Reading Acuity in Children: Evaluation and Reliability Using MNREAD Charts

Gianni Virgili,1 Claudia Cordaro,2 Anna Bigoni,2 Sabrina Crovato,2 Paolo Cecchini,2 and Ugo Menchini1

PURPOSE. To study reading acuity in children and assess the reliability of its measurement using the Italian version of the MNREAD reading chart.

METHODS. One hundred sixteen children from grades 3 to 8 with normal near vision were tested at a pediatric eye care institution in northeastern Italy. Visual acuity was evaluated with Early Treatment Diabetic Retinopathy Study (ETDRS) charts and reading acuity with MNREAD charts. Examination with charts 1 and 2 by the same examiner in the same visit were used as test-retest measurements.

RESULTS. Mean improvement of performance from grades 3 to 8 was approximately 1 line for ETDRS acuity and 1.5 sentences for reading acuity and critical print size. Mean maximum reading speed increased from 96 to 167 words/minute. Regression analysis showed that a stable reading speed was obtained throughout sentences of decreasing size up to the critical print size. Measurement error, expressed as 95% limits of agreement, was ±0.136 logarithm of the minimum angle of resolution (logMAR) and ±0.142 logMAR for ETDRS acuity and reading acuity, respectively. Critical print size had the lowest reliability (±0.193 logMAR). Maximum reading speed limits of agreement were ±0.077 logarithm of words per minute (logWPM), or a 19% change in words per minute. There were no detectable effects of grade and refractive error on measurement errors.

CONCLUSIONS. In children, MNREAD charts provide measurements of reading acuity as reliable as ETDRS chart measurements of distance acuity on a logMAR scale. They also provide highly reliable measurements of the maximum reading speed across all grades, independent of its noticeable increase. (Invest Ophthalmol Vis Sci. 2004;45:3349–3354) DOI: 10.1167/iovs.03-1304

Reading is a complex process involving several visual and nonvisual aspects. Print size is one of the factors that mainly influence reading speed in normal and low-vision subjects.1,2 Typically, reading speed is stable across a wide range of print sizes for one individual (maximum reading speed [MRS]). As print size decreases, there comes a point where reading starts to slow down, referred to as the critical print size (CPS). The reading acuity (RA) limit has been reached when the subject is no longer able to read. Print size corresponding to CPS is typically two times larger than RA, a difference of 0.3 in logarithm of the minimum angle of resolution (logMAR).

The effects of age on visual function testing have been studied in adults.3–10 The Bailey-Lovie near word chart11 was used in these studies to evaluate reading ability. Recently, the reliability of visual acuity measurement with an Early Treatment Diabetic Retinopathy Study (ETDRS) chart in children has also been assessed,12,13 but little is known about the age-specific reading performance of children.

The MNREAD charts are continuous-text reading-acuity charts suitable for measuring the RA and reading speed of normal and low-vision patients, developed at the Minnesota Laboratory for Low-Vision Research.13,14 Italian and Japanese versions of the charts are currently commercially available.

The purpose of this study was to evaluate the reliability of measurements of RA obtained with the Italian MNREAD charts in children in grades 3 through 8. A second purpose was to characterize the expected improvement of reading ability across grades and compare it with an ETDRS chart, a worldwide standard for visual acuity measurement.

METHODS

Subjects were recruited at the pediatric ophthalmic practice of La Nostra Famiglia, a scientific institution providing eye care to normal and visually impaired children in northeastern Italy. Children are referred by pediatricians for screening of ophthalmic and refractive abnormalities to the center, which is the only high-volume pediatric eye care institution in an area of approximately 300,000 residents, one third living in the town of Udine.

Consecutive children from grades 3 through 8 were included in the study. We planned to enroll 120 consecutive subjects who met inclusion criteria, with a minimum of 10 children per grade. Children and parents were informed about the purposes of the research and parents signed an informed consent. The study adhered to the tenets of the Declaration of Helsinki and was approved by the institution’s institutional review board.

Inclusion criteria were visual acuity at least 0.3 logMAR (20/40) with ETDRS charts, normal findings in an ocular examination, and normal binocular motility and stereoscopic sense on the Lang II test (complete test).15 The level of ETDRS acuity admitted in the study was relatively low because compliance may not be optimal with children using this chart. When tested with a single-letter presentation, all children could see at least some letters at 20/20 level.

Subjects were screened for dyslexia using the Memory Transfer (MT) test (Organizzazioni Speciali, Florence, Italy) and were excluded if the reading speed score was less than 10 or if errors were more than 15, as recommended.

One hundred twenty children were evaluated. Four were excluded because they tested positive for dyslexia with the MT test. Overall, 116 children were finally included. Mean age was 10.5 ± 1.5 years. Of the 116 children, 68 (59%) were girls. The number of subjects from grades 3 through 8 were 26, 22, 22, 15, 20, and 11, respectively.

Refraction was first obtained with an autorefractometer (Retinoscan; Nikon, Tokyo, Japan) and then refined subjectively. Mean spherical equivalent was −0.44 and −0.56 D in the right and left eyes,
respectively, ranging from −7.88 to +5.25 D overall. Approximately 30% of both right and left eyes needed a cylinder of 1 D or more; in 5%, the cylinder was 2 to 3.5 D. Subjects wore refractive error correction during testing.

All psychophysical tests were conducted by the same examiner for each child. A second examiner helped record reading data obtained with the MNREAD chart.

The MNREAD sentences provide samples of reading material designed to demand the visual processing capabilities and eye-movement control required for normal text reading. Each sentence contains 60 characters (including a space between each word and at the end of each line) printed as three lines with even left and right margins. The vocabulary used in the sentences is selected from high-frequency words that appear in second- and third-grade reading material. The charts contain sentences with 19 different print sizes. From the recommended viewing distance of 40 cm (16 in.) the print size ranges (from the smallest to the largest) 1.4 to 0.5 logMAR (Snellen equivalents 20/400–20/6). This range can be extended by using a shorter or longer viewing distance. The MNREAD charts have already been used in clinical and low-vision research.14–18

To evaluate the reliability of the measurement, MNREAD charts 1 and 2 were tested on the same subject consecutively. The two charts have the same layout but contain different sentences. Each child was asked to use the right eye to read one chart and the left eye to read the other. This design allowed us to evaluate whether laterality was associated with reading performance. To our knowledge, this question has not been addressed in psychophysical studies evaluating the association of lateral preferences with reading.19–21 The order of chart presentation was alternated in consecutive subjects, as shown in Table 1, to avoid an association between chart, eye, and order of presentation. Distance visual acuity was obtained with the ETDRS charts and recorded in logMAR for all subjects. Charts 1 and 2 were presented using the same method as for the MNREAD charts. Because the ETDRS acuity score is based on the number of letters correctly identified, the true unit of measure is 0.02 logMAR, because the difference in visual angle between two adjacent lines is 0.1 logMAR and there are five letters per line.

The difference in size between two MNREAD sentences is 0.1 logMAR. Each sentence comprises 60 characters, including spaces, corresponding to 10 average-length words each worth 0.01 logMAR. RA, or the smallest print size at which some words can still be recognized, can be approximated by 0.01 logMAR after subtracting the errors. These words are either missed or misread and are typically clustered between CPS and acuity limit. The following formula is used to compute RA in logMAR: \( RA = 1.4 - (\text{sentences} \times 0.1) + (\text{errors} \times 0.01) \). There was no need to adjust the value obtained with this formula by a factor accounting for viewing distance, because a standard testing distance of 40 cm was adopted. MRS is obtained by averaging the speed of the sentences with print size corresponding to CPS or larger. MRS is measured in words per minute (WPM), but the logarithm of words per minute (logWPM) is used to make its progression linear, thus ensuring a proportional percentage of change, which is recorded in 0.01 log units. CPS is recorded at 0.1 logMAR intervals. CPS was identified as the print size of the sentence at which both of the following conditions were satisfied: (1) all the following (smaller) sentences were read at a speed that was 1.96 times the standard deviation below the average of the largest preceding sentences and (2) all the following (smaller) sentences were read at a speed 5% slower (an approximate 25% change in WPM) than this average. In approximately one third of the eyes (32%) the two criteria disagreed, suggesting two different sentences as potential CPS. In such cases, the sentence with the larger print size was chosen, to avoid averaging some slower sentences in MRS computation, although this usually has little bearing on the estimate. An exception was made in five eyes in which the smaller sentence seemed preferable after graphic examination of the test result. Of note, with criterion 2, the larger sentence was preferred in 69 of 75 eyes presenting such a discrepancy.

A paired t test was used to test for equality of means of measures obtained with charts 1 and 2 of ETDRS and MNREAD. The intraclass correlation coefficient (ICC) was obtained as an index of reliability for continuous variables.22 Error of measurement was calculated as the square root of the error mean square from each ANOVA model.22 According to Aridt and Cagnlone7 the standard deviation of the distribution of the discrepancies between test and retest is equal to the SE of measurement times \( \sqrt{2} \). This value must then be multiplied by \( \sqrt{2} \) to obtain 95% confidence limits for the agreement between test and retest.

Univariate regression was used to evaluate whether the absolute value of the difference between test and retest changed with grade or with refractive error. Both a linear and a quadratic association with grade were assessed. Because subjects were the unit of analysis in these models, spherical equivalent and cylinder power were recorded as the average of the two eyes.

To evaluate the effect of school grade on ETDRS visual acuity and reading ability, a generalized least square (GLS) regression model was used to take into account the correlation between multiple measures in the same individual as a random effect. Multivariate models were then fitted in which other variables were evaluated, such as age, sex, refractive error (spherical equivalent and cylinder power of each eye), chart (1 vs. 2), eye (right versus left), and order of presentation (first versus second during individual test).

GLS regression was also adopted to evaluate whether a significant slope existed in reading speed from larger to smallest sentences of the MNREAD charts. Again, a random effect was attributed to intra-individual correlation. Cronbach’s α was used as an index of the measure of internal consistency of reading speed of sentences within each chart.

Statistical analyses were performed on computer (Stata, ver. 8.1; Stata Corp., College Station, TX).

### Table 1. Crossing Scheme for Chart Presentation in the Study

<table>
<thead>
<tr>
<th>Subject</th>
<th>Eye</th>
<th>Chart</th>
<th>Presentation Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>R</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>R</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>R</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 2. Mean (SD) ETDRS Acuity and MNREAD Variables for the Entire Sample

<table>
<thead>
<tr>
<th></th>
<th>ETDRS Visual Acuity (logMAR)</th>
<th>RA (logMAR)</th>
<th>CPS (logMAR)</th>
<th>MRS (logWPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean for chart 1 (SD)</td>
<td>0.074 (0.091)</td>
<td>0.026 (0.093)</td>
<td>0.244 (0.097)</td>
<td>2.101 (0.122)</td>
</tr>
<tr>
<td>Mean for chart 2 (SD)</td>
<td>0.054 (0.089)</td>
<td>0.023 (0.089)</td>
<td>0.234 (0.097)</td>
<td>2.105 (0.130)</td>
</tr>
<tr>
<td>Mean difference (95% CL)</td>
<td>0.020 (0.007; 0.033)</td>
<td>0.003 (−0.009; 0.015)</td>
<td>0.010 (−0.010; 0.028)</td>
<td>−0.004 (−0.011; 0.004)</td>
</tr>
<tr>
<td>Paired t-test</td>
<td>0.004</td>
<td>0.640</td>
<td>0.259</td>
<td>0.322</td>
</tr>
</tbody>
</table>

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RESULTS

Reliability of Measurement

Table 2 presents the mean and the standard deviation of the measures obtained with ETDRS charts 1 and 2 for RA, CPS, and MRS. As seen in the table, the test-retest means were significantly different for ETDRS acuity, but not for measures obtained with the MNREAD charts. In any case, mean differences were small and clinically unimportant, as indicated by their 95% confidence limits. The ICCs for ETDRS acuity (0.66, 95% CL: 0.55; 0.73) and RA (0.73, 95% CL: 0.65; 0.82) were similar and were consistent with good reliability. CPS yielded a lower ICC (0.49, 95% CL: 0.35; 0.63). On the other hand, reliability for MRS was very high (0.95, 95% CL: 0.93; 0.97).

The 95% confidence limits for agreement between test and retest in one subject were ±0.136 logMAR for ETDRS acuity, ±0.142 logMAR for RA, and ±0.193 logMAR for CPS. MRS was ±0.077 logWPM, which corresponds to ±19% change in WPM.

Table 3 shows 95% limits of agreement in the overall sample as well as by school-grade. Tables 4 and 5 present them for ETDRS acuity. When all chart sentences are considered, correlation of the chart was very high with respect to speed measurement. When all chart sentences are considered, corresponding α values were still very high: 0.93 and 0.95, respectively.

Influence of School Grade on Performance

Evaluating the relationship between grade and performance (Fig. 2) was one of the main objectives of the study and was explored with univariate regression analysis. Because one grade means one additional year of education, it was considered a discrete and quantitative variable, rather than a categorical one.

Regression analysis predicted an improvement of ETDRS acuity by −0.016 logMAR (95% CL: −0.025; −0.007 logMAR, P < 0.001) per grade, corresponding to a difference of approximately 1 line from grades 3 through 8.

Table 4. Measurement Error for Visual Acuity and Reading Ability by Quartile of Spherical Equivalent

<table>
<thead>
<tr>
<th>Quartile</th>
<th>1 (n = 29)</th>
<th>2 (n = 28)</th>
<th>3 (n = 29)</th>
<th>4 (n = 30)</th>
<th>Overall (n = 116)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETDRS visual acuity (logMAR)</td>
<td>−3.3 (−7.9/−2.1)</td>
<td>−1.1 (−2/−0.1)</td>
<td>+0.5 (0/0.8)</td>
<td>+1.8 (+0.9/+4.6)</td>
<td>±0.146</td>
</tr>
<tr>
<td>RA (logMAR)</td>
<td>±0.166</td>
<td>±0.145</td>
<td>±0.131</td>
<td>±0.142</td>
<td>±0.146</td>
</tr>
<tr>
<td>CPS (logMAR)</td>
<td>±0.111</td>
<td>±0.152</td>
<td>±0.119</td>
<td>±0.141</td>
<td>±0.132</td>
</tr>
<tr>
<td>MRS (logWPM)</td>
<td>±0.189</td>
<td>±0.166</td>
<td>±0.241</td>
<td>±0.164</td>
<td>±0.193</td>
</tr>
</tbody>
</table>

Data for RA, CPS, and MRS are 95% limits of agreement.

* Mean spherical equivalent of each individual.
The predicted difference in RA from grades 3 to 8 was grades and a tendency toward stabilization at higher grades. with grade, accounting for a larger improvement of RA in early were retained in the model evaluating the association of RA ETDRS visual acuity

Median cylinder power (D)

CPS (logMAR) MRS (logWPM)

Data are as described in Table 4. *Mean cylinder power of each individual was used to group subjects.

A linear term (P = 0.003) and a quadratic term (P = 0.051) were retained in the model evaluating the association of RA with grade, accounting for a larger improvement of RA in early grades and a tendency toward stabilization at higher grades. The predicted difference in RA from grades 3 to 8 was −0.156 logMAR (95% CL: −0.224; −0.088 logMAR)—approximately 1.5 sentences. CPS increased linearly with grade by −0.014 logMAR (95% CL: −0.023; −0.005 logMAR, P = 0.003).

Grade was also a strong predictor of RS, accounting for 48% of its variance. It increased by 0.052 logWPM (95% CL: 0.042; 0.062 logWPM, P < 0.001) per grade, corresponding to a 13% increase in WPM and to an increase of the mean value from 96 to 167 WPM from grades 3 through 8.

**Association of Other Variables with Performance**

The association of performance with grade was strong in multivariate models, in which its coefficients were similar to those from univariate analyses. RA worsened by approximately 0.029 logMAR for each additional diopter of astigmatism (95% CL: 0.017; 0.045 logMAR, P = 0.001). This value is almost identical with that found for ETDRS visual acuity (0.032 logMAR, 95% CL: 0.017; 0.048 logMAR, P < 0.001). Spherical equivalent showed no association with any other independent variables when grade was considered. CPS was found to be slightly better in the left eye than the right eye (−0.021 logMAR, 95% CL: −0.005; −0.058 logMAR; P = 0.021). No relationship between reading speed and other covariates was found when grade was considered in the model. Age was never as good a predictor as grade. A small difference in visual acuity was confirmed for ETDRS chart 1 versus chart 2, as seen in Table 2.

**DISCUSSION**

Several investigators have studied the reliability of visual acuity measurement in adults. In most studies, they found that test–retest error is within 0.04 to 0.06 logMAR. Thus, a change of 1 line or 0.1 logMAR is suggested to be clinically significant in normal adults. A modest decrease in performance with older age has been shown.

A recent study has assessed the reliability of visual acuity measurement with the ETDRS charts in children. Based on the 95% limits of agreement, the criterion for a statistically significant change in VA is no more than ±0.15 logMAR. These limits were not found to be associated with age, but there was a small difference between sexes, with boys approximately two letters more variable than girls.

Lovie-Kitchin and Brown provided data on age-related changes of RA using the Bailey-Lovie near word chart in adults aged 21 to 68. The mean value was 0.044 logMAR (SD: 0.057) and it declined by 0.016 logMAR per decade. The standard deviations of RA increased with age, but this was believed to be the result of imperfect near correction, and overall test variability was not greatly influenced by age in their sample. Overall, the 95% confidence limits for RA were ±0.114 logMAR. Practice effect was also modest in this study—approximately −0.013 logMAR improvement between the first and the fifth of a series of measurements.

Camparini et al. conducted a study on measurement error comparing full versus fast procedure for visual acuity measurement using the ETDRS charts in Italian subjects. Confidence limits at the 95% level were approximately eight letters, or 1.6 lines, for the full procedure. However, approximately one third of the patients in the sample were affected by some form of eye disease, and so these data cannot be assumed to be valid for normal Italian adults.

**FIGURE 1.** Mean reading speed of all sentences in the MNREAD charts 1 (top) and 2 (bottom), across six groups of children in the same grade.
In this study, a change of 1.5 lines was significant for ETDRS acuity, which is slightly larger than the limit allowed for adults in published reports on English-speaking people and is identical with that obtained by Manny et al. in English-speaking children aged 6 to 11 years.

The MNREAD charts allowed a precise measure of RA. In logMAR units, their reliability was at least as good as that of the ETDRS charts for normal children, beginning at grade 3. The reliability of MRS measurement was the highest, whereas that of CPS measurement was the lowest, although still acceptable. This could be because CPS is recorded in discrete steps of 0.1 logMAR—that is, with a larger approximation than other reading variables. The relatively low reliability coefficient for acuity measures also results from a "range effect," because vision was restricted within a narrow normal range.

Both VA with the ETDRS charts and reading performance increased with grade. Whereas measures of acuity improved only slightly, MRS increased markedly from grades 3 to 8, in accordance with the data previously published by Taylor and reviewed by Carver. Although a trend toward stabilization was shown graphically for most measures, a quadratic term in the model was retained for RA, indicating its tendency toward a plateau at grade 8. It is possible that the number of subjects in each grade was too small to detect a trend toward stabilization of performance for other variables. It should also be observed that a cross-sectional study is not the most appropriate design to obtain a precise estimate of the progression of reading ability with age, which would be best achieved with longitudinal studies.

Increasing astigmatism was found to be associated with lower RA. A similar association with VA suggests that there could be some residual optical blur, despite accurate refraction. No association was found between astigmatism and MRS, as could be expected if mild blur is the only limiting factor.

Both regression analysis and Cronbach’s α indicate that different sentences in the MNREAD charts provided very similar reading speeds for one individual, despite the fact that each sentence contained only 60 characters. This finding supports the decision of averaging over reading speed of several sentences to obtain MRS. It also suggests that estimates of MRS could be obtained using sentences of any size, provided that they are larger than the CPS.

In this study, one eye was used for test and the fellow eye for retest to assess whether reading with right versus left eye affects performance. Although this may cause the error estimate to include true interocular differences, these were likely to be small because subjects were best refracted and were included only if no anomaly of the visual system was found. Moreover, even a small systematic bias would have been in the direction of a larger error, rather than toward its underestimation. No difference of performance of right versus left eye was found for all measured variables, except for CPS which was better in the left eyes. This difference was clinically unimportant and could represent a chance finding. The confidence limits of RA using the MNREAD charts were similar to those of VA measured with the ETDRS charts, which are currently the standard for distance acuity measure. They are also close to the values found in English-speaking adults by Bailey and Lovie using a Bailey-Lovie word chart. No effect of practice was detected on the second test. Gender and age did not affect performance when grade was taken into account.

When results of reliability studies are considered, the characteristics of the sample are relevant for their generalizability. In this study, children were collected in an area in which industrial, commercial, and agricultural activities all contribute to provide one of the highest average incomes in Italy. The institution in which the study was conducted is the only high-volume eye-care service for children in this area. Its services are largely covered by the public healthcare system, so that access is not limited by family income. Children are thus representative of a well-educated population with income levels close to those of other industrialized Western countries.

Of course, the possibility of generalizing results to other countries may be limited by the language. This may be partly overcome by the use of the ETDRS charts, a worldwide standard tool, as a reference method for visual acuity testing. The reliability of the ETDRS charts was similar to that found in a recent U.S. study. Limitation to near normal acuity restricts the generalization of the findings. Not only is true error expected to be larger as acuity worsens, but with the MNREAD...
charts, there are also fewer data above CPS on which to estimate maximum reading rate. This would increase measurement error when estimating MRS and CPS.

Present results encourage more research on the validity of the MNREAD charts for assessing reading performance. In particular, reliability of measures from different examiners and among low-vision patients should be assessed. Ideally, studies to evaluate the reliability in patients with similar diseases and visual loss should be conducted in different countries, because MNREAD charts are already available in various languages and more are being developed. The ultimate goal of such studies would be to test whether the MNREAD charts can be a valid translinguistic tool. This would help multicenter low-vision research and facilitate the adoption of reading performance as an outcome measure in clinical research, given the fact that reading is a primary activity of daily life.

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References