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Printed Cards for Measuring Low-vision Reading Speed

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There is a growing consensus that clinical evaluation of the real-world consequences of eye disease requires new performance-based tests. This is because Snellen acuity and other common clinical tests are often poor predictors of everyday function. Ahn and Legge [(1995) *Vision Research*, *35*, 1931–1938] validated a computerized test of reading speed by showing that it provides an accurate prediction of low-vision reading performance with magnifiers. Here, we describe development of a printed-card version of the test suitable for clinical use. This printed-card test retains key design features of the validated computerized test, including the same set of sentences and display format. Data from 23 low-vision subjects showed that a very simple testing procedure using printed cards and a stop watch could be used effectively to estimate reading speed. Reading speed based on a single card was quite accurate (SD equal to about 18% of the mean) and showed no practice effects from one card to the next. Reading speeds obtained with printed cards correlated highly ($r = 0.887$) with those from computerized testing. We conclude that a simple test, using printed cards, can be used to obtain useful estimates of low-vision reading speed.

Low vision　Reading speed　Reading test　Printed cards

INTRODUCTION

A recent survey finds that there are about three million visually impaired Americans (Tielsch, Sommer, Will, Katz, & Royall, 1990). A common and serious effect of visual impairment is reading difficulty. In fact, low vision has been commonly defined as the inability to read the newspaper with best optical correction at a normal reading distance.

Legge, Ross, Isenberg, and LaMay (1992) showed that routine clinical measures such as Snellen acuity are poor predictors of low-vision reading performance. They suggested that a simple clinical test of reading speed could be used to predict real-world reading performance. There are various tests of reading performance, such as the Gray Oral Reading Test (Gray, 1967) and the Diagnostic Reading Scales (Spache, 1981). Most of these tests, however, are geared to educational issues, such as assessing proper grade or reading levels, and are relatively insensitive to visual factors.

The Sloan M cards (Sloan & Brown, 1963) were designed for measuring reading acuity in low vision. Typically, best reading occurs for print sizes substantially larger than the acuity limit (Legge, Rubin, Pelli, & Schleske, 1985b). The M cards were not intended for evaluating reading performance for characters larger than the acuity limit. The Pepper Visual Skills for Reading Test is another low-vision test (Baldasare, Watson, Whittaker, & Miller-Schafer, 1986). Rather than being a test that isolates visual factors in reading, the Pepper Test was designed to assess everyday low-vision reading *in situ*. Subjects choose their own lighting and preferred viewing distance (i.e. character size), and are often tested through magnifiers.

The Minnesota Low-vision Reading Test (MNREAD) is a reading test that was specifically designed to be sensitive to visual factors. MNREAD is a computer-based test which has been described in detail in Legge, Ross, Luebker, and LaMay (1989). MNREAD uses simple sentences and common vocabulary to minimize cognitive and linguistic demands. Sentences are presented at high magnification so that constituent large letters lie within the acuity limit of most low-vision subjects. Because subjects do not need to manipulate magnifiers, there is no demand for manual dexterity in the task. In short, the purpose of the computerized MNREAD test is to provide a realistic estimate of a low-vision person's best reading speed.

Ahn and Legge (1995) validated the computerized MNREAD test by showing that its scores correlated highly with a real-world reading task: low-vision subjects read paragraphs from print media with their preferred magnifiers. Computer-based MNREAD scores accounted for 79.7% of the variance in this task.

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By comparison, Snellen acuity accounted for only 1.2% of the variance.

There are several practical reasons for developing a simpler version of the MNREAD test of low-vision reading speed. While the computer-based test does provide accurate psychophysical measures of reading speed, it requires a computer and video display monitors, which can be costly, non-portable, and difficult to set up. A reading test requiring no equipment other than printed cards and a stop watch would be far less expensive, more portable, and much easier to set up and maintain than the computerized test. Moreover, the low-tech nature of printed cards means they would be more adaptable for use in developing countries.

Our purpose in using printed cards was to develop a simple, quick and accurate test of low-vision reading speed having a high correlation with our validated computer-based test. We created a set of printed cards (see Methods) and conducted experiments to (1) find the simplest procedure for manually presenting the cards; (2) measure the correlation of scores with computer-based reading speeds for the same sentences; (3) determine the amount of practice before subjects reached stable reading performance; and (4) estimate the accuracy of reading speeds measured with the printed cards.

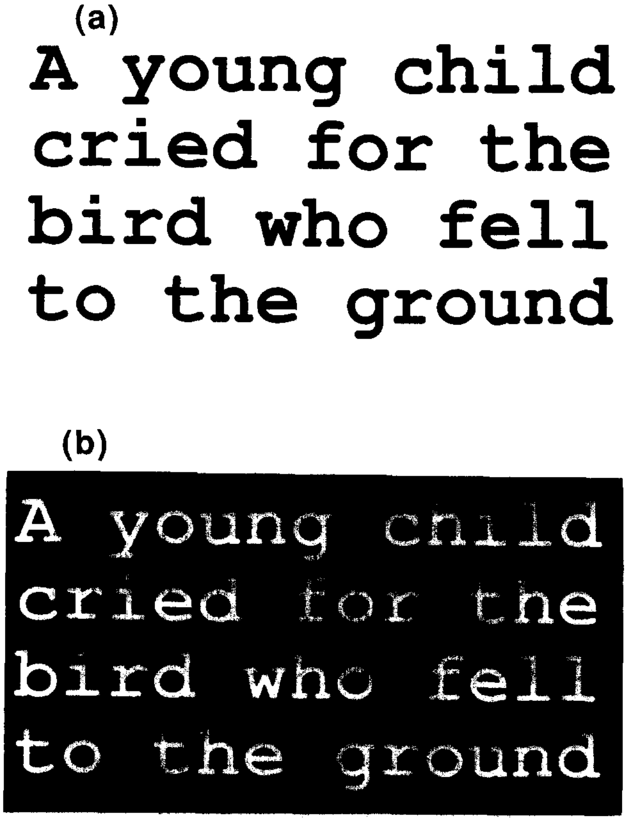

FIGURE 1. Illustration of a sample of large-print cards used by the MNREAD Low-vision Reading Test. One side of the card, shown in (a), is printed in black-on-white polarity and the reverse side, shown in (b), is printed in white-on-black polarity. The actual physical dimensions of each card are 8.5 × 11 × 0.03 in. At a viewing distance of 19 cm, the letters subtend 6 deg (center-to-center spacing).

METHODS

Description of the printed cards

The printed cards were designed to incorporate many of the design characteristics of the MNREAD computer-based test. The cards have the following properties in common with the computerized test: (1) they include the same set of 28 sentences; (2) the letters subtend 6 deg (center-to-center spacing) at a viewing distance of 19 cm (well within the acuity limit of most low-vision subjects); and (3) each sentence consists of four rows of 13 characters.

Each card contains one sentence, printed black-on-white on one side and white-on-black on the other, as shown in Fig. 1.* Sentences are printed in a fixed-width font (Courier Bold on Apple Laser Writer) at 96 pt. The sentences are printed in matte-black ink on matte-white plastic sheets (8.5 × 11 × 0.03 in.). The Michelson contrast of the letters, $(L_{white} - L_{dark})/(L_{white} + L_{dark})$, is 92%, close to the 99% contrast reported for the computer version (Legge *et al.*, 1989). Printed cards were presented at a luminance of approx. 80 cd/m^2 (white parts of the card) produced by fluorescent overhead room light.

Finding the simplest testing procedure

We tested three different presentation methods to find the simplest testing procedure. The cards were either (1) hand-held; (2) mounted on board; or (3) inserted into a self-supporting stand. In each presentation condition, subjects were asked to read aloud the sentence presented on a card while the experimenter noted reading speed and accuracy.

In the hand-held condition, the subject held the card at a distance of 19 cm. Illumination was provided by overhead, fluorescent room lighting. A blank sheet of cardboard was placed over the card prior to each trial. In the board-mounted condition, the subject held a piece of cork board (at a distance of 19 cm), with the card affixed to the board. As with the hand-held condition, illumination was provided by room lighting. Prior to each trial, a blank sheet of cardboard covered the card. In the stand condition, the card was placed in a viewing frame provided by an upright, self-supporting stand. The subject viewed the card at a distance of 19 cm from the stand. A black, opaque shutter covered the card prior to each trial. Illumination was provided by both room lighting and two fluorescent light bulbs placed at the top and bottom of the viewing frame. In each presentation condition, care was taken to ensure that the viewing distance was maintained at 19 cm.

In each condition, the subject was asked to read aloud the sentence on the card as rapidly as possible. The examiner said "go", started a stop watch immediately after uncovering the card, and stopped the watch

*The test also includes a 29th card which contains all 28 sentences in small print (Courier Bold on Apple Laser Writer, 12 pt), black-on-white on one side and white-on-black on the other side. This card can be used to measure reading speed with magnifiers thereby enabling a comparison with reading speeds obtained with the large-print cards.

TABLE 1. Characteristics of 23 low-vision subjects

Subject	Age (yr)	Sex	LogMAR	Diagnosis
A	61	F	1.22	Congenital cataract
B	36	F	0.30	Retinitis pigmentosa
C	41	M	1.70	Corneal opacification
D	46	M	1.00	Macular degeneration
E	71	F	1.30	Macular degeneration
F	45	M	1.22	Leber's disease
G	62	F	1.22	Retinitis pigmentosa
H	31	M	1.30	Macular degeneration
I	39	M	0.70	Optic neuritis
J	43	F	0.30	Diabetic retinopathy
K	67	M	0.51	Optic atrophy
L	30	F	0.70	Aphakia, glaucoma
M	30	F	0.30	Diabetic retinopathy
N	36	M	1.00	Macular pucker
O	41	M	1.00	Histoplasmosis
P	28	M	1.22	Diabetic retinopathy
Q	36	M	0.80	Histoplasmosis
R	55	M	1.30	Diabetic retinopathy
S	53	F	0.89	Cone distrophy
T	53	M	1.10	Congenital cataracts
U	25	M	1.52	Retinitis pigmentosa
V	48	M	1.00	Optic atrophy
W	57	F	0.89	Congenital cataract

immediately after the subject uttered the last word of the sentence. Reading speed was then computed in words/min as the number of words read correctly divided by the time measured with the stop watch. We defined error as words omitted or read incorrectly (e.g. reading "mountain" as "fountain" or "apples" as "apple").

The subject read aloud eight cards (four cards for each contrast polarity) in each of the three presentation conditions. The cards were selected randomly (without replacement) from the set of 28 cards. For each of the 23 low-vision subjects, the three presentation conditions and two contrast polarities were tested in random order.

Comparison with the computer version

For each low-vision subject, we compared reading speeds measured with the printed cards to those measured with the validated MNREAD computer test.

The MNREAD test has been described in detail in Legge *et al.* (1989) and is briefly described here. The test uses simple sentences presented at high magnification on a computer screen. The subject is asked to read the sentence aloud as rapidly as possible. Each sentence,

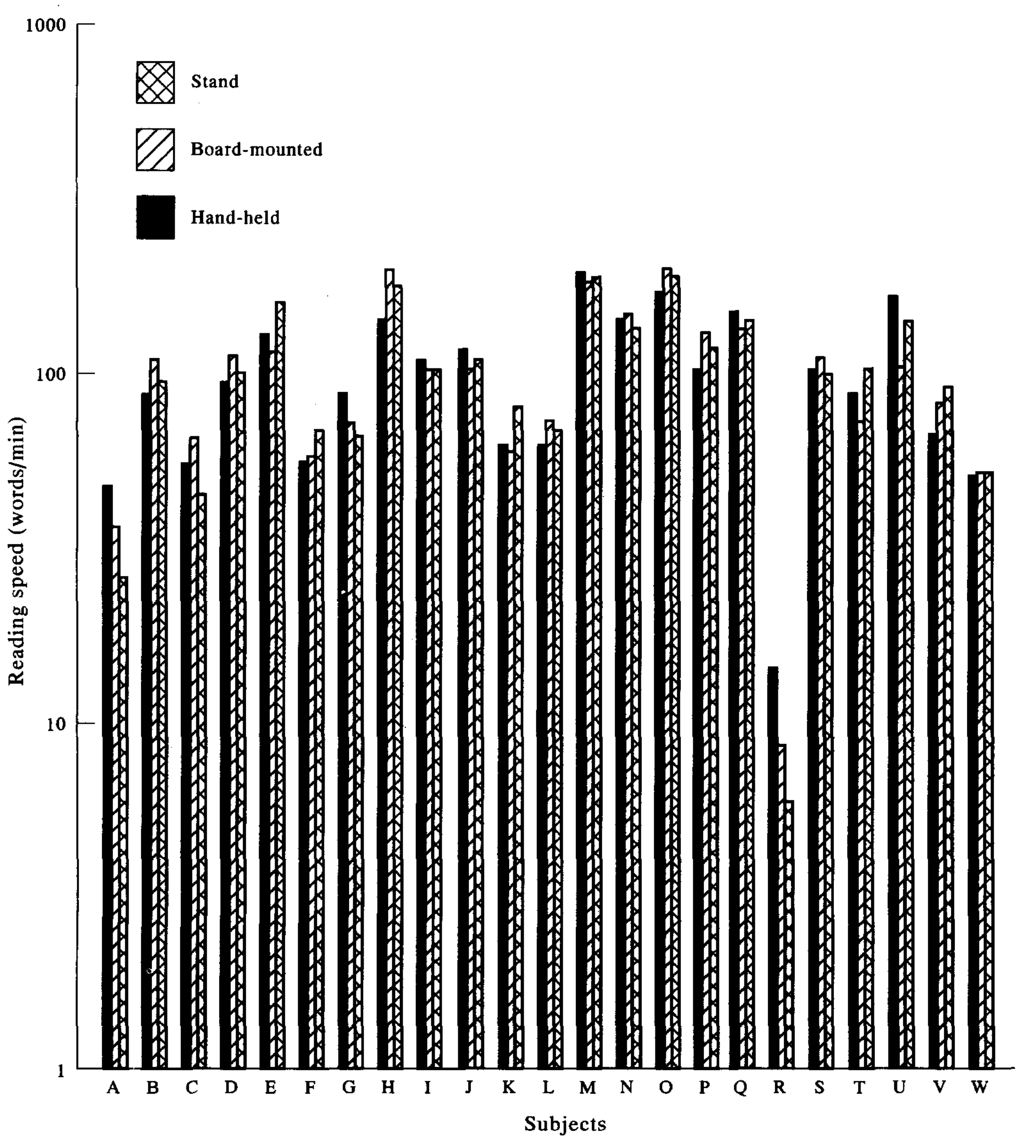

FIGURE 2. Reading speeds obtained for the three conditions for each subject reading black-on-white text.

rendered as black letters on a white background, consists of four lines of 13 character spaces. At a viewing distance of 19 cm, each fixed-width character subtends 6 deg (center-to-center character spacing). This large character size (equivalent to Snellen 20/1440 or logMAR 1.86) lies within the acuity limit of almost all low-vision subjects, thereby enabling these subjects to read near their peak rate. Each sentence was selected at random without replacement from the same pool of 28 sentences described above for use in the printed card tests and was presented for timed exposures. If the subject read the entire sentence, the exposure time was reduced for the next sentence. This procedure continued until the exposure time was short enough so that the subject couldn't complete the sentence. Reading rate was then computed in words/min as the number of words read correctly divided by the exposure time.

Subjects

We studied 23 subjects with low-vision. There were nine women (mean age = 49 yr) and 14 men (mean age = 42 yr). The subjects were either referred to us from the Minneapolis Society for the Blind or selected from our laboratory's low-vision subject roster. Characteristics of these subjects are presented in Table 1.

Diagnosis was derived from a clinical summary obtained from the subject's clinician (ophthalmologist or optometrist). We measured Snellen acuity with the Lighthouse Distance Visual Acuity Test (2nd edn). The entries for LogMAR in Table 1 refer to the highest-acuity eye. All subjects were native English speakers.

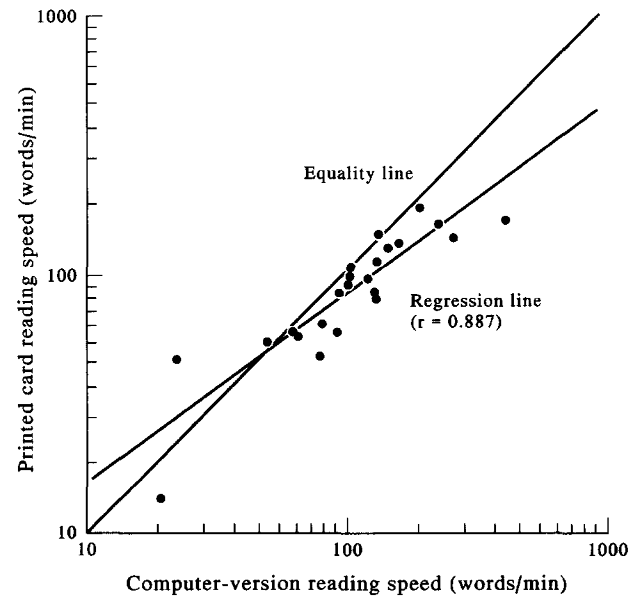

FIGURE 3. A scatter plot of the printed card reading speeds and the computer reading speeds for all the subjects, along with the regression line. Also shown is the equality line, which would be obtained if there were a perfect match between the card and computer reading speeds.

RESULTS

What is the simplest valid testing procedure for presenting the cards? An analysis of variance (within the subjects, repeated measures) indicated no significant difference in reading speed between the three presentation conditions. (Mean reading speeds obtained with the cards either hand-held, mounted on board, or inserted into a self-supporting stand were 82.0, 80.5, and 80.3 words/min respectively.) Figure 2 shows reading speeds obtained for the three conditions for each individual subject. Data presented here are for the black-on-white polarity. (There were no significant differences for the white-on-black polarity.) These results indicate that reading speeds do not depend on the details of the presentation method: The simple hand-held procedure, requiring no extra equipment, yields the same estimates of reading speed as the more complex methods.

Do the printed cards yield the same reading speeds as the computer-based MNREAD? Because there was no significant difference between card presentation modes, we compared the reading speeds obtained with the hand-held method (the simplest method) to those obtained with the computerized test. We found that the printed cards gave estimates of reading speed that were highly correlated ($r = 0.887$) with those of the computer version of MNREAD. Figure 3 shows a scatter plot of the printed-card reading speeds and the computer-based reading speeds for all subjects. Also shown in Fig. 3 is the equality line, which would be obtained if there was a perfect match between the card and computer-based reading speeds. Comparison of the equality line and the regression line indicates that the reading speeds measured with the printed cards are good approximations to the reading speeds measured with the computer-based MNREAD.

Six test–retest correlation measures are computable for four presentations of cards (based on the hand-held condition). These r values ranged between 0.819 (when comparing the second and third presentations across all subjects) and 0.925 (when comparing the first and fourth presentations across all subjects). The mean of these six measures yielded a r value of 0.867. This high test–retest reliability is nearly equal to that for the computer version shown previously to have a test–retest correlation of 0.88 (Legge *et al.*, 1989). These analyses reveal that the intertest correlation (between printed cards and the computer-version) is as great as the intratest correlation for the purpose of estimating test reliability.

How many cards should be used to avoid practice effects within a testing session and to ensure a good estimate of reading speed? Data from the hand-held condition indicated that reading rates, based on results from presentation of the first card, were not significantly different from scores on subsequent cards. The mean reading rate across subjects did not increase monotonically upon repeated testing. These mean reading rates were 80.4 words/min for presentation of the first card, 83.4 words/min for presentation of the second card, 82.0 words/min for presentation of the third card, and 80.9 words/min for presentation of the fourth card. Reading rates were stable across repeated testing, with a correlation between presentation of the first and second cards of 0.884, between the second and third cards of 0.819, and between the third and fourth cards of 0.862. Similarly, there was no significant card-sequence effect for white-on-black presentations.

We note, however, that because the presentation conditions were randomly ordered for each subject, not all subjects were tested in the hand-held mode first. Therefore, some subjects may have benefited from practice on other presentation modes before doing the hand-held part of the experiment.

To address the issue of the appropriate number of cards, we analyzed the variability of the four scores obtained from each subject in the hand-held condition. Estimates of the SDs of the log reading speeds average 0.071 log units across subjects and did not vary systematically with mean reading speed. A value of 0.071 log units corresponds to a SD of 18% of the mean. Therefore, a single card can be used to obtain an estimate of reading speed accurate to within 18% of the mean reading speed. Measurements from additional cards should improve the accuracy of the estimate. As a statistical rule of thumb, the degree of accuracy possible for a given number of cards can be determined by using the following equation for SEM (σ_M): $\sigma_M = \sigma/\sqrt{n}$, where σ is the SD and n is the number of cards tested. By using the above equation, we can determine that using two cards, for instance, will reduce the estimated error to 12% of the mean:

$$\text{given } \sigma = 0.071 \text{ log units; and } n = 2,$$
$$\sigma_M = 0.071 \text{ log units}/\sqrt{2}$$
$$= 0.050 \text{ log units}$$

0.05 log units correspond to about 12% of the mean.

DISCUSSION

Legge *et al.* (1989) described a computer-based test of reading speed called MNREAD. Ahn and Legge (1995) validated this test by showing that it is a fairly accurate predictor of real-world low-vision reading performance with magnifiers. In the present paper, we have described a version of the MNREAD test using printed cards. Reading speeds measured with the cards correlate highly with scores from the computer version. The card test is simple to administer and requires no extra equipment. In addition, we showed that an estimate of reading speed from a single card is stable (no significant practice effects) and quite accurate (SD approximately equal to 18% of the mean).

Vision loss has an impact on many important daily activities. Ophthalmologists, optometrists and rehabilitation specialists must often make decisions or recommendations based on their assessment of the impact of vision loss on real-world function. Standard clinical measures such as acuity or diagnosis are poor predictors of performance on real-world tasks such as reading or mobility. This is probably because these tasks involve much more than vision (e.g. effects of cognition, motivation, and motor control). Our approach to dealing with this problem has been to develop a standardized reading test, suitable for use by eye-care specialists. There are three major questions that arise in the development of any test of the visual component of reading.

Is the reading test sensitive to visual factors? As described in the Introduction and elsewhere (Legge, Pelli, Rubin, & Schleske, 1985a; Legge *et al.*, 1985b; Legge, Rubin, & Luebker, 1987; Rubin & Legge, 1989), a suitably designed test of reading speed is sensitive to text factors such as character size, field size, or contrast, and to ocular factors such as central-field loss or reduced contrast sensitivity. As such, reading speed has proven to be a useful measure for research studies. The original MNREAD test, on computer, is one means for measuring reading speed.

Does the test validly predict real-world function? Clinicians are often more interested in performance outside the laboratory. Ahn and Legge (1995) showed that the MNREAD test could be used to predict how well low-vision patients read regular text with their magnifiers in actual practice. This indicates that a standardized test of reading speed can assess the impact of vision loss on real-world reading performance.

Is the test convenient for clinical use? The original MNREAD test runs on a computer with a particular hardware configuration.* In principle, the test can be replicated quite easily. In practice, appropriate computers or technicians to reconfigure equipment are often not available. Computers are not as portable or convenient to use as charts or cards. For this reason, we asked whether useful measurements of reading speed could be obtained from a test using printed cards. The results of the present paper indicate that the answer is yes.

In short, we conclude that: (1) reading speed is a good performance measure because it is sensitive to visual factors; (2) a simple clinical test of reading speed can provide information about real-world reading; and (3) printed cards can be used for measuring reading speed.

There are several possible uses for a printed-card test of reading speed, including evaluation of changes in reading performance due to eye therapy or rehabilitation training, estimation of potential performance with suitable magnifiers (cf. Ahn & Legge, 1995), and prescription of magnifiers or other low-vision reading aids. In the case of prescription, reading speed measured with the large-print cards could be compared with reading speed measured with the prescribed magnifier and regular text. For example, suppose a patient reads the printed cards at 100 words/min but reads small-print text with a magnifier at only 40 words/min. The difference indicates that there is room for improvement, either with further training or with an alternative magnifier. To make such comparisons, we have included a small-print card (12 pt print) that contains all 28 sentences from our set of 28 large-print cards (see Methods).

*We make the software available to interested individuals.

The empirical results of the present study may be useful in designing other reading tests. For example, in a separate project, we have developed a reading-acuity chart (Mansfield, Ahn, Legge, & Luebker, 1993). This chart contains sentences (very similar to those on the printed cards) in a logarithmic progression of print sizes (steps of 0.1 log units). This chart can be used to measure reading acuity and also reading speed as a function of print size. The chart has only one sentence at a given print size.* But the findings reported in this paper—lack of practice effects and good accuracy of measurement from a single sentence—indicate that this may be sufficient for estimating reading speeds.

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*The chart is called the MNREAD Acuity Chart. Although each physical chart has only one sentence at a given print size, there are two distinct sentence sets on two, otherwise identical, versions of the chart.

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