 40 cm and size of 1 M to assess reading speeds of 25 normally sighted native speakers (age range, 18 to 35 years). The participants read the texts aloud while reading time was measured by stopwatch. Reading performance included measurement of reading speed in three units of analysis. Reading efficiency was assessed using a word-level oral reading task. Statistical analysis included evaluation of subject- and text-related variability, as well as correlations between reading speed and specific textual and subject-related factors.

RESULTS: The average reading speed between texts was 208 ± 24 words/min, 450 ± 24 syllables/min, and 1049 ± 105 characters/min. Differences between readers accounted for the 76.6%, whereas differences across texts accounted for the 23.4% of the total variability of reading speed. Word length (in syllables per word) and median word frequency showed a statistically significant contribution to the variability of reading speed ($r = 0.95$ and 0.70, respectively). Reading speed was also statistically correlated with word reading efficiency ($r = 0.68$).

CONCLUSIONS: The addition of the Greek version in the IReST language pack is expected to be a valuable tool for clinical practice and research, enriching interlanguage comparisons and international studies of reading performance.

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Reading is fundamental to functioning in today's society because it affects a person's social, educational, and professional efficiency and independence. Reading skill is influenced by visuomotor as well as cognitive and demographic factors, such as individual reading habits, formal education and past reading experience, learning and memory capacity, and age.[1–6] People with reading difficulties, associated with optical, neurodevelopmental or acquired neurological conditions, face significant inconvenience in a plethora of daily activities, which explains why restoring reading ability is a common reason for referral to clinical optometric services and/or other forms of intervention.[3,7]

Reading performance is currently evaluated using clinical tests through artificially constructed texts presented within well-controlled conditions (for a review, see Rubin[3]). However, textual characteristics, reading optical conditions (i.e., distance, luminance, contrast), and individual reading capacity vary significantly in daily life, resulting in differences in reading performance.[8–10] Therefore, it remains questionable what standardized clinical tests can tell us about real-world reading performance and which test is the most appropriate to use.[3]

Generally, the optimal test depends on the intended set of factors that affect reading performance. When assessing visual function, standard visual acuity tests or sentence-level reading acuity tests, such as the Colenbrander, Minnesota Low-Vision Reading Test (MNREAD), and RADNER cards, are preferable.[11,12] However, such tests are not predictive of functional vision and reading ability, which typically places higher demands on more complex cognitive functions. Accordingly, continuous texts rather than single sentences are preferable to assess functional visual capacity especially in verified or suspected neurological impairment.[3,13,14]

One widely used clinical tool to assess reading performance that uses continuous passages is the International Reading Speed Texts (IReST) set, consisting of 10 standardized paragraphs of approximately 140 words, suitable for repeated measurements within and between languages.[6,15–17] The IReST was first created in German and subsequently adapted in several other languages. Homogeneity

within each language, as well as comparability between languages, was achieved by matching the texts for content, text length, and linguistic difficulty.

The IReST are available in 17 languages worldwide, but not in Greek. The primary objective of the present study was to develop a standardized Greek version of the IReST set, taking into account various characteristics of the Greek language. Second, we opted to investigate how specific textual and subject-related factors modulate the variability of reading speed across texts and readers.

METHODS

Development of the Greek IReST

The English IReST passages were adapted by a linguist, native speaker of the Greek language. The content of the English IReST, originating from a sixth-grade German reading material,[6,15] was transferred to Greek. Linguistic transformations were made where needed, to maintain the overall amount of information constant between the Greek and the English texts.

Most words in the Greek texts were of high word frequency (>0.0001%) as originally recommended by the IReST study group.[6,15] A few exceptions did not meet this criterion because of the need to literally translate them to Greek. Word frequencies were obtained from the Hellenic National Corpus developed by the Greek Institute for Language and Speech Processing (http://hnc.ilsp.gr).[18]

In accordance with the guidelines of the IReST study group, the syntactic difficulty of the Greek passages was adjusted according to the rules of Gibson's Dependency Locality Theory.[6,15,19,20] Simply put, when reading a sentence, each new word read is syntactically related to specific words of the text previously read. Gibson's theory suggests that the difficulty of integrating syntactically dependent words in a sentence is proportional to the distance between them. Thus, the greater the distance between two dependent words, the more complex the syntactic structure.[19–22] For an example of how dependency distance affects the complexity of a sentence, see Hahn et al.[6]

In the Greek IReST, dependency distance between the words of the sentences was manually measured and further examined by means of a dependency parser developed by the natural language processing group of the Institute for Language and Speech Processing.[23] By limiting the dependency distance between related words,[6,19,20,24] we were able to create passages that are easy to process.

The IReST were printed on white paper in high contrast, with a letter size of 10-point Times New Roman font (1-M unit or 0.4 logMAR at a 40-cm viewing distance), a line spacing of 12 points, and a maximal line length of 8.5 cm. The text size in the IReST was constant, approximating typical newspaper print.[6]

A pilot study was conducted with the first version of the Greek IReST set, to determine if there were any parts of the texts that caused confusion or needed further modifications due to readers' struggle. Pilot testing was conducted on five young, normally sighted, native Greek speakers, who read the Greek IReST aloud. After modifications were made in the parts where the readers made mistakes or seemed to hesitate, the final version of the texts was created. An example of the final layout of a Greek text in the IReST along with the English version of the same text is depicted in Fig. 1.

Participants

A group of 25 volunteers (14 women, 11 men) aged 18 to 35 years (mean [standard deviation], 27 [5] years) with an average of 17 ± 2 years of formal education participated in the study. All participants were native Greek speakers who were not familiar with the texts used. They had no ocular pathology or reading disorder, and their near visual acuity in each eye had to be better than 0.1 logMAR. Binocular near visual acuity at 40-cm distance was –0.10 ± 0.04 logMAR, measured with habitual refractive correction (if needed) using the modified European-wide Early Treatment Diabetic Retinopathy Study visual acuity charts (https://www.precision-vision.com/).[25,26] The study was conducted in adherence to the tenets of the Declaration of Helsinki and followed a protocol approved by the University of Crete Research Board.

Procedures

Text reading speed measurements were performed under photopic lighting conditions (card luminance was 330 cd/m^2 and illuminance at the cornea was 280 lux). The participants sat comfortably at a desk on which the reading card was placed. Reading time was measured by a stopwatch. The onset of reading was controlled by keeping the text covered until the experimenter activated the stopwatch.

Participants were instructed to read each text aloud and as quickly as possible, trying not to correct any possible mistakes, especially not to go back in the text. The misread and missed words were noted and subtracted from the total number of words read in each text. The texts were presented in a counterbalanced order across participants. Short breaks were allowed between measurements.

Before text reading performance measurements, a standardized test of word-level reading efficiency was administered to all participants to estimate age- and education-adjusted oral reading capacity.[2] The word reading efficiency task comprises 112 high-frequency words, and the pseudoword reading efficiency task uses a list of 70 phonotactically matched pseudowords. Word and pseudoword reading efficiency was calculated as the number of words or pseudowords, respectively, read correctly in 45 seconds, and then converted in words per minute.

Data and Statistical Analysis

Reading speed was calculated in words per minute by first deducting any misread words and then dividing the correctly read words for each text by the time taken to read the text. Reading speed was also estimated in syllables and characters (without spaces and punctuation marks) per minute.

Potential deviations of reading speed distributions from normality were tested using the Shapiro-Wilk test. A one-way analysis of variance followed by Tukey honestly significant difference tests to evaluate pairwise text differences was performed and evaluated at a nominal $P = .05$. By applying the criterion of a clinically relevant difference of more than 10 words/min, as proposed by the IReST study group,[15] the 10 texts were grouped into performance categories, so that texts with reading speed differences within ±10 words/min were grouped into the same performance category.

The following potential predictors of text reading speed were assessed through bivariate Pearson correlation coefficients and linear regression: average word length, sentence length, and

Σε μια μικρή πόλη ένας μανάβης είχε ανοίξει το μαγαζί του πάνω από μια υπόγεια αποθήκη. Πλήθη από ποντίκια έβγαιναν κάθε βράδυ από την αποθήκη και έμπαιναν στο μαγαζί. Έτρωγαν μήλα και αχλάδια, σταφύλια και καρύδια, και δεν έλεγαν όχι στα λαχανικά και στις πατάτες. Κατά τη διάρκεια της νύχτας κανένα από τα τρόφιμα στο μαγαζί δεν ξέφευγε από τα μικρά ενοχλητικά τρωκτικά. Όσο υπήρχε θόρυβος στους δρόμους και κυκλοφορούσαν αυτοκίνητα, τα ποντίκια έμεναν ήσυχα μέσα στην αποθήκη. Μόλις όμως το παλιό ρολόι στο δημαρχείο της πόλης έδειχνε μεσάνυχτα και επικρατούσε ησυχία στο δρόμο, τα ποντίκια εμφανίζονταν στο μαγαζί. Απολάμβαναν τα γλυκά φρούτα και έστηναν κανονικές γιορτές, των οποίων τα υπολείμματα γέμιζαν με θλίψη το μανάβη κάθε πρωί όταν έμπαινε στο μαγαζί. Έτσι λοιπόν ο μανάβης προσπάθησε να προστατεύσει τον εαυτό του από τα ποντίκια. Στην αρχή έβαλε παγίδες σε όλο το μαγαζί.

number of text: 1
name of text: Ποντίκια
performance category: B
number of words: 143
number of syllables: 322
number of characters: 731
reading time in seconds
(mean ± SD): 42.8 ± 4.5
reading speed (mean ± SD)
words/min: 202± 23

In a small town a greengrocer had opened a shop that was located above a deep cellar. Every night, mice came in droves out of this cellar into the shop. They ate apples and pears, grapes and nuts and did not spare the vegetables and potatoes either. No goods that were in the shop were safe from the small intrusive rodents between midnight and sunrise. As long as there was noise in the streets at night and cars were driving by, the mice still stayed quietly in the cellar. But as soon as the old clock on the town hall had struck midnight and it became quiet in the street, they came out in droves, enjoyed the sweet fruits and celebrated real feasts, whose remains filled the owner with despair every morning when he entered the shop. So he tried to protect himself against the mice. At first he set up traps all over the shop.

number of text: 1
name of text: Mice
performance category: AB
number of words: 156
number of syllables: 205
number of characters: 662
reading time in seconds
(mean ± SD): 40.4 ± 6.2
reading speed (mean ± SD)
words/min: 236 ± 29

FIGURE 1. One of the IReST Greek passages (left) and its corresponding English version (right). IReST = International Reading Speed Texts.

median word frequency. The relative predictive value of these variables was further assessed through hierarchical regression analyses. Moreover, individual scores on standardized word and pseudoword reading efficiency tests were used to account for interindividual differences in the IReST reading speed (averaged across the 10 passages) using Pearson correlation coefficients and linear regression.

Finally, mixed-effects analyses were conducted to assess the relative contribution of interindividual and intraindividual (i.e., text-related) sources of variance in text reading performance. All analyses were conducted in Microsoft Excel (Redmond, WA) and IBM SPSS 22 (Armonk, NY).

RESULTS

Textual Characteristics of the Greek IReST

The newly designed texts in the Greek IReST were matched for textual parameters, such as number of words, syllables, and characters, as well as average sentence length (measured in words per sentence), average word length (measured in syllables and characters per word), and median word frequency (Table 1). Median word frequency was used instead of mean frequency because word frequency distributions for each text significantly deviated from normality (Shapiro-Wilk test, $P < .0001$).

Average reading time of the 10 texts was 42 ± 4 seconds, with reading speed averaging 208 ± 24 words/min, 449 ± 45 syllables/min, and 1049 ± 104 characters/min. Reading errors were rare and not systematic, averaging 0.9 ± 0.4 misread word across texts, whereas no errors were committed in 43.2% of text readings.

The 10 texts were ranked by average reading speed, as shown in Table 2, demonstrating notable homogeneity. Thus, the mean difference between the fastest (no. 6) and slowest text to read (no. 4) was 33 words/min, which was only slightly higher than the minimal standard deviation of between-subject differences (18 words/min). The maximal difference in average reading speed expressed in syllables/min (31) and characters/min (61) was smaller than the minimal standard deviation of corresponding between-subject differences (43 syllables/min and 94 characters/min). Despite similarities, however, texts could be grouped into three performance categories so that text from a given category may be considered as alternate versions for repeated testing over relatively brief time intervals. A somewhat arbitrary criterion of average reading speed ≤10 words/min was used, as recommended by the IReST group, to tentatively group texts in the same category, which corresponds to approximately 0.5 standard deviation of the distribution of reading speed between participants. The distribution of texts per performance category is shown in Table 2. Two texts belong to both B and C categories.

Statistically significant differences in reading speed on Tukey honestly significant difference ($P < .05$) were found for 18 of

TABLE 1. Textual parameters and mean values (±SD) for the 10 Greek IReST passages

Text	No. words	No. syllables	No. characters	Syllables per word	Characters per word	Median word frequency (‰)
1	143	322	731	2.3	5.1	0.2
2	149	303	712	2.0	4.8	0.5
3	147	310	756	2.1	5.1	0.3
4	151	296	695	1.9	4.6	0.4
5	143	323	775	2.3	5.4	0.3
6	138	324	747	2.4	5.4	0.3
7	146	335	763	2.3	5.2	0.4
8	143	303	677	2.1	4.7	0.5
9	148	304	725	2.1	4.9	0.4
10	139	312	726	2.2	5.2	0.4
Mean	145 (4)	313 (12)	731 (31)	2.2 (0.1)	5.1 (0.2)	0.4 (0.1)

IReST = International Reading Speed Texts.

45 pairwise comparisons, involving only texts from different performance categories. Significant differences in reading speed were found between each text from category A and each text from category C (12/12 pairs), and in 14 of 20 pairs comprising a text from category A and a text from category B. Differences in reading speed between texts in categories B and C did not reach statistical significance. Based on these results, two difficulty levels are firmly supported: an "easy" set consisting of texts 2, 4, 8, and 9 and a more difficult set including the remaining six texts.

Sources of Intraindividual Differences in Text Reading Speed

Fig. 2 presents regression plots of reading speed as a function of word length (in number of characters per word and syllables per word) and median word frequency. Bivariate analyses revealed significant correlations between reading speed and all of the textual factors ($r = 0.689$ to 0.946, $P < .05$), with the exception of the average length of the constituent sentences ($P = .14$). A multiple linear regression model including all correlates of reading speed associated with $P > .10$ in the bivariate analyses showed that median word frequency ($b = 74.86$; standard error, 27.87; $P = .03$) and word length measured in syllables per word ($b = 89.72$; standard error, 10.86; $P < .001$) were independently associated with reading speed and jointly accounted for 92% of variance in reading speed.

Sources of Interindividual Differences in Text Reading Speed

The average reading speed computed across all texts varied between 156 and 279 words/min across participants (averaging 208 ± 24 words/min; Fig. 3). Corresponding scores on the standardized reading efficiency tests were 127 ± 13 words/min and 65 ± 9 pseudowords/min.

Fig. 4 shows bivariate regression plots of text reading speed as a function of word and pseudoword reading efficiency. As expected, word reading efficiency significantly and strongly predicted text

TABLE 2. Average (SD) reading speed in wpm for each text, ranked in order of decreasing speed

				Reading speed		
Text	Performance category			wpm	Syllables/min	Characters/min
4	A			223 (22)	436 (43)	1025 (101)
2	A			222 (21)	452 (43)	1062 (102)
9	A			222 (19)	455 (40)	1086 (94)
8	A			220 (24)	465 (50)	1040 (112)
3		B		208 (20)	434 (42)	1059 (103)
1		B		202 (23)	455 (52)	1033 (119)
7		B		201 (19)	461 (43)	1049 (98)
10		B	C	198 (21)	443 (46)	1032 (107)
5		B	C	198 (21)	448 (46)	1075 (111)
6			C	190 (18)	445 (43)	1026 (98)
Mean				208 (24)	449 (45)	1049 (104)

Texts in each category did not differ by more than 10 wpm on average reading speed. wpm = words per minute.

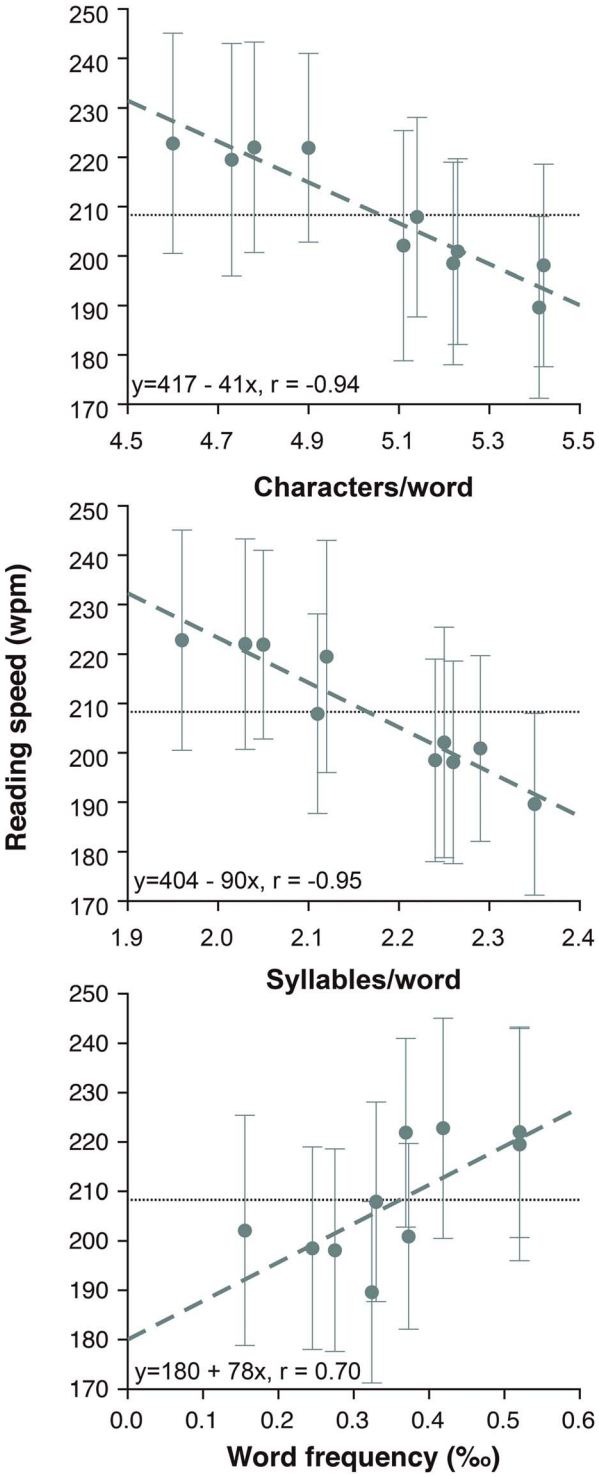

FIGURE 2. Bivariate linear regression plots of average reading speed as a function of word length in number of characters per word (left) and syllables per word (middle) and median word frequency (right). Vertical bars correspond to ±1 SD.

reading speed ($r = 0.64$, $P = .001$), whereas a modest-size correlation was found between text reading speed and pseudoword reading efficiency, which did not reach significance ($r = 0.39$, $P = .05$). Bivariate correlations between text reading speed age ($P = .11$), education ($P = .79$), and visual acuity ($P = .77$) were negligible as expected given that individual variance on these factors was kept at a minimum by design. According to the mixed-level analyses, intraindividual differences in reading speed across texts accounted for only 23.4% of the total variability, whereas interindividual differences in the present sample accounted for the remaining 76.6%.

DISCUSSION

The results of the present study are generally consistent with previous IReST reports in other languages.[6,15,16] Notably, however, the average reading speed for the Greek IReST was found to be significantly higher than the minimal limit of functional reading performance (80 words/min),[3,27] ranking as the third fastest among the 17 languages.[15]

Text classification into performance categories was determined by criteria adopted in previous IReST reports[15] to maintain consistency and allow for comparisons with the IReST in other languages. The number of performance categories obtained in the present study (only three categories using this criterion with two categories verified statistically through pairwise comparisons) indicates relatively small variability among all the Greek IReST on reading speed.

It should also be noted that the magnitude of between-subject variability (as indicated by standard deviation values for each text) is comparable with those in other languages (Table 2).[6,15,16]

The percentage of intersubject variability in reading speed (76.6%) is in agreement with findings in other languages.[16] Considering that the Greek texts are standardized according to the same criteria as the IReST in other languages, the relatively lower between-subject variability (averaging 88.5% across other languages) possibly reflects a high degree of homogeneity characterizing the current sample. This may be due to the high educational level of the participants in this study (averaging 17 ± 2 years of formal education) in view of evidence that performance on clinical reading tests can be affected by educational level.[28,29] This notion is supported by the observation that the average score on the reading efficiency tests was greater than the population mean (near the 80th and 70th percentiles for the word and pseudoword tasks, respectively), suggesting that the participants of the present study demonstrated highly efficient word recognition.[2]

The proportion of variance accounted for by text differences in the IReST (16.2%) is well within the range across languages (7.1 to 24.5%).[15] In the present study, reading speed differences across texts significantly correlated with two textual factors, word length and median word frequency. Although such correlation was not shown in previous IReST studies, it was implied that reading speed may depend on these textual factors.[6,15] Other studies have demonstrated that word length and word frequency are interrelated and belong to the most influential textual factors during visual word recognition and natural reading.[30–32] Words of higher frequency are usually smaller in length,[33] whereas they are more often skipped and fixated for shorter durations than infrequent, larger words.[34–36] Moreover, word frequency modulates parafoveal processing of the following word.[37,38] Using relatively short- and high-frequency words in the Greek IReST guarantees that the lexical processing of the texts is of low difficulty.[6,15]

Syntactic complexity, another important factor that affects variability of reading performance,[20,22,39] was adjusted using the

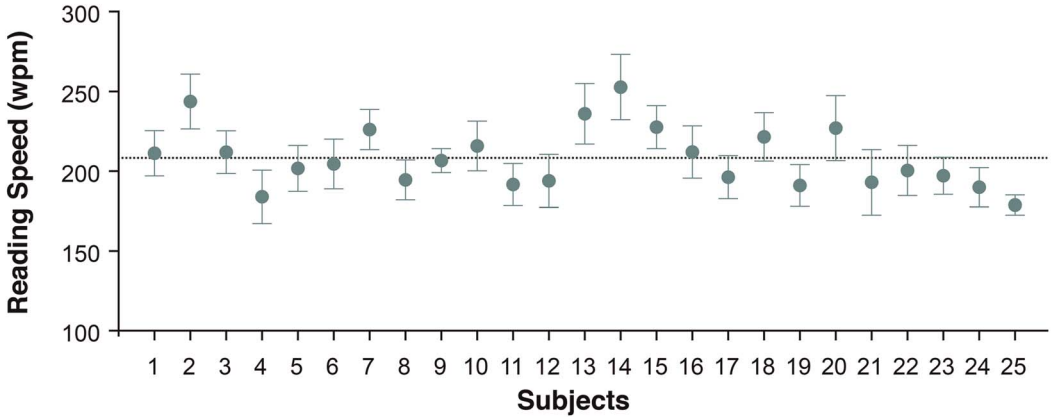

FIGURE 3. Average reading speed across the 10 texts for each participant (N = 25). The dotted line indicates grand average reading speed (208 words/min). Vertical bars correspond to ±1 SD.

rules derived from Gibson's theory,[19,20] in accordance with the guidelines of the IReST study group.[6,15] Although the principles of this theory are applicable to different languages, possible effects of interlanguage structural differences on reading performance should be taken into consideration when making cross-linguistic comparisons using the IReST. Another issue that should be further examined is the fact that oral reading speed may be limited by various processes, such as pronunciation (because the articulatory motor system has a lower speed threshold than the visual decoding system),[40] the eye-voice span,[41] or psychological stress during examination. Recent studies show advantages of evaluating reading performance using silent instead of oral reading[3,42]; however, the choice depends on the question of the study.

Because reading speed is affected by various factors,[3,13,14,42] it may not be used as the sole indicator of functional visual performance. Identifying and distinguishing the effect of several sources of variance are crucial when assessing reading performance, as it may reveal additional aspects of the complex process of reading. Eye movement–based analyses and supplementary assessments of reading capacity and comprehension could provide more detailed information on reading performance[3,43] and functional vision performance during reading.[3,43]

The IReST set is currently one of the most reliable reading tests for reading speed measurements owing to the use of standardized passages rather than single sentences, which are long enough to provide an accurate estimation of reading speed but short enough to prevent fatigue effects.[14] It has already been used in evaluation of the effect of glare on reading, in age-related macular degeneration patients, in glaucoma patients, and even in evaluation of therapeutic and surgical results.[15,42,44]

To conclude, the Greek version in the IReST language pack is expected to be a valuable tool for clinical practice and research, enriching interlanguage comparisons and international studies of reading performance especially in clinical populations.[45]

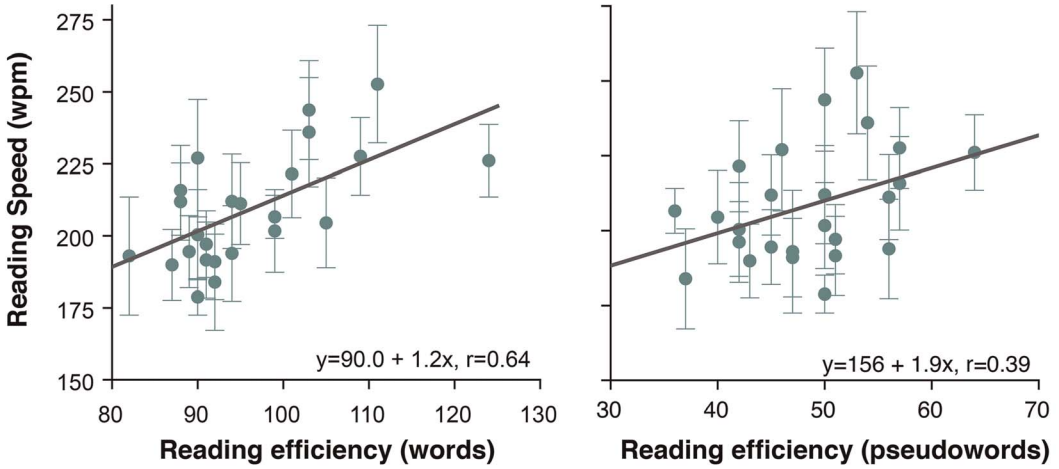

FIGURE 4. IReST reading speed as a function of word (left-hand panel) and pseudoword reading efficiency (right-hand panel). Only word reading efficiency correlated significantly with text reading speed ($r = 0.68$, $P = .001$). Error bars correspond to ±1 SD.

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