Contrast Reduction and Reading: Assessment and Reliability with the Reading Explorer Test

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ORIGINAL ARTICLE

Contrast reduction and reading: assessment and reliability with the Reading Explorer test

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PURPOSE. *To investigate the reliability of the Reading Explorer (REX) charts and to assess the impact of text contrast reduction (1.5 cycle/degree) on reading speed in subjects with normal and low vision.*
METHODS. *Standard visual acuity (ETDRS charts), reading speed (MNread charts), and contrast sensitivity (Pelli-Robson charts) measurements were obtained in 3 groups of subjects stratified by visual acuity level in the better eye from 0.0 to 1.0 logMAR, with intermediate cutoffs at 0.3 and 0.6 logMAR. Measurements of reading speed for decreasing levels of text contrast were obtained with the REX charts using a 1.5 cycle/degree text.*
RESULTS. *Since in many patients with lower vision a plateau of maximum reading speed across different levels of text contrast was not found, reliability indexes were computed for average reading speed and reading contrast threshold. In the group with lower visual acuity, 95% limits of agreement were ±0.134 log word/minute and ±0.175 log contrast sensitivity, suggesting good reliability. The proportion of subjects with a 20% loss of reading speed from 90% to 45% text contrast was estimated to be 1/3 at 0.6 logMAR visual acuity level and 2/3 at 1.0 logMAR.*
CONCLUSIONS. *The adverse effect of decreased text contrast, which may be found in ordinary reading material, on the reading performance of subjects with advanced and initial low vision is probably underestimated. The REX test proved to be a reliable investigation tool for this phenomenon. (Eur J Ophthalmol 2010; 20: 389-96)*

KEY WORDS. *Contrast sensitivity, Low vision, Visual acuity*

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INTRODUCTION

In addition to visual acuity, contrast sensitivity is instrumental in the reading performance of low-vision patients. MNREAD eye charts have been recognized as one of the most reliable and powerful reading tests available. They have been developed to investigate how letter size affects the reading performance of both normal and low vision subjects (1-6).

Investigating reading performance with a text/background contrast level that is not 100% is important because most common reading material, particularly newspapers, is printed at nonoptimal contrast levels. Moreover, a decrease in reading speed due to a reduction of contrast sensitivity can be rectified to some extent by providing suitable lighting or using electronic devices.

For these reasons, we have developed a new eye chart, REX (Reading Explorer), to investigate the reading performance of low vision subjects in terms of reading speed for several text/background contrast levels. The REX test was developed by the Department of Ophthalmology of the University of Florence in collaboration with the National

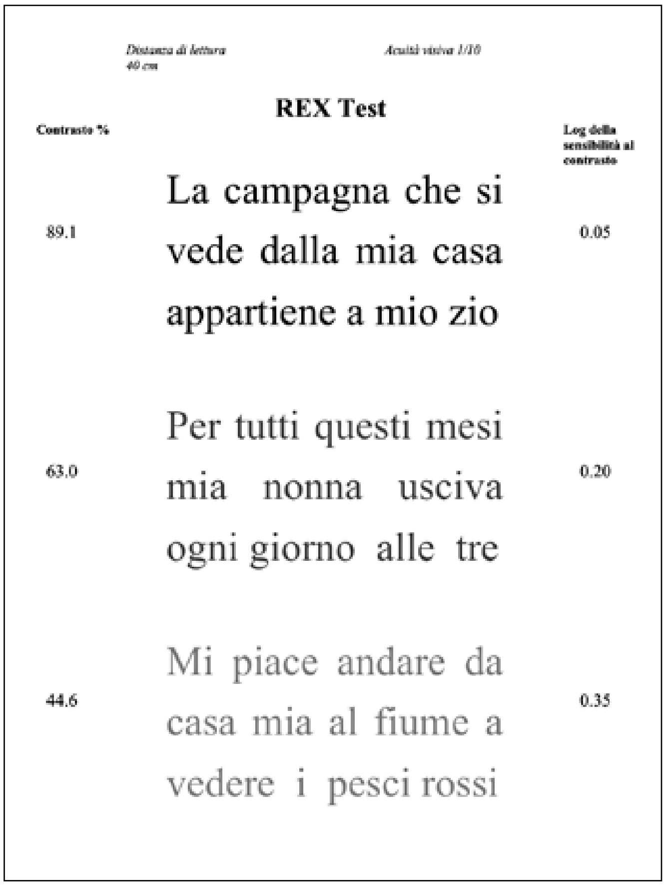

Fig. 1 - *First page of the REX chart 1. Each of the 2 charts (1 for the right eye and 2 for the left eye) includes a set of 4 pages with sentences of decreasing contrast. The text/background contrast in the first phrase of the REX charts is equal to 89.13%. The reading of this contrast level requires a contrast sensitivity of at least 1.122% that is 0.05 in logarithmic units. Each following phrase corresponds to a logarithmic contrast sensitivity 0.15 units higher than the previous one, up to 1.7 units for the last (12th) phrase.*

Institute of Applied Optics (INOA_CNR).
In the present study, we aimed to assess the reliability of the REX test on people with normal and low vision. Furthermore, we wished to evaluate the impact of decreased text contrast on reading speed.

METHODS

Structure and use of the REX test

The REX eye charts consist of 2 sets of 4 reading charts. Each chart shows 3 different phrases arranged vertically in the middle of the chart. The contrast of each phrase from top to bottom decreases with a logarithmic profile. The phrases in the REX charts satisfy the same standards as those of the MNREAD eye charts (2).
The font used in the REX eye charts is Times New Roman, as is that of the MNREAD eye charts (2).
At a viewing distance of 40 cm, the letter size (i.e., the dimension of the lower case character “x”) on each chart is equal to 1.0 logMAR. By shortening the viewing distance, we get 1.3 logMAR for a viewing distance of 20 cm. Therefore, we tested reading contrast sensitivity at a frequency of 1.5 cycle/degree.
The text/background contrast in the first line phrase of the REX charts is equal to 89.13%. The reading of this contrast level requires a contrast sensitivity of at least 1.122%; that is, 0.05 in logarithmic units. Each following phrase corresponds to a logarithmic contrast sensitivity 0.15 units higher than the previous one, up to 1.7 units for the last (12th) phrase (Fig. 1).
The chart illumination has to be set up at around 80 cd/m^2 (range 60-100 cd/m^2), the same requested for the Pelli-Robson eye charts or the MNREAD charts (2, 7).

Clinical applications of the REX eye charts

With the REX test, it is possible to measure 2 different visual dimensions: reading contrast threshold and reading speed for several contrast levels.
An estimate of the reading contrast threshold is given by the lowest text contrast a subject is able to read without significant errors.
The reading speed, or the number of words per minute that is read by a subject, is an objective index to measure reading ability. The REX charts can be used to measure reading speed at different contrast levels. Reading speed, as for the MNREAD test, is given by: reading speed (words/min) = 600/time required to read a phrase (s).

Patient selection

Patient enrollment was stratified in 3 groups according to visual acuity in the better eye: normal and near-normal vision (VA at least 0.3 logMAR); initial low vision (VA less than 0.3 logMAR but 0.6 logMAR or more); advanced low vision (VA less than 0.6 logMAR but 1.0 logMAR or more). We used the 0.6 and 0.3 logMAR cutoff values since the visual angle doubles between them.

Methods of measurement

Visual acuity was measured with ETDRS charts at 2 meters. Contrast sensitivity was measured with Pelli-Robson charts at 1 meter (7). Reading ability was measured with the Italian version of the MNREAD charts at 20 cm and reading speed at variable levels of text contrast was obtained with the REX test at a distance of 20 cm, both with appropriate near correction. All measurements were obtained from the eye with better visual acuity by the same trained personnel according to a standard protocol. Reading speed parameters with the MNREAD charts were computed according to a previously described method (6), while those with the REX test were calculated as described above. Measurements using the MNREAD and REX charts were obtained twice using version 1 and 2 of the charts in random order.

Statistical methods

To assess the reliability of the REX test, we obtained 2 measurements using charts 1 and 2 in a random order. We computed intraclass correlation coefficient and 95% limits of agreement from multilevel or variance component models (8). Particularly, we obtained the reliability of each sentence of the REX test as well as global measures of performance such as 1) the mean of the values of reading speed of all sentences in a single REX assessment; 2) reading contrast threshold, or the lowest text contrast a subject is able to read without significant errors. The reliability of maximum reading speed with the REX test was not obtained since a plateau of the reading speed values across sentences with decreasing contrast was not found in most patients with low vision. Pearson correlation was used to investigate the association between different psychophysical variables.

To estimate the impact of reduced text contrast on reading speed, we used a logistic regression mixed model to obtain a smoothing of the reading speed curve of each test, with nonlinearity accounted for by a cubic spline as a level 1 random effect and the individual as a level 2 random effect to include the test-retest assessments in the model. Then, we computed the change in reading speed from the first (90% contrast) to the third (45% contrast) sentence of the REX test. We chose the 45% level since this is commonly found in reading material. Finally, we computed the proportion of people with a drop in reading speed of 10% and 20% at the third sentence using the estimates from the logistic regression model. We also obtained receiver

TABLE I - AGE AND VISUAL FUNCTION DATA FOR THE WHOLE SAMPLE AND IN THE 3 STUDIED GROUPS

	Overall (n = 99)	Normal or near normal (n = 33)	Initial low vision (n = 33)	Advanced low vision (n = 33)
Age, y, median (min/max)	67 (18/90)	35 (18/89)	75 (41/90)	67 (40/85)
Visual acuity (ETDRS charts), logMAR, min/max	0.0/1.0	0.0/0.3	0.3/0.6	0.6/1.0
Contrast sensitivity (Pelli-Robson charts), logCS, mean (SD)	1.21 (0.37)	1.57 (0.21)	1.11 (0.32)	0.95 (0.26)
MNREAD maximum reading speed, logWPM, mean (SD)	1.94 (0.28)	2.16 (0.15)	1.96 (0.17)	1.69 (0.25)
MNREAD reading acuity, logMAR, mean (SD)	1.21 (0.37)	0.09 (0.13)	0.47 (0.17)	0.69 (0.15)
REX mean reading speed, logWPM, mean (SD)	1.80 (0.29)	2.09 (0.14)	1.77 (0.19)	1.55 (0.23)
REX reading contrast threshold, logCS, mean (SD)	1.37 (0.34)	1.81 (0.22)	1.26 (0.38)	1.05 (0.27)

WPM = words per minute; logMAR = log_{10} of the minimum angle of resolution; logCS = log_{10} contrast sensitivity.

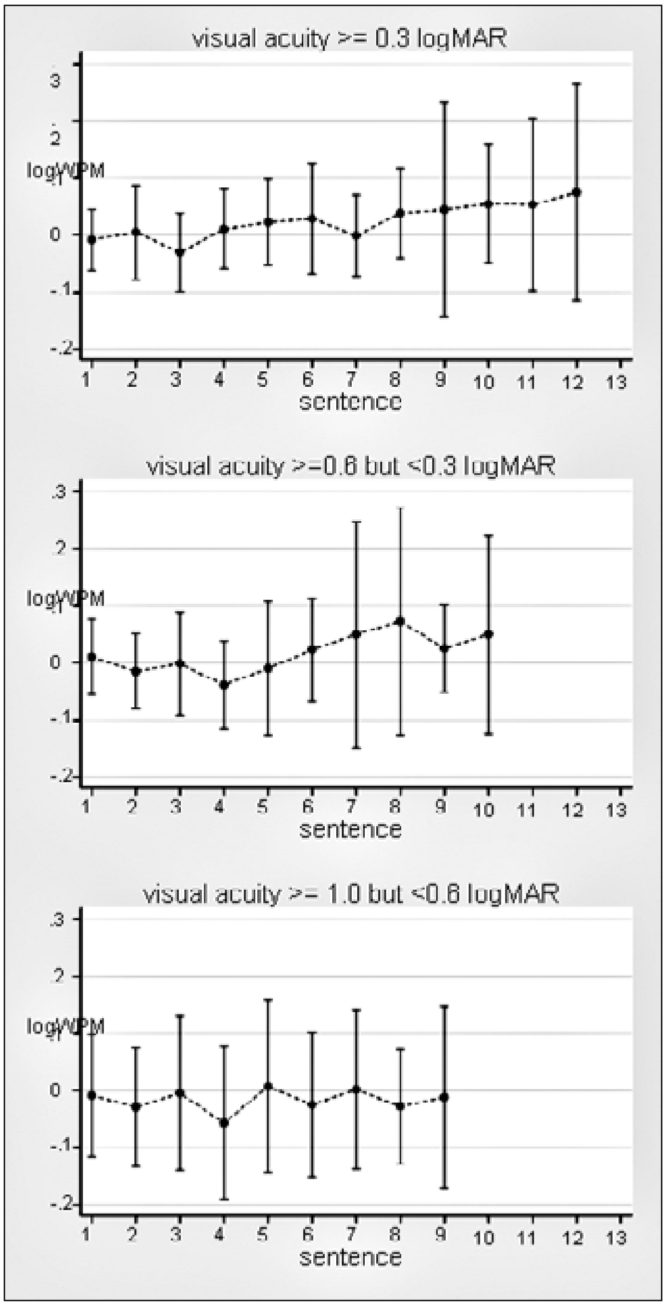

Fig. 2 - *Measurement error (vertical bar) and mean error (central dot of each bar) for test-retest of each sentence of the REX charts by visual acuity group.*

operating characteristic (ROC) curves from logistic regression models to compute the area under the curve (AUC) for the ability of ETDRS visual acuity and Pelli-Robson contrast sensitivity to diagnose a 20% reduction of reading speed.

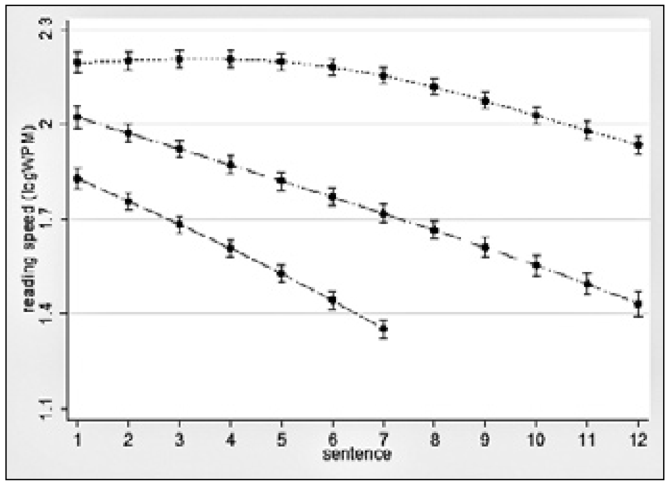

Fig. 3 - *Estimated mean reading speed curve for decreasing levels of text contrast in the subgroups of visual acuity in the better eye (see Methods): normal and near-normal vision (upper dashed line), initial low vision (middle dashed-dotted line), and advanced low vision (lower dashed line). While a plateau can be seen for the group with better vision, reading speed is shown to decrease for any text contrast reduction in the 2 groups with worse vision. Vertical bars are standard error bars.*

RESULTS

For the study, 99 individuals were selected according to 3 levels of visual acuity in the better eye. Table I presents age and visual function data for each of the 3 groups.

Reliability of REX test measurements in normal and low vision subjects

Figure 2 shows the 95% limits of agreement of reading speed for each REX sentence in normal and low vision subjects. The larger variability near the reading contrast threshold means that the chart is less reliable at this level, as expected. As seen in Table II, the reliability of REX measurements is very good for people with normal vision or initial low vision. In fact, if log10 limits of agreement are converted to percent change, a significant change of mean reading speed is diagnosed using the REX test if the change exceeds -16% to +19% in normal subjects, -18% to +22% in initial low vision subjects, and -27% or +36% in advanced low vision patients. These limits are still close to the values found for maximum reading speed in normal children using the Italian MNREAD charts (5). For the reading contrast threshold the limits would be -11% to +12% for normal and initial low vision subjects, and -33% and +50% change in advanced low vision patients.

For patients with advanced low vision, intraclass correlation coefficients are very high, suggesting good ability to discriminate between subjects, but 95% limits of agreement are larger than in initial low vision.

Correlation of REX parameters with other psychophysical variables

In general, mean reading speed using the REX test was equally correlated (Pearson r between 0.77 and 0.82) with several measures such as Pelli-Robson contrast sensitivity, ETDRS visual acuity, and REX reading contrast threshold. Despite the high correlation, this means that only 60% of the variance of REX reading speed (i.e., the R^2 value) can be explained by these variables.

The reading contrast threshold also proved to be well correlated with Pelli-Robson contrast sensitivity (Pearson r = 0.88). However, if the contrast threshold assessed with the REX is matched with that obtained using the Pelli-Robson charts by Bland-Altman methods, a mean difference of 0.154 $\log_{10}$ units was found; i.e., the REX test yielded better values of contrast sensitivity, and the 95% limits of agreement were wide (-0.580 to +0.275 $\log_{10}$ units), suggesting that different phenomena are studied by the 2 charts.

Impact of text contrast reduction on reading speed

Figure 3 presents the model-estimated reading speed curve at different levels of text contrast for the 3 visual

TABLE II - RELIABILITY OF READING SPEED AND READING CONTRAST THRESHOLD MEASUREMENTS FOR SELECTED INDEXES OF PERFORMANCE USING THE REX TEST (95% LIMITS OF AGREEMENT, INTRACLASS CORRELATION COEFFICIENT)

Measure	Overall	Visual acuity 0.0 to 0.3 logMAR	Visual acuity 0.3 to 0.6 logMAR	Visual acuity 0.6 to 1.0 logMAR
Any sentence, logWPM (ICC)*	±0.175 (0.94)	±0.145 (0.89)	±0.172 (0.90)	±0.240 (0.89)
Mean reading speed of all sentences, logWPM (ICC)	±0.103 (0.99)	±0.077 (0.98)	±0.087 (0.98)	±0.134 (0.96)
Reading contrast threshold, logCS (ICC)	±0.109 (0.99)	±0.049 (0.99)	±0.051 (1.00)	±0.175 (0.95)

*Except for the 2 sentences closer to the contrast reading acuity limit.
logMAR = $\log_{10}$ of the minimum angle of resolution; ICC = intraclass correlation coefficient; WPM = words per minute; logCS = $\log_{10}$ contrast sensitivity.

TABLE III - PERCENTAGE OF SUBJECTS WITH A DROP OF 10% OR 20% FROM THE FIRST (90% TEXT CONTRAST) TO THE THIRD (45% TEXT CONTRAST) SENTENCE OF THE REX TEST

		Change of reading speed from 90% to 45% text contrast with the REX test	
		-10% or worse	-20% or worse
ETDRS visual acuity group, logMAR (crude data)	0.0 to 0.3	3% (1/33)	3% (1/33)
	0.3 to 0.6	45% (15/33)	24% (8/33)
	0.6 to 1.0	78% (25/32)*	44% (14/32)*
Pelli-Robson contrast sensitivity, logCS (model estimated probability)	1.35	8%	1%
	1.20	34%	6%
	1.05	74%	20%
ETDRS visual acuity, logMAR (model estimated probability)	0.3	23%	12%
	0.6	66%	32%
	1.0	96%	71%

Percentages are computed from crude data for visual acuity groups and from logistic regression models for Pelli-Robson contrast sensitivity (CS, expressed as log10) and ETDRS visual acuity (logMAR).
*One patient could read only 2 REX sentences.

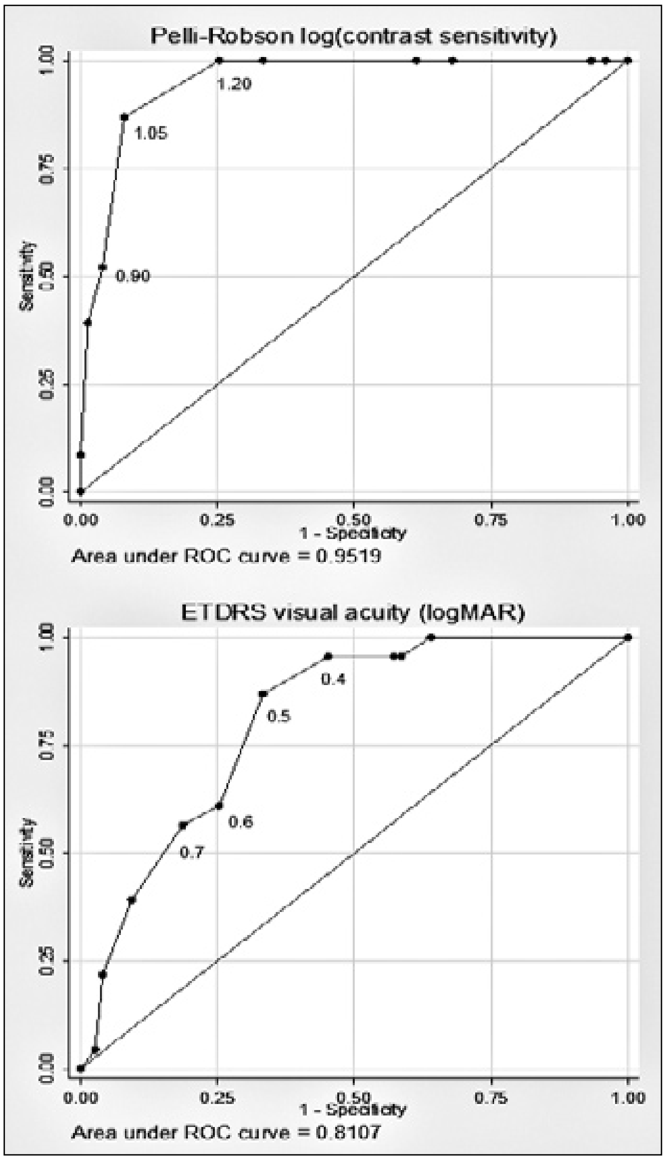

Fig. 4 - *Receiver operating characteristic (ROC) curves plotting the sensitivity and (1 minus) specificity of Pelli-Robson contrast sensitivity (expressed as log_{10} units) and ETDRS visual acuity (in logMAR) for detecting a 20% drop in reading speed from the first (90% text contrast) to the third (45% text contrast) sentence of the REX test.*

acuity groups as measured with the REX charts. A plateau corresponding to maximum reading speed was only seen in the group with normal or near-normal vision. Reading speed declined for any contrast decrease in the 2 other groups. As an example, reading speed dropped from 105 to 84 words/min, a 16% reduction for subjects with initial low vision from 90% contrast (first sentence of the REX test) to 45% contrast (third sentence). The corresponding values for subjects with advanced low vision were 67 and 48 words/min, representing a 29% drop. A 10% or 20% drop in reading speed between these 2 sentences was found in nearly 1/2 and 1/4 of the subjects with initial low vision, respectively (Tab. III).

Using ROC analysis (Fig. 4), a value of 1.20 log_{10} contrast sensitivity with the Pelli-Robson charts was 100% sensitive and 75% specific for detecting a 20% drop in reading speed, whereas a visual acuity of 0.4 logMAR was 95% sensitive but only 45% specific and the AUC was 0.95 and 0.81, respectively, for the 2 measures.

DISCUSSION

Contrast sensitivity is the visual requirement for which the largest reserve is needed to allow an individual to reach maximum reading performance (9). Other requirements concern the field of view (number of letters visible), and in cases of maculopathy, central scotoma size and the resulting eccentricity of fixation (9, 10).

It is commonplace in low vision rehabilitation that a contrast sensitivity below 10% based on the Pelli-Robson charts is associated with patientsí inability to read most types of text at their maximum reading speed. An unexpected finding of this study is that a significant proportion of our subjects with mild or moderate visual loss experienced a limitation in reading speed related to a modest decrease in text contrast (about 50%) as can be found in common reading text. As a result, the concept of maximum reading speed used for print size cannot be applied to text contrast in patients with exudative maculopathies, the most common disease among adult and elderly people attending a low vision clinic in industrialized countries.

REX chart reliability

A consequence of the statement made above is that the reliability of reading speed measured with the REX charts had to be estimated for the mean speed of all sentences. This measure had a reliability close to that of the maximum reading speed with the MNREAD charts (5).

The reading contrast threshold had very narrow limits of agreement in subjects with near-normal vision, corresponding to about 3 words in a REX sentence, and about 12 words or slightly more than one sentence for those with advanced low vision. These results prove that the REX charts are sufficiently reliable in detecting a clinically meaningful change in performance. In fact, these limits of agreement are similar to those found for contrast sensitivity in young (11) or elderly healthy subjects using the Pelli-Robson charts (12).

Implications for clinical practice of reading rehabilitation

The main consequence of our findings is that contrast sensitivity should be tested regularly in all patients attending a reading rehabilitation clinic regardless of visual acuity, at least if they are affected by choroidal neovascularization due to age-related macular degeneration, as are many of our patients, which is the most common cause of low vision among elderly Caucasians. We suggest that a contrast sensitivity of 16% or 1.2 log using the Pelli-Robson charts has the maximum sensitivity to detect this type of impairment in a low-vision population such as ours.
Compared to the Pelli-Robson charts, the REX test is a more direct measurement tool for detecting a contrast-related decrease in reading speed. We suggest that a 1/4 drop in speed from the first sentence to the third, in an individual REX assessment, is a reliable indicator of the need for contrast enhancement to optimize reading performance. In fact, ordinary reading material is often printed at relatively low contrast levels. Thus, the detection of patients who have reading speed loss at decreasing contrast is important for rehabilitation and reading aid selection.

Limitations of this study

The main limitation of our study is that the effect of contrast on reading speed was investigated only for one spatial frequency, specifically about 0.6 cycle/degree. Previous research suggests that the most important information for letter recognition lies in the range of 2 cycle/degree (13). Nonetheless, this research showed that reading speed is still close to its maximum when normally sighted subjects read low-contrast text with 0.5-2.0 cycle/degree (13), suggesting that the REX test also estimates the optimal reading performance in people with good vision. It must be observed that the relationship between reading speed and text contrast is modified by character size but this can be explained by a scale factor (13). Furthermore, our findings may apply to people with initial low vision when reading smaller characters. We will investigate this issue in future research using a version of the REX test with smaller print size.
Because a few normal subjects were part of the clinic personnel, the mean age of this group was lower compared to patients with reduced vision. Thus, contrast-related reading performance may have been better than in aged normal-sighted people; however, this limitation does not alter our conclusions regarding the impact of contrast reduction on low vision patients.

CONCLUSIONS

Our study shows that contrast sensitivity should always be assessed in low-vision patients undergoing reading rehabilitation even at mild levels of low vision. The Pelli-Robson charts are a valid instrument for the screening of a contrast-related reduction in reading speed but a more direct way to measure this is using the REX charts, which proved to be reliable in this study on low vision patients. Further research should assess the impact of the REX test on the outcome of rehabilitation programs. We hypothesize that a better recognition of contrast-related reading speed impairment may allow the prescription of low-vision aids that maximize text contrast.

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REFERENCES

1. Legge GE, Ross JA, Luebker A, LaMay JM. The Minnesota low-vision reading test. Optom Vis Sci 1989; 66: 843-53.
2. Ahn JS, Legge GE, Luebker A. Printed cards for measuring low-vision reading speed. Vision Res 1995: 35: 1939-44.
3. Ahn SJ, Legge GE. Psychophysics of reading. XIII. Clinical predictors of magnifier-aided reading speed in low vision. Vision Res 1995; 35: 1931-8.
4. Mansfield JS, Legge GE, Bane MC. Font effects in normal and low vision. Invest Ophthalmol Vis Sci 1996; 37: 1492-501.
5. Virgili G, Cordaro C, Bigoni A, Crovato S, Cecchini P, Menchini U. Reading acuity in children: evaluation and reliability using MNREAD charts. Invest Ophthalmol Vis Sci 2004; 45: 3349-54.
6. Virgili G, Pierrottet C, Parmeggiani F, et al. Reading performance in patients with retinitis pigmentosa: a study using the MNREAD charts. Invest Ophthalmol Vis Sci 2004; 45: 3418-24.
7. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clin Vis Sci 1988; 2: 187-99.
8. Euser A, le Cessie S, Finken M, Wit J, Dekker F. Reliability studies can be designed more efficiently by using variance components estimates from different sources. J Clin Epidemiol 2007; 60: 1010-4.
9. Whittaker SG, Lovie-Kitchin J. Visual requirements for reading. Optom Vis Sci 1993; 70: 54-75.
10. Fletcher DC, Schuchard RA, Watson G. Relative locations of macular scotomas near the PRL: effects on low vision reading. J Rehabil Res Dev 1999; 36: 356-64.
11. Lovie-Kitchin JE, Brown B. Repeatability and intercorrelations of standard vision tests as a function of age. Optom Vis Sci 2000; 77: 412-20.
12. Elliott DB, Sanderson K, Conkey A. The reliability of the Pelli-Robson contrast sensitivity chart. Ophthalmic Physiol Opt 1990; 10: 21-4.
13. Legge GE. Visual mechanisms in reading. In: Psychophysics of Reading in Normal and Low Vision. Mahwah, NJ: Lawrence Erlbaum Associates; 43-105.