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MEASURING BRAILLE READING SPEED WITH THE MNREAD TEST

Gordon E. Legge, Cindee Madison & J. Stephen Mansfield

Minnesota Laboratory for Low-vision Research
University of Minnesota

75 East River Road
Minneapolis, MN 55455

Corresponding Author:

Gordon E. Legge

Phone (612) 625-0846
Fax (612) 626-2079
Email legge@eye.psych.umn.edu

ABSTRACT

Braille is an important form of written communication for many visually disabled people. Perceptual factors limiting Braille reading speed are poorly understood, partly because of the lack of accurate, standardized testing methods. In this paper, we describe a new, standardized method for measuring Braille reading speed, adapted from the MNREAD test for print reading speed. The key principles include the use of well-characterized text samples composed of simple vocabulary, presented in a standard spatial layout, with sample length measured as the number of characters.

We used the MNREAD test to study Braille reading speed in 44 experienced participants. The median reading speed was 124 words per minute, equivalent to 7.5 characters per sec. When measured in words per minute, Grade 1 reading speed was 71.5% of Grade 2 reading speed. This difference could be accounted for by the difference in the number of characters. This finding argues for the use of characters per sec as an appropriate metric for measuring Braille reading speed.

A comparison of Braille and print reading speed shows that when viewing conditions are matched (i.e., only one character available at a time) and the methods of measurement are the same, the characteristics of reading speed are qualitatively and quantitatively similar.

Key Words: Braille, reading speed, tactile acuity

INTRODUCTION

Modern computer technology has helped bring about a renaissance in Braille. Any digital document can be passed through translation software and sent to a Braille printer or Braille display. But many aspects of Braille reading are poorly understood including reading speed (Foulke, 1982). Accurate and standardized measures of reading speed would be useful in rehabilitation, education, and research. A principal goal of this paper is to report reading speeds obtained with a standardized and reproducible method.

The MNREAD Acuity Chart (Lighthouse Low Vision Products, Inc., Long Island City, New York) was developed as a standardized method for measuring visual reading speed. It has been used in both normal and low-vision applications. A major goal of this paper is to describe how we adapted the MNREAD test for measuring Braille reading speed.

Fig. 1. Illustration of the MNREAD Acuity Chart. This chart is used for measuring three characteristics of reading vision--reading acuity, critical print size, and maximum reading speed.

The MNREAD Acuity Chart, illustrated in Fig. 1, contains 19 sentences which vary in print size in steps of 0.1 log units (~ 26%) from Snellen 20/6.3 to 20/400. Each sentence contains exactly 60 characters on three lines, formatted into a block of text with a fixed aspect ratio. The vocabulary is composed of high-frequency words from children's books. The chart is used at a standard reading distance of 40 cm, but the log progression means that the chart is easily recalibrated for viewing distances other than 40 cm.

Participants are timed with a stopwatch as they read each sentence aloud. Reading time is easily converted to reading speed in words/minute. Data from the chart are plotted as reading speed vs. print size.

We also created a set of 30 cards containing MNREAD sentences at a single large print size (Snellen 20/800 at 20 cm distance), sufficient magnification for most people with low vision. Ahn, Legge & Luebker (1995) showed that a good estimate of reading speed could be obtained from a single card and showed no practice effects from one card to the next.

We have designed a Braille version of the MNREAD test to measure reading speed. Like the large-print MNREAD cards just described, there is no variation in character size (i.e., only standard size Braille characters are used).

Braille reading speed is a controversial topic. The conventional estimate of mean reading speed of adults is about 100 words/minute (Foulke, 1982; Lorimer & Tobin, 1979), but others have claimed that experienced Braille readers achieve rates between 200 and 400 words/minute (Grunwald, 1966; Stocker, 1995). In a recent study, Knowlton & Wetzel (1996) measured speeds for experienced Braille readers who were asked to read as quickly as they could. The mean speed was 136 words/min with a range of 65 to 185 words/min.

Some of the discrepancy in estimated speeds across studies may be due to differences in text materials, measurement methods and definitions of reading speed. The MNREAD test has the potential to address these problems by providing an accurate, well-defined and reproducible means for measuring Braille reading speed.

Although reading speed (print or Braille) has traditionally been measured in words per minute, other metrics may provide more reliable measures. Carver (1990) argued that measurement of print reading speed in words/minute is problematic because mean word length varies from passage to passage, increasing with text difficulty. He showed that characters/sec is a better metric because participants' reading speeds are constant across text sources when measured in this unit.

If Carver's analysis holds true in Braille, a person's speed for different types of text would exhibit less variability if measured in characters/sec rather than words/min.

Adopting the character as the unit of measure would also be consistent with the view that the cell is the perceptual unit in Braille reading (Nolan & Kederis, 1969).

After describing the Braille MNREAD test, we will demonstrate its application in testing 44 experienced Braille readers. These tests will address three factors that may influence Braille reading speed: Grade 1 vs. Grade 2 code, context, and individual differences.

Grade 1 and Grade 2 Braille.
Direct one-to-one translation from print letters to Braille letters is called Grade 1 Braille. The Grade 1 version of the MNREAD test consists of direct Braille transcriptions of the set of MNREAD sentences in the same format as the printed test--3 rows, with a total of 60 characters.

The standard Braille code, called Grade 2, contains 192 contractions. The contractions reduce the number of characters in text by about 25% (see Table 2 below). We have created a version of the MNREAD test in Grade 2, using the same set of sentences, but a corresponding reduction in the number of characters.

In adapting the MNREAD test to Braille, we had to consider the difference between the Grade 1 version of the test in which Braille and print sentence formats are identical, and the Grade 2 version in which the number of characters per sentence varies and is less than the 60 characters in the printed sentences.

Nolan & Kederis (1969) compared word-recognition times for contracted and uncontracted words of high and low familiarity. Their general conclusion was that contractions slowed recognition, but their results were complicated by an interaction; contractions resulted in faster recognition for words of high familiarity, and slower recognition for words of low familiarity. Since the MNREAD sentences are composed of high-frequency vocabulary, Nolan & Kederis's results would suggest faster reading speed for contracted MNREAD sentences.

We have tested a simple model relating reading speed of Grade 1 and Grade 2 Braille. The model, extrapolated from Carver's analysis of print reading speed, predicts that the Grade 1 and Grade 2 speeds are equal when measured in characters per second.

Context Effects. Nolan & Kederis (1969) studied context effects in Braille word recognition and once again found an interaction with familiarity; words of high familiarity were recognized more rapidly in context, but words of low familiarity were recognized more slowly. Because the MNREAD sentences contain familiar words, we expect the contextual support to enhance reading speed.

We evaluated context effects by comparing Braille reading speed for the MNREAD sentences and for “scrambled” versions of the sentences containing the same words but in random word order.

Individual Factors. We considered the influence on Braille reading speed of several individual variables: tactile acuity, finger size, age at testing, age at which Braille was learned, and number of years reading Braille. Only the age at which Braille was learned proved to be significant.

METHODS

Participants

Forty-nine Braille readers participated in the study. Five were removed from the data analysis--three because of incomplete data, one because a pre-existing injury prevented use of the preferred reading hand, and one because of a large number of reading errors.

Of the forty-four participants in the data analysis, 10 were male and 34 were female. Three had low vision and could read very large print (acuities of 20/400 or less), 11 had light perception or very coarse pattern vision (insufficient to read any print), and 30 had no residual vision.

We found a lack of congruence between handedness defined by Braille reading and by a standard test (Edinburgh Handedness Inventory, adapted for use by blind people). When forced to choose, 21 of the participants preferred to read Braille with their left hand. Of these, 2 were left handed, 17 right-handed, and 2 ambidextrous on the Edinburgh. Twenty-three of the participants preferred to read Braille with their right hand. Of these, 4 were left handed, 18 right handed, and 1 ambidextrous on the Edinburgh. Cross-overs in handedness for Braille reading have been noted elsewhere (cf., Hermelin & Connor, 1971; Millar, 1984).

Participants were recruited from the Twin Cities area of Minneapolis and St. Paul, Minnesota, by word of mouth and through the help of local organizations for the blind. The participants were paid for their time. Prior to testing, they were informed about the nature of the research and signed a consent form.

Table 1 summarizes group characteristics of these 44 participants.

Table 1: Group characteristics of the 44 Braille readers

	Mean	S.D.	Range
Age when Tested (yrs)	45.0	15.5	18 to 74
Age Braille was Learned	8.8	8.4	3 to 36
Years Reading Braille	36.0	17.5	2 to 69
Tactile Acuity	-0.269	0.040	-0.3‡ to -0.088

‡ -0.3 was the best possible score on the chart corresponding to no errors on the smallest character line. Six of the participants scored -0.3 on the chart.

We consider the participants experienced Braille readers because of the number of years reading (minimum of two), and amount of regular reading time (minimum of an hour per week). All knew and preferred to use Grade 2 Braille. All the participants relied on Braille for vocational, recreational or other activities of daily life.

All participants reported having normal healthy hands. Tactile acuity of the preferred index finger for Braille reading was tested on a tactile letter-acuity chart. This chart, developed in our lab, is described in Appendix 1. Although sighted participants show a steady age-related decline in tactile acuity on this chart, consistent with previous findings (Stevens, Foulke, & Patterson, 1996), our Braille reading participants retained high tactile acuities at all ages tested. The details of this important age-related difference in tactile acuity between sighted and Braille-reading participants is described by Madison & Legge (in preparation). All the participants in the present study had high tactile acuity (see Table 1).

Although we cannot be sure of the representativeness of our sample of Braille readers, we estimate that our sample contained between 6% and 30% of the total relevant population. We arrived at this estimate as follows. A lower bound on the number of adult Braille readers in the United States is about 15,000, the number served by the National Library Service for the Blind and Physically Handicapped (Judith M. Dixon, personal communication, Nov. 4, 1999). An upper bound estimate is 85,000 (JVIB, 1996), but this estimate includes people who use Braille only for labeling or other identification tasks. Our sampling area, the Twin cities, contains about 1% of the U.S. population. Scaling the numbers just given, we estimate that there are between 150 and 850 Braille readers in the Twin Cities area of whom we recruited 49.

Test Materials and Procedure

Fifty MNREAD sentences (38 of which appear on the two versions of the MNREAD Acuity Chart, plus 12 having the same characteristics) were used in testing. Eight additional sentences were used to familiarize participants with the test material. The 50 test sentences were converted to Grade 1 and Grade 2 ASCII Braille format using Duxbury Braille Translator for MS-Windows software. They were then embossed on 11x11.5 inch Braille paper with an interpoint (double-sided) Juliet Braille printer (Enabling Technologies Co, Jensen Beach FL).

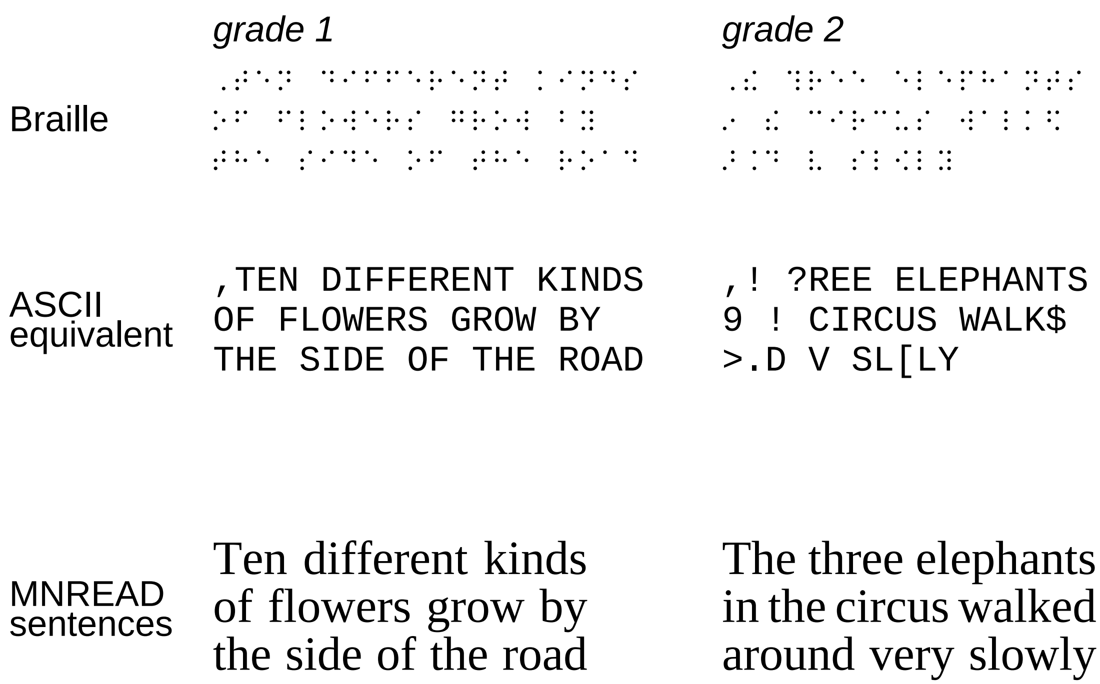

Fig. 2 illustrates Grade 1 and Grade 2 versions of two MNREAD sentences, their computer codes (ASCII Braille equivalents), and printed MNREAD versions. All 50 MNREAD sentences, and their Grade 1 and Grade 2 ASCII Braille equivalents can be downloaded from our web site at <http://vision.psych.umn.edu/www/mnread2000/braille.html>.

A single piece of Braille paper contained 10 MNREAD sentences, 5 on the front and 5 on the back. As shown in Fig. 2, each sentence was formatted onto three single-spaced lines. A number from 1 to 5 (preceded by a number sign) was positioned immediately above the first two characters of each sentence. This number was used as a starting position for the fingers prior to a test trial.

The sentences were separated on the page by two empty lines.

Grade 1 sentences were derived from printed MNREAD sentences on a character-for-character basis (except for a capitalization marker that appeared at the beginning of each Braille sentence), and line-for-line basis. Like their printed counterparts, the Grade 1 sentences all had three lines and 60 characters, where spaces between words, and end-of-lines count as characters. The 60 characters in the printed MNREAD sentences do not always split evenly into 20 characters per line; because some printed letters are wider than others, maintaining equal line widths sometimes results in unequal numbers of letters per line. Likewise, the Grade 1 MNREAD sentences sometimes had unequal numbers of letters on their three lines.

Grade 2 sentences were derived from Grade 1 sentences by including the Braille contractions, but retaining the same number of words on each line. As a result the Grade 2 sentences had three lines, but typically fewer characters and a more ragged right margin than their Grade 1 counterparts.

We counted the number of words, characters, and dots for all 100 Braille sentences using a Perl computer program.

An additional 100 “sentences” were produced by scrambling the word order randomly in the 50 Grade 1 and 50 Grade 2 versions of the MNREAD sentences.

A single test trial consisted of timing participants as they read aloud a single sentence. They were instructed to read as quickly and accurately as possible.

Prior to the trial, participants placed their reading fingers on the sentence’s number. They were instructed not to “look ahead.” After a countdown and GO signal, the experimenter started a stopwatch and the participant began reading aloud. The experimenter stopped timing after the participant said the last word. The raw data for each trial consisted of reading time and number of errors. From these data, reading speeds could be computed in words, characters, or dots per unit time.

Words that were missed or read incorrectly were counted as errors. Errors were rare; in the Regular reading condition (see below) consisting of 10 sentences, 31 participants made no errors, 7 made one error, 5 made 2 errors, and one made 3 errors. Error rates were slightly higher in the other conditions. Errors were taken into account in computing reading speed, but the data in this paper would be little affected had we entirely ignored errors.

Appendix 2 explains the relationship between reading speed in words per minute and characters per second for Grade 1 and Grade 2 Braille, and the method for correcting for errors.

Design

Each participant was timed on 10 sentences in each of 5 conditions. For one block of 10 Grade 2 sentences, participants were instructed to use their normal reading strategies. This condition was termed Regular Reading.

The remaining four blocks consisted of a 2 x 2 cross: Grade 1 / Grade 2 x normal / scrambled sentences. In these four blocks, we enforced uniformity of strategy. Participants were instructed to use their preferred hand only. In these conditions, all subjects read with the index finger of their preferred hand (21 left and 23 right).

Because the 50 sentences were printed in all formats, the blocks of sentences were rotated through the five conditions so that no two participants read the same sentences in the same formats.

Prior to testing on the five blocks, participants read two sentences of all types for practice. For half the participants, the Regular Reading block came first, and for the other half it came last. The other 4 conditions (24 possible orderings) were rotated through the 44 participants.

RESULTS AND DISCUSSION

Text Statistics: Number of Words, Characters, and Dots

Before describing the reading-speed data, we will compare some of the statistical properties of the MNREAD sentences to other texts.

Table 2a. Word, character, and dot counts

	Printed Text		Grade 1 Braille			Grade 2 Braille		
Source*	Words†	Chars‡	Words	Chars	Dots	Words	Chars	Dots
MNREAD	597	3,000	597	3,050	7,226	561	2,200	4,819
DNR	5,123	30,757	5,177	32,159	76,012	4,912	25,975	60,127
Norman	6,870	41,511	6,915	42,379	101,881	6,569	32,248	74,560
Alice	26,458	142,508	26,660	149,416	341,362	25,443	112,254	242,608
Starr	65,090	382,926	65,566	411,496	963,741	62,912	337,608	760,654
Grimm	281,047	1,442,477	282,871	1,469,443	3,378,562	269,681	1,061,193	2,305,859
TOTAL	385,185	2,043,179	387,786	2,107,943	4,868,784	370,078	1,571,478	3,448,627

**MNREAD*, the 50 MNREAD sentences; *DNR*, Wisconsin boating regulations (extracted from Wisconsin Department of Natural Resources Bureau of Law Enforcement web pages); *Alice*, "Alice's adventures in wonderland" by Lewis Carroll (The Millennium

Fulcrum Edition 3.0); *Starr*, Extract from the Starr Report. *Norman*, Chapter 1 from "The Invisible Computer" by D.A. Norman. MIT Bradford Books, 1998; *Grimm*, Grimm's Fairy Tales (Project Gutenburg).

† number of words (i.e., strings of letters, numbers, and punctuation delimited by spaces or a newline)

‡ number of characters including punctuation, spaces, and newlines. Prior to counting, consecutive spaces and/or newlines were reduced to a single space. Table 2b. Ratios of word, character, and dot counts for printed text, Grade 1 Braille, and Grade 2 Braille

Source	Print chars/ Print words	Gr1 chars / Print chars	Gr2 chars/ Print chars	Gr2 chars / Gr1 chars	Gr2 dots/ Gr1 dots	Gr1 dots/ Gr1 chars	Gr2 dots/ Gr2 chars
MNREAD	5.02	1.02	0.73	0.72	0.67	2.37	2.19
DNR	6.00	1.05	0.84	0.81	0.79	2.36	2.31
Norman	6.04	1.02	0.78	0.76	0.73	2.40	2.31
Alice	5.39	1.05	0.79	0.75	0.71	2.28	2.16
Starr	5.88	1.07	0.88	0.82	0.79	2.34	2.25
Grimm	5.13	1.02	0.76	0.72	0.68	2.30	2.17
OVERALL*	5.30	1.03	0.77	0.76	0.71	2.31	2.19

*Overall ratios are based on counts summed across all sources, therefore, the overall values are dominated by the longer sources.

Table 2 presents data from the corpus of 50 MNREAD sentences in comparison with five other texts available in electronic form on Internet sites. The first part of the table shows word and character counts for printed, Grade 1 and Grade 2 versions of the text, and dot counts for the Grade 1 and Grade 2 Braille versions. The second part of the table shows some ratios. Spaces and new lines count as characters.

The MNREAD sentences contain 5.025 characters/word (~ 11.9 words per 60-character sentence), compared with a range of 5.13 to 6.04 characters/word for the other texts. The low value for MNREAD reflects the use of simple children's vocabulary. Our results are consistent with the general finding that mean word length increases with text complexity (cf., Carver, 1990).

Although Grade 1 Braille is nearly a character-for-character transcription from print, all the texts in Table 2 have more Grade 1 characters than printed characters, ranging from 1.67% more for MNREAD to 7.46% more for the Starr Report. Capitalization and number signs in Grade 1 text account for most of the difference. MNREAD text contains no numbers, but the 50 extra characters in the Grade 1 version are the capitalization markers for the 50 sentences. These capitalization markers were not included in the reading speed calculations.

The reduction of text length for Grade 2 relative to Grade 1 is represented by the Grade 2 / Grade 1 character ratio. The value is 72% for MNREAD, virtually identical for Grimm, and larger for the other texts (maximum 82% for Starr). This ratio appears to vary with text complexity, so that Grade 2 text with simple vocabulary is more contracted than technical text. Accumulated across all our text samples, the Grade 2 / Grade 1 character ratio is 74.6%.

The difference between Grade 1 and Grade 2 is slightly greater when measured in number of dots rather than number of characters. Grade 2 MNREAD has 66.7% of the number of dots of Grade 1 MNREAD. Accumulated across all our text samples, the Grade 2 / Grade 1 dot ratio is 70.8%.

MNREAD text averages 2.37 dots/character for Grade 1 and 2.19 dots/character for Grade 2. These figures are within the narrow range of dot densities observed for the other texts. The lower dot density in Grade 2 is due to the higher proportion of spaces in Grade 2 relative to Grade 1.[1]

[1] Because Grade 2 preserves most of the spaces found in Grade 1 while reducing the number of non-space characters, the proportion of spaces in Grade 2 is greater and the dot density lower. A few of the spaces in Grade 1 are deleted in Grade 2 such as those between the contracted forms for "of the" or "to the".

Overall, the statistical differences between the MNREAD text and the other text samples are small, with some of the differences being due to the simple vocabulary used in MNREAD.

Regular Reading Condition

"Regular reading" refers to the condition in which participants were allowed to use both hands and their preferred reading strategy.

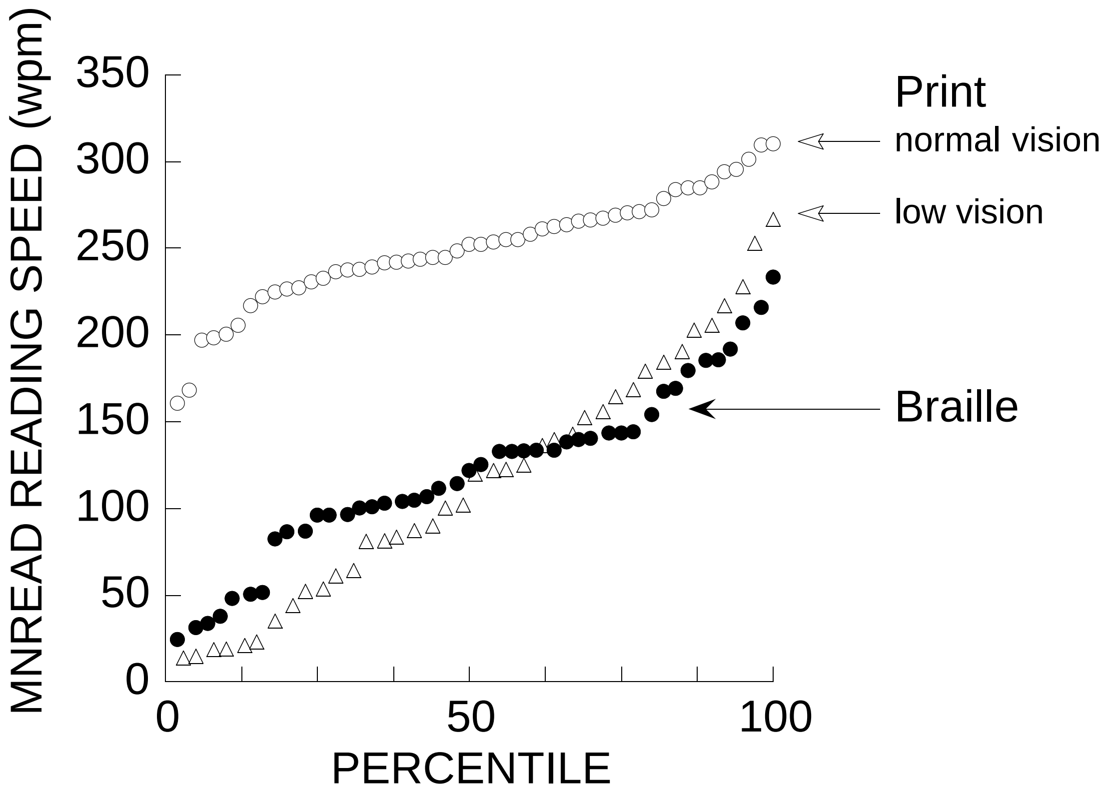

Fig. 3. Reading speeds (in words per minute) are shown for three groups--44 Braille readers (filled circles) from this paper, and groups of 50 normally sighted (open circles) and 39 low-vision (open triangles) print readers studied by Mansfield et al. (1996). The Braille and print reading speeds were measured with nearly identical MNREAD sentences and procedures. The graph shows a reading speed for each participant plotted against their percentile position within their group.

Reading Speeds. The filled symbols in Fig. 3 show the regular reading speeds for all 44 participants. (Print reading speeds for groups of normally sighted and low-vision participants are also shown, and will be discussed later.) Reading speeds are plotted against each individual's percentile speed within the group. The mean of ten MNREAD sentences is shown for each Braille reader. In most cases, the standard errors are smaller than the plotted symbol; they ranged from 1.54 to 12.57 wpm.

The distribution of Braille reading speeds in Fig. 3 clusters into 3 groups of participants: a slow group of seven (24 to 51 wpm), an intermediate group of 27 (82 to 144 wpm) and a fast group of 10 (154 to 232 wpm).

The median speed (the 50^{th} percentile in Fig. 3) was 124 wpm, with a range from 24 to 232. The corresponding speeds in characters/sec were: median 7.5 cps, range from 1.5 to 14.4 cps.

Given the density of 2.19 dots/character for Grade 2 MNREAD (Table 2), the corresponding median dot reading speed is 16.4 dots/sec. Translated into an hour a day of Braille reading over 50 years, this corresponds to about a billion dots on the fingertip.

Each Braille reading speed in Fig. 3 is the mean speed for 10 MNREAD sentences. Analysis of variance showed no significant practice effects, that is, no significant variation in reading speed from the first to last sentence in the set of 10.

Test Precision. The precision of reading-speed measurement from a single MNREAD sentence can be estimated as follows (see also Ahn, Legge & Luebker, 1995). For each participant, we estimated the standard deviation of log reading speeds across the 10 sentences. (We used log reading speeds because the variances were more nearly homogeneous.) The mean standard deviation was 0.0625 log units (base 10), equivalent to saying that the standard deviation is 15% of the mean. This is the precision of reading-speed estimates from a single MNREAD sentence. Using more sentences improves precision (reduces the error in the estimated mean) to $0.0625 / \sqrt{n}$ log units, where n is the number of sentences used.

Comparison of Braille and Print reading Speeds. Fig. 3 also shows distributions of print reading speeds for a group of 50 normally sighted participants and a group of 39 low-vision participants, most of whom had macular degeneration (data from Mansfield, Legge

& Bane, 1996). These speeds were obtained from the MNREAD Acuity Chart using materials and methods almost identical to those used for measuring Braille reading speed.[2]

The median for the normally sighted participants was 251 wpm, compared to 124 wpm for the Braille readers. But notice that the subgroup of fast Braille readers had speeds that match or exceed some of the normally sighted print readers.

Why is Braille reading usually slower than print reading? Foulke (1991) has argued that Braille reading is slow compared to print reading because only about one character is recognized at a time. If so, we might expect Braille reading speed to be equivalent to print reading speed when only one print character is visible at a time. Legge, Pelli, Rubin & Schleske (1985) measured print reading speed as a function of the number of characters simultaneously visible on a display in which text drifted horizontally across the screen. For windows wider than 4 characters, reading speed was almost independent of window size, but for less than 4 characters, reading speed decreased as the square root of the number of visible characters. There was an approximate two-fold reduction in reading speed for a one-character window compared to a 4-character window. If Braille reading is equivalent to print reading with a one-character window, the results of Legge et al.(1985) would predict a factor of two difference between Braille reading speed and print reading speed. This is almost exactly the difference in the median speeds in Fig. 3 (124 and 251 wpm). This finding supports Foulke's view that Braille reading speed is limited by a tactile window in which one character is recognized at a time. (This nearly exact quantitative agreement may be fortuitous. The comparison in Fig. 3 is between print and Grade 2 reading speeds. In the preferred metric of characters/sec, the difference is substantially greater than a factor of two.) Loomis Klatzky & Lederman (1991) have also shown that the recognition of tactile line drawings has the same latency and accuracy as visual recognition through a window one finger in size.

The median reading speed of the group of low-vision participants was 111 wpm with a range of 13 to 264. The distribution is very similar to the distribution of Braille reading speeds.

Effects of Braille Code and Context

[2] The major difference in the print reading study was that print size varied across trials; but the print reading speeds in Fig. 3 are "maximum reading speeds" based on sentences in which print size did not limit performance. As another potential difference, it is possible that the upper end of the distribution of print reading speeds was attenuated by speed of talking. (Recall that the test sentences are read aloud.) This limitation is less likely to hold for low-vision print readers or Braille readers for whom the reading speeds are lower. Also note that the print reading speeds in Fig. 2 are about 19% higher than the corresponding values in Mansfield et al. Because we used the wpm metric in the current paper rather than the SLwpm metric (see Appendix 2 of the current paper.)

We compared the effects on reading speed of the Braille code (Grade 1 or Grade 2), and the effect of context (normal vs. scrambled sentences). For these conditions, all participants read with their preferred hand only.

Table 3: Preferred hand reading speeds for Grade1 and Grade 2 combined across context.

	wpm		cps		dps	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Grade 1	57.08	25.65	4.86	2.18	11.50	5.16
Grade 2	80.34	34.85	4.97	2.15	10.80	4.72

Table 3 shows mean reading speeds for Grade 1 and Grade 2 (combined across context condition), expressed in words per minute (wpm), characters per second (cps), and dots per second (dps). When expressed in wpm, Grade 1 reading speed is substantially slower than Grade 2 reading speed; the ratio is 71.5%. This ratio is almost identical to the Grade 2 / Grade 1 character count ratio for MNREAD text (Table 2). But expressed in cps, the reading speeds are almost identical; the Grade 1 / Grade 2 ratio is 0.979. Similarly, the reading speeds are close in dots per sec; the ratio is 1.063. In short, the difference in reading speeds between Grade 1 and Grade 2 almost entirely disappears when speed is expressed in cps or dps.

Our findings are consistent with the prediction, extrapolated from Carver's finding for print reading, that the difference in Grade 1 and Grade 2 reading speeds is explained by the difference in character counts. This result is also consistent with the view that Braille reading speed is limited by the number of characters (or dots) that can be processed per unit time.

Context has an effect. Speeds for the normal sentences were faster than for the scrambled sentences (31% faster for Grade 1, and 40% faster for Grade 2). This finding is consistent with the findings of Nolan & Kederis (1969) on Braille word recognition.

We conducted within-subjects repeated measure 2 x 2 analyses of variance on reading speeds (Grade 1 vs. Grade 2) and context (normal sentences vs. scrambled sentences). These ANOVAs were done separately for reading speed in wpm and cps. In both cases, there was a significant main effect of context: in wpm, ($F_{1,43}$= 199, $p < .0001$), and in cps, ($F_{1,43}$= 192, $p < .0001$). For reading speed in wpm, there was a significant main effect of Braille code ($F_{1,43} = 283$, $p < .0001$), but not when speed was measured in cps. There was a small but significant interaction such that the context effect was slightly greater for Grade 2 than Grade 1: in wpm ($F_{1,43} = 64$, $p < .0001$), and in cps, ($F_{1,43} = 15$, $p < .0001$).

We note that the Regular Reading condition (in which participants were free to use both hands and their preferred strategy) yielded reading speeds that were significantly faster (t= 8.25, $p < .001$) than reading speed with the preferred hand only. On average, the difference was 28%. The ratio of two-handed to one-handed speeds ranged from 0.8 (one hand faster than two) to 2.0 (two hands twice as fast as one.)

The 28% speed advantage for two vs. one hand that we found is similar to the 32.3% advantage measured by Bertelson, Moustly & d'Alimonte (1985). They videotaped the hand movements of Braille readers. They observed that for most two-handed reading, the right hand finished one line while the left hand retraced to the beginning of the next line. They attributed a portion of the two-handed speed advantage to savings in retrace time. From their Table 4, we computed that this factor could account for a 16% speed advantege. Bertelson et al. attributed the rest of the advantage to simultaneous reading of the end of one line with the right hand and the beginning of the next line with the left hand, but Millar (1987) has disputed this simultaneous processing.

Individual Factors

The distribution of reading speeds across our participants was quite broad, covering almost a factor of ten. For the Regular Reading condition, the standard deviation is 43.2% of the mean reading speed, measured in characters per second. Although we did not select our sample of subjects with the intent of assessing individual factors, we have examined our data to search for predictors of this variability.

We computed the correlations between Braille reading speeds and several individual factors. The only significant correlation was with the age at which Braille was learned (r = .64, $p < .02$). Our subgroup of the 10 fastest readers all learned Braille between the ages of 3 and 7 (mean 5.1). Our seven slowest readers learned Braille at the ages of 36, 10, 36, 24, 35, 6, and 21 years (from slowest to fastest respectively).

There were no significant correlations between Braille reading speed and tactile letter acuity, finger size, chronological age, and number of years reading Braille. It should not be concluded that these factors have no impact on Braille reading speed, but only that the variation within our participant sample cannot be explained by these factors. For instance, high tactile acuity is likely to be crucial for Braille reading, but all of our participants had high acuity.

CONCLUSIONS

In this paper, we have described a standardized method for measuring Braille reading speed. Although we have framed the description as an adaptation of the MNREAD method, the key principles are quite general. They include the use of well-characterized text samples composed of simple vocabulary, presented in a standard spatial layout, and equated for length in characters. We also advocate a procedure in which participants are asked to read as quickly and accurately as possible and in which scoring takes errors into account.

We used this method to study Braille reading speed in 44 experienced participants. We found a wide range of reading speeds with a median of 124 wpm, equivalent to 7.5 cps. This value is close to measurements for print when speed is limited by use of a one-character-wide window. It seems likely, therefore, that perceptual factors limiting reading speed in Braille and print, viewed through a one-character window, are similar.

We compared speed for Grade 1 and Grade 2 Braille. Our analysis showed that the speed advantage for Grade 2, when measured in words/minute, is accounted for by the difference in the number of characters. Grade 1 and grade 2 speeds are virtually identical when measured in characters per sec. This finding argues for the use of characters per sec as an appropriate metric for measuring Braille reading speed. Consistent with the “window” argument above, this finding also suggests that Braille reading speed is limited by the number of characters that can be recognized per unit time.

Although we did not select our sample of participants to span a wide range of individual factors, we did discover a significant correlation between reading speed and the age at which Braille was learned. Like some other language-related skills, highest achievement in Braille reading may require early learning.

Our analysis leads us to the general view that Braille reading is remarkably similar to print reading. When conditions are matched and the methods of measurement are the same, the characteristics of reading speed are qualitatively and quantitatively similar.

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APPENDIX 1: TACTILE ACUITY CHART

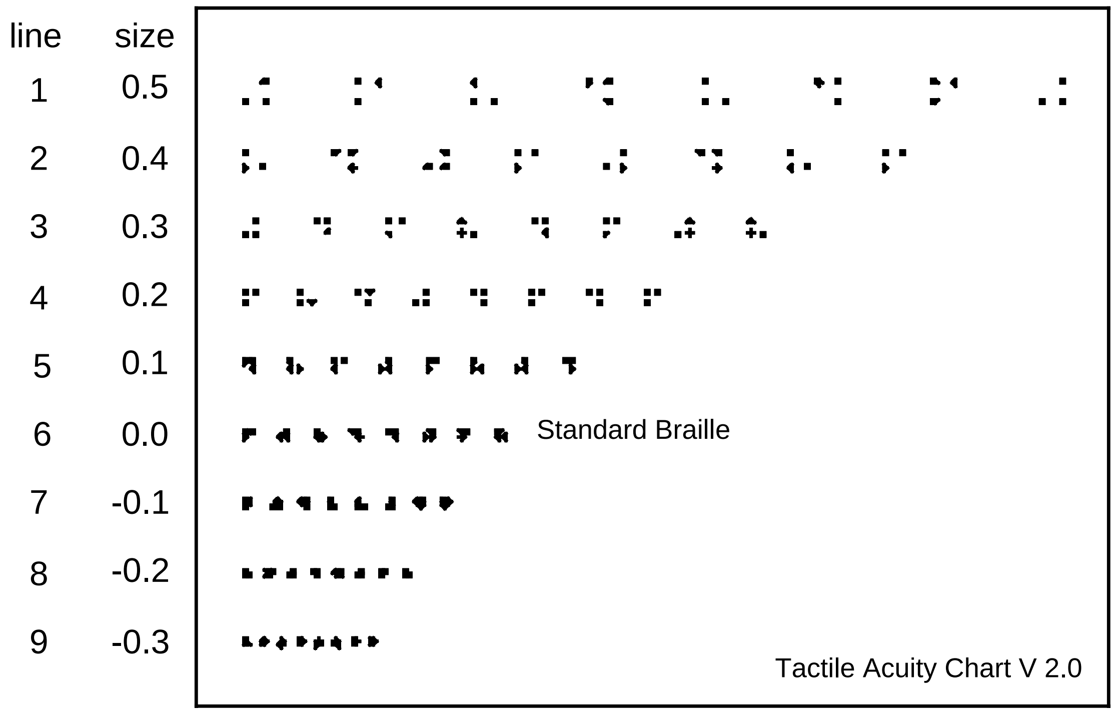

Fig. 4. Illustration of the chart we used for measuring tactile letter acuity. Size = $\log_{10}($ symbol size / standard Braille size).

The tactile acuity charts, Fig. 4, were made on a carbon-plastic sheet. Two versions of the chart with different random sequences of symbols were constructed. Test targets were four 3-dot patterns that correspond to four Braille letters (d, f, h, and j). These characters are matched for tactile legibility (Nolan & Kederis, 1969). Each chart had nine lines of eight characters: dot separations decreased by 0.1 log unit (~26%) per line. The dot spacing on the 6^{th} line, labeled 0.0 in Figure 4, corresponded to standard Braille characters. Dot amplitude and shape remained constant throughout. Tests were scored on a letter-by-letter basis; each error was worth 0.0125, which was added to the best possible score of –0.3 log units. (Score = –0.3 +(# of errors × 0.0125)). The test was not timed, and accuracy was stressed over speed. Negative values of tactile acuity mean that participants could identify the symbols when they were smaller than standard Braille.

APPENDIX 2: READING SPEED MEASURED IN WORDS PER MINUTE AND CHARACTERS PER SECOND

Carver (1990) recommended measuring print reading speed in characters per sec (cps) or, equivalently, standard-length words per minute (SLwpm), where one standard-length word is equal to six characters. The printed MNREAD sentences all contain exactly 60 characters, that is, 10 standard length words.

In scoring the print version of MNREAD, speed is measured in SLwpm. One standard-length word is deducted for each word missed or said incorrectly. For instance if a participant reads the MNREAD sentence in 5 seconds and makes 2 errors, their speed is computed as 10–2 standard length words / 5 sec = 96 SLwpm.

An identical approach would work for Grade 1 Braille where there is a one-to-one correspondence between print and Braille characters in the MNREAD sentences. But for Grade 2 Braille, this correspondence breaks down, complicating the definition of standard length words. In this paper, we have used the cps metric for reading speed which is unambiguous for Grade 1 and Grade 2.

When we use a words/min (wpm) metric, we assume that each MNREAD sentence has 11.9 words (the mean value). For instance, if a Braille MNREAD sentence is read in 6 sec with no errors, we compute the reading speed to be 119 wpm. This definition works equally well for Grade 1 and Grade 2. But because the Grade 2 sentences average only 72% the number of characters of the corresponding Grade 1 sentences (see Table 2), the relationship between reading speed in cps and wpm is different for Grade 1 and Grade 2, as follows:

$$\text{speed (wpm)} = 11.9 \times \text{speed (cps)}, \text{ for Grade 1}$$

$$\text{speed (wpm)} = 16.2 \times \text{speed (cps)}, \text{ for Grade 2}$$

To correct for errors in the speed computation, we subtracted 10% of the length of the sentence (in words or characters) for each error. This value was chosen to be compatible with the error-deduction procedure for the printed MNREAD, i.e., one of the ten standard-length words deducted for each error. For instance, if a Grade 2 sentence had 50 characters, and the participant read the sentence with 2 errors in 10 second, the reading speed was 40 characters in 10 sec = 4 cps.

The wpm and cps reading speeds in this paper were calculated as described in this appendix.

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FIGURE CAPTIONS

Fig. 1. Illustration of the MNREAD Acuity Chart. This chart is used for measuring three characteristics of reading vision--reading acuity, critical print size, and maximum reading speed.

Fig. 2. Illustrations of Grade 1 and Grade 2 MNREAD Braille sentences, their ASCII equivalents (codes used to communicate with computer-controlled Braille printers), and the corresponding printed MNREAD sentences.

Fig. 3. Reading speeds (in words per minute) are shown for three groups--44 Braille readers (filled circles) from this paper, and groups of 50 normally sighted (open circles) and 39 low-vision (open triangles) print readers studied by Mansfield et al. (1996). The Braille and print reading speeds were measured with nearly identical MNREAD sentences and procedures. The graph shows a reading speed for each participant plotted against their percentile position within their group.

Fig. 4. Illustration of the chart we used for measuring tactile letter acuity. See the Appendix 1.