Psychophysics of Reading

XV: Font Effects in Normal and Low Vision

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Purpose. Little is known about the effect of font on low-vision reading. In this study, the authors measured the influence of font in reading with normal and low vision.

Methods. Reading acuity, maximum reading speed, and critical print size (the smallest print that can be read with maximum speed) were measured in 50 normal subjects and 42 subjects with low vision. Data were collected using versions of the MNREAD Acuity Chart printed with the Times (proportionally spaced) and Courier (fixed-width) fonts.

Results. Reading acuity scores obtained with Courier were better than those obtained with Times for both normal (mean difference, 0.05 logMAR, $P < 0.001$) and subjects with low vision (0.09 logMAR, $P < 0.001$). Similarly, critical print sizes measured with Courier were smaller than those measured with Times (mean difference, 0.06 logMAR for normal subjects and subjects with low vision, $P < 0.002$). Maximum reading speeds for normal subjects were 5% faster with Times than with Courier ($P < 0.001$), but for subjects with low vision, maximum reading speeds were 10% slower with Times than with Courier ($P < 0.05$). For print smaller than the critical print size, the reading speeds of normal subjects and subjects with low vision were substantially slower (by as much as 50%) for Times than for Courier.

Conclusions. There are small, but significant, advantages of Courier over Times in reading acuity, critical print size, and reading speed for subjects with low vision. For normal subjects, the differences are slighter, with an advantage in reading speed for Times. However, for print sizes close to the acuity limit, choice of font could make a significant difference in both normal and low-vision reading performance. Invest Ophthalmol Vis Sci. 1996;37:1492–1501.

How is reading performance influenced by font?‡ This question has particular importance, not only for the improved design of everyday reading material (e.g., road signs, medicine labels, news print, and books) but also for the design of clinical reading acuity tests.

Tinker[1] performed a systematic analysis of the influence of font on print legibility and found only small effects on reading performance. Recently, however, studies have investigated specific differences in reading performance found with fixed-width and proportionally spaced fonts.[2–5] In a fixed-width font, each character takes up the same amount of horizontal space, whereas in a proportionally spaced font, different letters take up different amounts of horizontal space. Arditi et al[4] measured reading speeds with proportionally spaced and fixed-width versions of the same font. For large print sizes, proportionally spaced text was read slightly faster than fixed-width text, whereas with small print, proportionally spaced text was read considerably slower than fixed-width text. Morris et al[5] attempted to replicate this finding but, over a wide range of angular print sizes, found no difference in reading speed between fixed- and proportionally spaced fonts. They noted that Arditi et al[4] had manipulated print size in two ways: either by changing the viewing distance to the screen, or by using physically smaller, lower-resolution renderings

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‡ We use the term font to refer to a particular design of printed type, such as Helvetica, Times, or Courier. Our use differs from the precise typographical definition of font but is consistent with common usage.

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of the font. For the smallest print sizes used by Arditi et al,[4] the print resolution was 9 pixels per letter height. Only by using a similarly low print resolution were Morris et al[5] able to find a reading speed advantage for the fixed-width font at small sizes.

Thus, it is uncertain whether the differences between fixed- and proportional-spacing found by Arditi et al[4] reflect reading performance with normal print or whether they are limited to print rendered at low resolutions. One purpose of our study was to reexamine the effect of proportional versus fixed-width spacing on reading.

Recent estimates[6,7] suggest that more than 3 million people in the United States are visually impaired. Of these, approximately 120,000 are classified as blind (no useful pattern vision) and the remainder are classified with low vision (corrected visual acuity less than 20/60 or a visual field less than 30°). A more functional definition of low vision is the inability to read newsprint at a normal reading distance (40 cm) with standard refractive correction. Indeed, most people with low vision have difficulty reading.[7] Earlier articles in this series have shown how reading speed with low vision depends on character and field size,[8] text contrast,[9] and color.[10] Little is known, however, about the impact of font on reading for patients with low vision.

Few studies have addressed directly how font affects low-vision reading. Prince[11-13] measured reading speed in subjects with low vision and in normal subjects with pseudomyopia (myopia simulated using dioptric blur). He found that, for a given print size, faster reading speeds were obtained by increasing the width of the space between letters (from 0.2 to 0.4 letter widths). Arditi et al[4] noted that patients with low vision with macular disease found fixed-width text to be easier to read than proportionally spaced text.

There is reason to suspect that low-vision reading may be particularly sensitive to font. For example, crowding effects purportedly are stronger in peripheral vision,[14,15] raising the possibility that people with central field loss, who use peripheral vision to read, would be at a special disadvantage reading a font with tight letter-to-letter spacing. Furthermore, many persons with low vision read text at print sizes near their acuity limit. In such circumstances, even a small difference in the legibility between fonts could make the difference between ability and inability to read. Indeed, some subjects in Prince's study[12] were unable to read text with normal letter spacing but were able to read text with broader letter spacing.

In this study, we addressed the following questions: What is the effect of font on normal reading performance? Are these effects the same with low vision? How might the choice of font influence the clinical assessment of low-vision reading performance?

A

Everyone wanted to
go outside when the
rain finally stopped

B

We both raced
into the yard
when we heard
the fire bell

FIGURE 1. (**A**) Times-Roman, and (**B**) Courier-Bold sentences from the MNREAD Acuity Charts.

METHODS

Stimuli

We used two versions of the MNREAD Acuity Chart[16] to compare reading performance with two fonts. The MNREAD Acuity charts are continuous-text reading-acuity charts, consisting of a series of 19 sentences printed at progressively smaller sizes. Within each chart, the sentences have the same number of characters and geometrical layout. The vocabulary was chosen from the most common words in printed English,[17] and the charts were matched for reading difficulty.

We compared reading performance with two fonts: Adobe's Times-Roman (version 001.007) and Courier-Bold (version 002.004). These fonts resemble those found in everyday reading material: Times is a proportionally spaced font similar to that used in many books, magazines, and newspapers, whereas Courier has fixed width and is like that produced by typewriters or some computer displays. Our font selection differs from that of Arditi et al,[4] who constructed their fixed-width font by adding extra white space to either side of the letterforms in their proportionally spaced font so that they all had the same width. Their method produced fonts that were identical in all aspects other than in their character spacing, but the resultant fixed-width type was unlike any font found in normal typography. In our study, the two fonts come from different type families, and, accordingly, they differed in numerous aspects besides either fixed or proportional spacing (see Fig. 1). Any of the differences between the fonts might be expected to influence reading performance.

Sample sentences for both fonts, formatted as they are on the MNREAD charts, are shown in Figure 1. Each Times sentence had 60 characters (including spaces between words and an implied period at the end) and was printed onto three lines of left–right justified text. Each Courier-Bold sentence had 56 characters and was printed onto four lines of text.

For both fonts, print size was defined as the height of a lower case x (x-height), in accord with the recommended procedure for the specification of visual acuity.[18] LogMAR print size is given by: $\log_{10}$[(angle subtended by x-height)/5 arc min]. At a viewing distance of 40 cm, the print sizes ranged from 1.3 to −0.5 logMAR (Snellen, 20/400 to 20/6.3; visual angles, 1.66° to 0.026°) with a step size of 0.1 logMAR (i.e., the print on each successive sentence is 80% the size of the previous sentence). When necessary, a larger angular print size could be obtained by using a shorter viewing distance.

The charts were viewed in a well-lit room so that light reflected from the chart surface was at least 80 cd/m^2. The charts were printed with high-contrast (Michelson contrast, 90%) black text on a white background at a resolution of 3000 dots per inch. With this high resolution, the x-height of the smallest print (−0.5 logMAR) corresponded to 22 pixels. For comparison, 12 point Times-Roman type rendered with 300 dots per inch also corresponds to 22 pixels per x-height. This print resolution avoids the low-resolution problems noted by Morris et al.[5]

Subjects

Data were collected from 50 undergraduate psychology students with normal or corrected-to-normal vision and from 42 subjects with low vision. All subjects spoke English as their native language and gave their informed and written consent to participate in the study (in accordance with the Declaration of Helsinki). Low-vision data were collected at two sites: 22 subjects were tested at the Minnesota Laboratory for Low-Vision Research (Minneapolis), and 20 were tested at the Retina Foundation of the Southwest (Dallas, TX). Age, distance acuity, and diagnoses of both subject pools are shown in Table 1. We subdivided the subjects with low vision into two groups based on the status of their central visual field: either *intact* or *loss* (scotomas covering all or part of the central 5° of visual field).[8] Mean age and distance acuities (± SD) for these groups were as follows: intact central vision, 41 ± 11.2 years, 0.87 ± 0.52 logMAR (20/148); central vision loss, 68 ± 15.4 years, 0.85 ± 0.35 logMAR (20/148).

Procedure

For subjects with normal vision, the viewing distance was 40 cm. For subjects with low vision, viewing distance was chosen so that, using their usual optical correction for reading, they would be able to read six or more sentences. Viewing distance was maintained either by resting the subject's head against a forehead rest or by verifying the viewing distance throughout the reading trials. The charts were placed on a reading stand in front of the subject. Subjects with low vision who preferred to read using a specific retinal location were allowed to position the chart so that the text would fall into their preferred region of vision.

Starting with the largest print size, subjects were instructed to read each sentence, one at a time, as quickly and as accurately as possible. Subjects continued reading the smaller sizes until they could not read any words in a sentence. The subjects were informed that reading speed was being measured and were asked to continue reading to the end of the sentence before correcting any reading errors they might have made. To prevent subjects from reading ahead, the unread sentences were covered with a piece of card held by the experimenter. For data collected at the Minnesota laboratory, a stopwatch was used to record the time taken to read each sentence, and any reading errors were noted during the test session. For data collected at the Texas laboratory, the test session was recorded on audiotape, and reading time and reading errors were scored after the test session.

Data Analysis

We measured three parameters of reading performance: reading acuity, the smallest print size that can just be read; maximum reading speed, the reading speed at which print size is not a limiting factor; critical print size, the smallest print that can be read at the maximum reading speed.

Reading acuity was calculated in a similar manner to the "letter-by-letter" method described by Ferris et al[19] for scoring visual acuity with letter charts. On each chart, the sentences were subdivided into "standard-length" words of six characters each.[20] Each sentence had 10 standard-length words on the Times charts and 9.33 standard-length words on the Courier charts. The sentence-to-sentence size increment was 0.1 logMAR, so that, following the principle of Ferris et al,[19] each word was "worth" either 0.01 or 0.0108 (i.e., 0.1/9.33) logMAR for the Times and Courier charts, respectively. (Our use of standard-length words was intended to minimize the differences in scoring that would occur because of the different word lengths found in different sentences. For example, some of the test sentences have 13 relatively short words, whereas others have just 10 words of a longer length.) Reading acuity was determined as follows: Starting with an acuity score of 1.4 (i.e., one 0.1 logMAR step larger than the largest print on the chart) the subject's logMAR score was decremented by 0.1 logMAR for

TABLE 1. Subjects With Low Vision

Subject	*Age (years)*	*Distance Acuity (logMAR)*	*Central Field Status*	*Diagnosis*
MN01	47	0.90	Intact	Cataract, nystagmus
MN02	39	1.16	Intact	Cataracts
MN03	43	1.01	Intact	Cataracts
MN04	46	1.68	Intact	Corneal opacification
MN05	34	0.30	Intact	Diabetic retinopathy
MN06	23	1.40	Intact	Glaucoma
MN07	35	0.98	Intact	Glaucoma
MN08	44	0.90	Intact	Optic neuritis
MN09	70	0.40	Intact	Optic neuritis, ischemic
MN10	25	0.22	Intact	Progressive myopia
MN11	31	−0.10	Intact	Retinitis pigmentosa
MN12	36	1.40	Intact	Retinopathy of prematurity
MN13	43	1.00	Intact	Retinopathy of prematurity
MN14	81	1.18	Loss	Age-related macular degeneration
MN15	82	0.94	Loss	Age-related macular degeneration
MN16	46	1.10	Loss	Detached retina
MN17	45	0.64	Loss	Diabetic retinopathy
MN18	38	1.22	Loss	Juvenile macular degeneration
MN19	35	0.86	Loss	Leber's disease
MN20	48	1.30	Loss	Leber's disease
MN21	47	0.58	Loss	Optic nerve deterioration
MN22	44	1.20	Loss	Optic neuritis, atrophy
TX01	60	1.32	Loss	Age-related macular degeneration
TX02	63	0.68	Loss	Age-related macular degeneration
TX03	68	0.12	Loss	Age-related macular degeneration
TX04	68	1.04	Loss	Age-related macular degeneration
TX05	69	0.00	Loss	Age-related macular degeneration
TX06	71	1.26	Loss	Age-related macular degeneration
TX07	72	0.26	Loss	Age-related macular degeneration
TX08	74	0.76	Loss	Age-related macular degeneration
TX09	75	0.88	Loss	Age-related macular degeneration
TX10	76	0.44	Loss	Age-related macular degeneration
TX11	76	0.94	Loss	Age-related macular degeneration
TX12	77	0.50	Loss	Age-related macular degeneration
TX13	78	0.92	Loss	Age-related macular degeneration
TX14	81	1.14	Loss	Age-related macular degeneration
TX15	81	1.12	Loss	Age-related macular degeneration
TX16	81	0.72	Loss	Age-related macular degeneration
TX17	82	1.06	Loss	Age-related macular degeneration
TX18	82	0.86	Loss	Age-related macular degeneration
TX19	83	1.14	Loss	Age-related macular degeneration
TX20	83	0.54	Loss	Age-related macular degeneration

every *sentence* that was read with less than 10 reading errors. Then, for each *word* that was missed or read incorrectly, the subject's score was *increased* by 0.01 logMAR on the Times charts or 0.0108 logMAR on the Courier chart. Finally, the reading acuity score was modified to take into account the viewing distance used (if it was other than 40 cm).

Reading speed in words per minute (wpm) was determined for each sentence as the number of standard length words read correctly, divided by the time taken to read the sentence (measured to the nearest 0.1 seconds). For data collected in the Minnesota laboratory, the reading time was measured from the moment the sentence was revealed to the subject until the subject finished uttering the last word of the sentence. For data collected in the Texas laboratory, reading time was recorded from when the subject started to utter the first word until the last word was finished. Patients with central vision loss may experience difficulties in finding the sentence on the page. The latter method for calculating reading speed excludes the time taken to localize the sentence and may give a better representation of reading time for subjects with central field loss.

Typically, reading speed remains constant over a wide range of print sizes, but, as print size is reduced, reading speed deteriorates before the acuity limit is reached (see Fig. 2). We defined the maximum read-

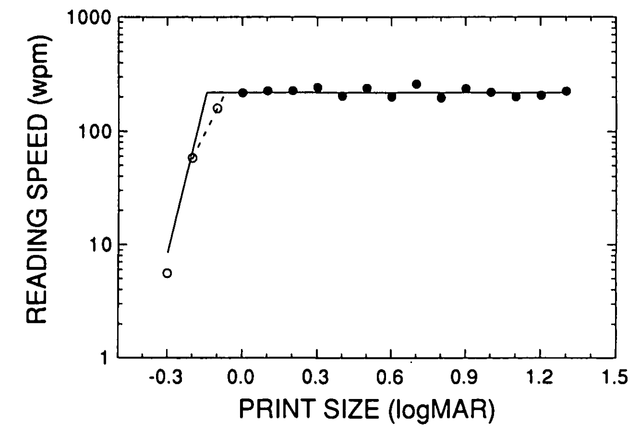

FIGURE 2. Reading speed as a function of print size is shown for a subject with normal vision. Solid lines indicate the best-fitting two-limbed fit for the data. The dashed line indicates the two-limbed fit when the data point for the -0.3 logMAR size is excluded from the two-limbed-fit analysis. Filled symbols indicate data points considered to lie on the plateau region of the reading speed curve (see Data Analysis and appendix for details). Hollow symbols represent speeds that are significantly slower than the mean reading speed across the plateau.

ing speed as the reading speed across the plateau region and the critical print size as the print size at which reading speed starts to deteriorate. Both these parameters are important functional measures of reading performance. The maximum reading speed is an objective measure of the best reading performance attainable by the subject. The critical print size is the optimal print size for reading because it is the smallest print size at which subjects read with their maximum rate. When prescribing a magnifier or reading aid, the critical print size indicates the optimum magnification that would suit the patient.

Previously[21,22] we obtained estimates of the critical print size using a two-limbed straight-line fit to the reading speed data: a sloped line for small print sizes and a horizontal line for larger sizes (shown by the solid lines in Fig. 2). Using this method, the critical print size is at the elbow (the intersection) of the two lines. We have not used this method in the current study, however, because the precise location of the elbow in the two-limbed fit is acutely dependent on the reading speed measurements that define the sloped line. Typically, these data points are collected at print sizes close to the observer's acuity limit, where the reading speed measurements can be noisy. For example, in Figure 2, the intersection of the two-limbed fit corresponds to a print size of -0.14 logMAR. In this example, the subject read only two words correctly in the -0.3 logMAR sentence. Had the subject failed to read *any* words at this print size, the elbow of the best-fitting two-limbed fit (shown by the dashed line) would be at -0.06 logMAR. Thus, a very small change in reading performance on one sentence can have a large effect on the critical print size estimate. Our new method for estimating the critical print size is less dependent on the data collected at the print sizes close to the acuity limit.

Critical print size and maximum reading rate were estimated for each subject's reading speed data using our new algorithm (see Appendix). This algorithm

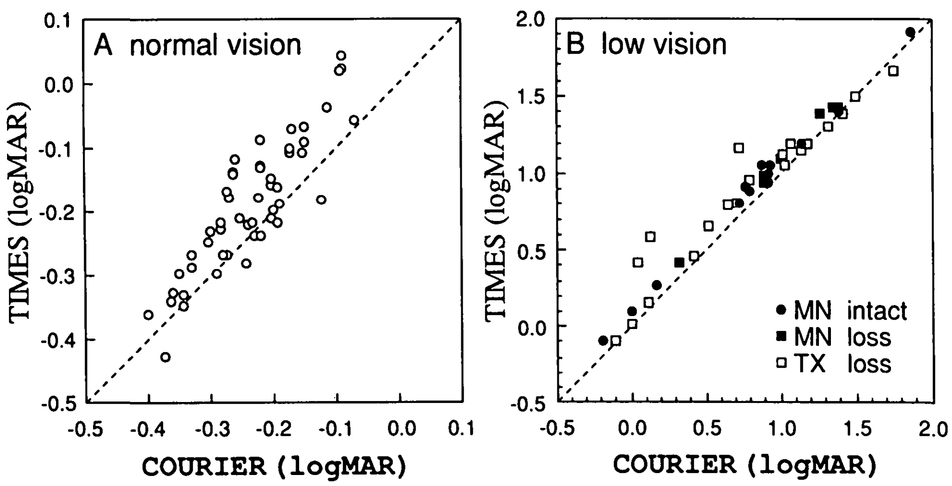

FIGURE 3. Reading acuity on the Times and Courier charts for (**A**) normal subjects and (**B**) subjects with low vision. Diagonal lines indicate equal scores on both charts. Filled symbols in **B** indicate data collected at the Minnesota Laboratory for Low-Vision Research. Hollow symbols show data collected at the Retina Foundation of the Southwest. Circle data points are from subjects with intact central vision, and squares are from subjects with central vision loss. The correlation between reading acuities measured on the Times and Courier charts are: normal vision, 0.88; low vision, 0.98.

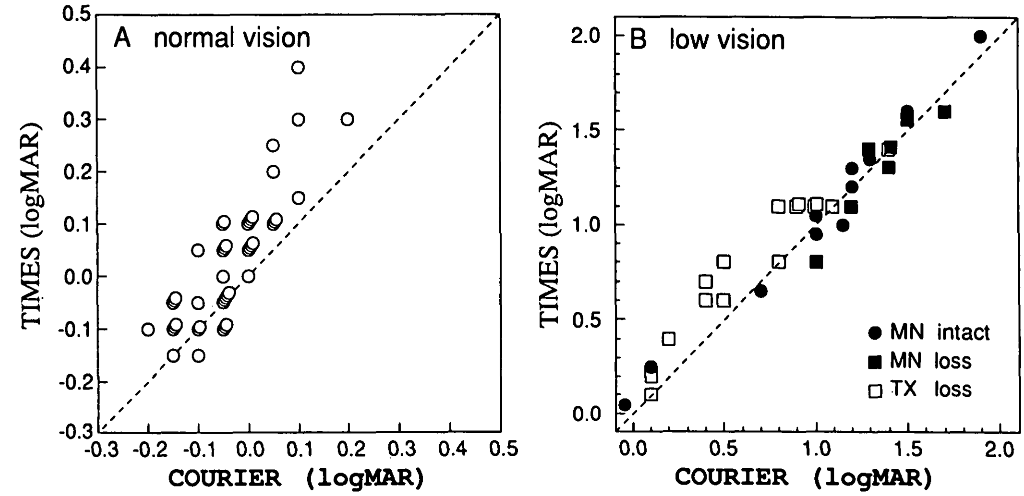

FIGURE 4. Critical print size on the Times and Courier charts is shown for (A) normal subjects and (**B**) subjects with low vision. Filled symbols in **B** indicate data collected at the Minnesota Laboratory for Low-Vision Research. Hollow symbols show data collected at the Retina Foundation of the Southwest. Circle data points are from subjects with intact central vision, and squares are from subjects with central vision loss. The correlation between critical print sizes measured on the Times and Courier charts are: normal vision, 0.84; low vision, 0.97.

identifies the reading speed plateau. This is a range of print sizes over which reading speed was close to the maximum reading speed (shown by filled symbols in Fig. 2), whereas the reading speeds at larger or smaller print sizes were significantly slower (i.e., more than two standard deviations removed) than the plateau reading speed (shown by hollow symbols in Fig. 2). Maximum reading speed was defined as the geometric mean of the reading speeds across the plateau. Critical print size was defined as the smallest print size included in the plateau.

RESULTS

Normal Vision

None of the subjects could read the tiniest print on either the Courier or Times charts successfully, so the reading acuity scores were not influenced by a ceiling effect. Figure 3A shows reading acuity scores measured with the Times and Courier charts for all the normal subjects. The diagonal line in this figure indicates equal scores on the two charts. Data tend to lie above this line, indicating that reading acuity is poorer on the Times chart than on the Courier chart. On average, this difference is 0.05 logMAR (pairwise *t*-test, $df = 49$, $P < 0.001$). This corresponds to a 12% size difference (i.e., reading acuity with the Times chart is at a print size with x-height 12% larger than with the Courier chart).

Figure 4A shows critical print sizes (in logMAR) measured with the Times and Courier charts. Again, the data tend to lie above the equality line, indicating that the critical print size is larger with the Times chart than with the Courier chart. On average, this difference is 0.06 logMAR ($P < 0.001$), corresponding to a 15% size difference.

Figure 5A shows maximum reading speeds measured with the Times and Courier charts. Once more, the data tend to lie above the equality line, indicating that maximum reading speeds with the Times chart are faster than with the Courier chart. On average, reading speeds are 4.7% ($P < 0.001$) faster with Times than with Courier.

The reading speed advantage with the Times font does not exist for all print sizes. Figure 6A shows the ratio of the Times and Courier reading speeds as a function of print size for all 50 normal subjects. In this figure, the print sizes in each data set have been normalized relative to each subject's critical print size with the Courier font. The dashed line indicates the mean reading speed ratio pooled across all subjects. For print smaller than the critical print size, reading speeds with Times are substantially slower than those with Courier (i.e., for a relative print size of −0.3, the reading speed ratio is 0.5, indicating that Courier was read twice as fast as Times).

Low Vision

Figure 3B shows reading acuity scores measured with the Times and Courier charts for all the subjects with low vision. The data tend to lie above the equality line, indicating that reading acuity is poorer with the Times chart than with the Courier chart. On average, this difference is 0.09 logMAR (pairwise *t*-test, $df = 41$, P

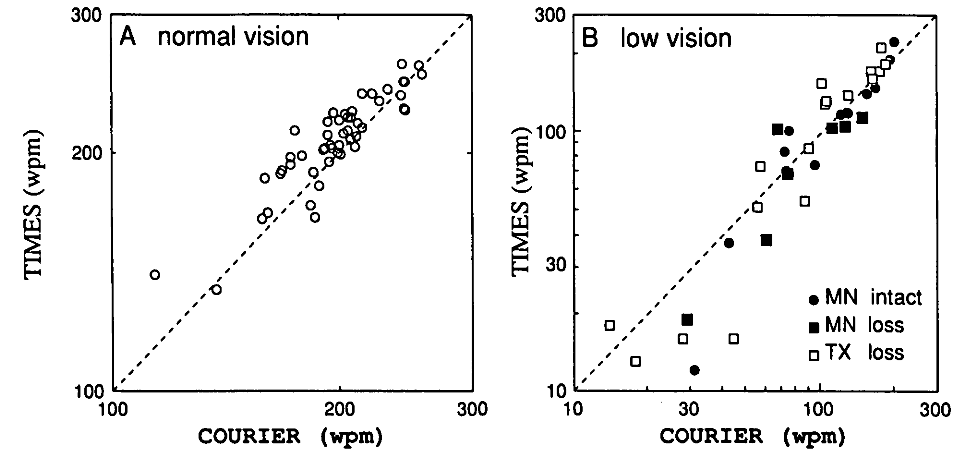

FIGURE 5. Maximum reading speed on the Times and Courier charts is shown for (A) normal subjects and (B) subjects with low vision. Filled symbols in B indicate data collected at the Minnesota Laboratory for Low-Vision Research. Hollow symbols show data collected at the Retina Foundation of the Southwest. Circle data points are from subjects with intact central vision, and squares are from subjects with central vision loss. The correlation between log maximum reading speeds measured on the Times and Courier charts are: normal vision, 0.90; low vision, 0.94.

< 0.001), which corresponds to a size difference of 23%. The font-dependent difference in reading acuity was 0.08 logMAR ($P < 0.001$) for subjects with intact central vision and 0.10 logMAR for subjects with central vision loss ($P < 0.001$).

Figure 4B shows critical print sizes measured with the Times and Courier charts. Data tend to lie above the equality line, indicating that the critical print size is larger with the Times chart than with the Courier chart. On average, this difference is 0.06 logMAR ($P < 0.002$), corresponding to a 15% size difference. The font-dependent difference in critical print size was slight and not significant for subjects with intact central vision (mean difference, 0.04 logMAR, $P = 0.06$) but was larger and significant for subjects with central vision loss (mean difference, 0.07 logMAR, $P < 0.01$).

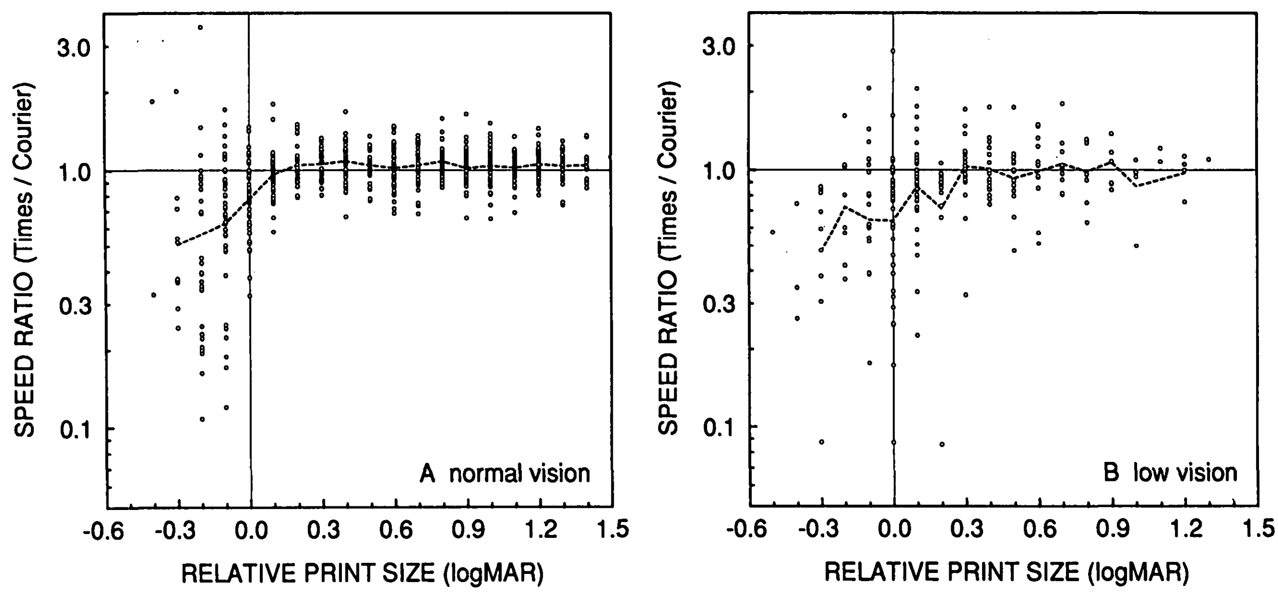

FIGURE 6. The ratio of reading speeds on the Times and Courier charts for the (A) normal subjects and (B) subjects with low vision are shown as a function of print size relative to each person's critical print size for Courier. A speed ratio greater than 1 indicates Times was read faster than Courier, a ratio less than 1 indicates Courier was read faster than Times. Dashed lines indicate the mean speed ratio at each relative print size.

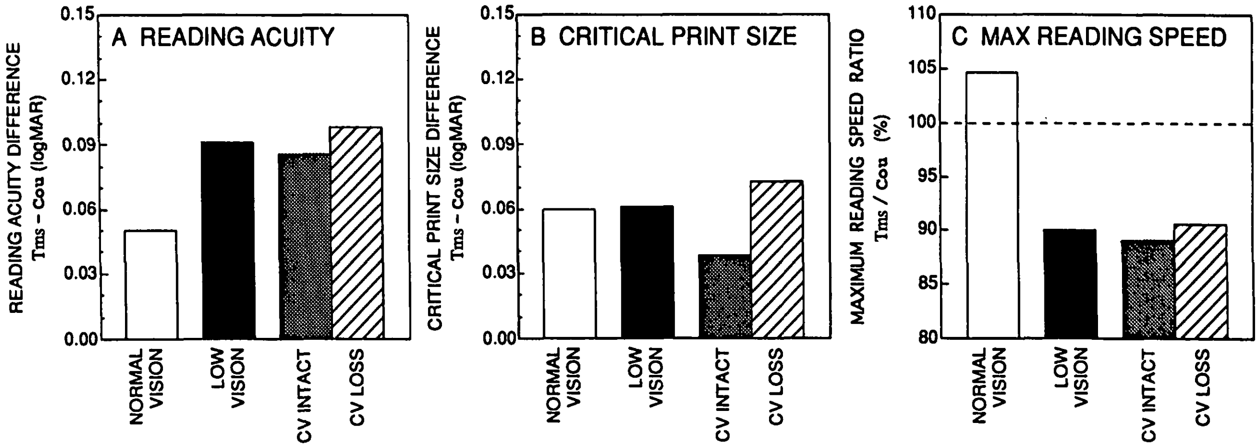

FIGURE 7. Summary of the differences between the Times (Tms) and Courier (Cou) fonts for (**A**) reading acuity, (**B**) critical print size, (**C**) maximum reading rate.

Figure 5B shows maximum reading speeds measured with the Times and Courier charts. Unlike the normal subjects, these data tend to lie *below* the equality line. On average, reading speeds are 10% *slower* with Times than with Courier ($P < 0.05$). Both the central-intact and central-loss groups also showed 10% slower reading speeds with Times than with Courier. Larger differences in reading speed were found for subjects with slower overall reading speeds. Figure 6B shows the ratio of the Times and Courier reading speeds as a function of print size for all 42 subjects with low vision. The dashed line indicates the mean reading speed ratio pooled across all subjects. As with normal subjects, at sizes smaller than the critical print size, Courier can be read substantially faster than Times.

DISCUSSION

The data in Figures 3, 4, and 5 show that there are differences in reading acuity, critical print size, and maximum reading speed measurements obtained with the Times and Courier charts. Differences in acuity size and critical print size for the normal subjects were 0.05 and 0.06 logMAR. Arditi et al[4,23] have attributed the superior acuity scores found with widely spaced texts (as found with fixed-width fonts) to crowding effects: The close proximity of adjacent letters in the proportionally spaced text interferes with individual letter recognition. However, the differences in reading performance found in the current study could just as well be attributed to other differences between the fonts used, such as stroke thickness and serif size.

For normal subjects, the maximum reading speed with the Times font was 5% faster than with the Courier font. This finding is comparable to the data from other studies.[4,24] Klitz et al[24] measured silent reading speeds for text passages presented using either AvantGarde, Bookman, Courier, Helvetica, or Times fonts. The greatest reading speed difference, 5%, was found between Times and Courier, suggesting that the current findings are comparable to silent reading and that the magnitude of the font-dependent difference in reading speed found here may represent the upper bound for reading speed differences between other pairs of common fonts. The difference between Times and Courier maximum reading speeds may be caused by differences in the letter spacing for each font.[4] A tighter horizontal packing of characters allows more characters to fit into the higher resolution area of the retina, so that more letters can be processed in each fixation.

The current study's finding that, at small print sizes, reading speeds with Courier can be much faster than those with Times is similar to the data of Arditi et al[4] but contradict the results of Morris et al.[5] The failure of Morris et al to find a reading speed difference at small print sizes may be explained by the fact that they did not test at sizes smaller than their subjects' critical print sizes (see their Fig. 3.1). It should be noted, however, that at larger print sizes, the results of Morris et al[5] are similar to those reported in the current study and by Arditi et al.[4]

Comparing Normal and Low Vision

Figure 7 compares the font-dependent differences in reading acuity, critical print size, and maximum reading speeds for the normal subjects and subjects with low vision. The reading acuity difference for subjects with low vision was 0.09 logMAR. This difference is 0.04 logMAR greater than that for the normal subjects.

On average, the data for the critical print size are similar between subjects with low vision and normal subjects. However, the group with low vision and central vision loss show a 0.06 logMAR greater effect than the intact central vision group. These differences are consistent with the hypothesis that reading performance with low vision, especially with central field loss, is more sensitive to the differences between fonts.

Conclusion

Our findings indicate that, for suitably magnified text, differences in reading performance with different fonts are slight. However, it may not always be possible to achieve suitably magnified text. If print size is smaller than the critical print size (as might occur if there were physical limitations on the maximum magnification possible with certain magnifiers, or if a patient was required to use a specific print size in his or her work), the choice of font could make a functionally significant difference in reading speed and accuracy. Such effects should be considered when prescribing a reading aid. It is generally good practice to verify performance with a new reading aid using the reading material and reading conditions commonly used by the patient.

What are the implications of our findings for printing low-vision reading material? Presumably, a publisher would seek to maximize the quantity of text per page for a given level of reading performance. Our data show that maximum reading speeds for readers with low vision are 10% faster with Courier than with Times. However, when matched for x-height, the mean character width, measured from the left edge of one letter to the left edge of the next, is 40% wider for Courier than it is for Times. The small reading speed advantage we have found for Courier may be offset by the larger number of pages required to print using the Courier font.

A final observation concerns the specification of print size on tests of reading acuity. The National Academy of Sciences–National Research Committee on Vision[18] recommends defining print size as the height of a lowercase letter such as 'x'. Our finding of significant differences in reading performance with text rendered in different fonts that were matched for x-height indicates that letter height alone is an inadequate metric for describing print size in tests of reading acuity.

Key Words

acuity, font, low vision, normal vision, reading, typeface

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Appendix

Calculating Critical Print Size and Maximum Reading Rate

Reading speeds were measured at each print size. A range of print sizes (S_i:S_j) was found such that:

$\max(S_{min}:S_{i-1}) < \text{mean}(S_i:S_j) - A$

and

$\max(S_{j+1},S_{max}) < \text{mean}(S_i:S_j) - A$

where

$A = \max[2 \times \text{stdev}(S_i:S_j), 0.05 \times \text{mean}(S_i:S_j)]$

max(a:b) is the maximum log reading speed for sizes from a to b inclusive,

mean(a:b) is the mean of the log reading speeds from a to b inclusive,

stdev(a:b) is the standard deviation of log reading speeds from a to b inclusive,

max(a,b) is the larger of a or b,

S_i, S_{max}, and S_{min} are the log reading speeds for the *i*th, the largest and the smallest print sizes read.

If more than one pair of i and j satisfied these criteria, the size range that produced the largest mean(S_i:S_j) was selected.

Mean(S_i:S_j) was taken as the maximum reading speed. The critical print size was taken to be S_i.