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# Serifs and font legibility

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**Abstract**

Using lower-case fonts varying only in serif size (0%, 5%, and 10% cap height), we assessed legibility using size thresholds and reading speed. Five percentage serif fonts were slightly more legible than sans serif, but the average inter-letter spacing increase that serifs themselves impose, predicts greater enhancement than we observed. RSVP and continuous reading speeds showed no effect of serifs. When text is small or distant, serifs may, then, produce a tiny legibility increase due to the concomitant increase in spacing. However, our data exhibited no difference in legibility between typefaces that differ only in the presence or absence of serifs.

*Keywords:* Legibility; Reading; Typography; Low vision

## 1. Introduction

It is well accepted that typeface affects text readability (Mackeben, 1999; Mansfield, Legge, & Bane, 1996; Roethlein, 1912; Tinker, 1963; Whittaker, Rohrkaste, & Higgins, 1989), but apart from a few studies (Arditi, 1996; Arditi, Cagenello, & Jacobs, 1995a, Arditi, Cagenello, & Jacobs, 1995b; Arditi, Knoblauch, & Grunwald, 1990; Arditi, Liu, & Lynn, 1997; Berger, 1944a, 1944b, 1948) few experiments have addressed how carefully controlled, specific characteristics of font design contribute to legibility. One reason for the paucity of research in this area is that it is only since the advent of computer fonts that it has it been reasonably easy to construct fonts that can be varied parametrically. Indeed, most studies assessing the impact of font characteristics that use pre-existing fonts have difficulty drawing definitive conclusions since virtually all such fonts differ in more than a single characteristic (e.g., Mansfield et al., 1996; Yager, Aquilante, & Plass, 1998).

In the present study, we address the issue of how the presence or absence of serifs contributes to readability both at typical print sizes and close to the acuity limit. To be able to draw firmer conclusions, we used fonts of our own design that differ only in the presence or absence, and size of serifs. Since illegible typography appears to be a common complaint among people with impaired vision, we also included two readers with age-related macular degeneration (AMD) in our sample of subjects. Given the small sample size, however, we cannot draw firm or general conclusions about low vision from these data.

In the typographic literature, serifs are generally believed to have a significant impact on readability. There are two main reasons cited to explain why serifs should enhance legibility. First, they are believed to increase letter discriminability by making the spatial code of letter forms more complex. A well-known authority on typography writes:

> "Sans-serif type is intrinsically less legible than seriffed type...because some of the letters are more like each other than letters that have serifs, and so the certainty of decipherment is diminished." (McLean, 1980)

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Second, serifs are thought to increase the visibility of the ends of strokes, increasing the salience of the main strokes of the letters Rubinstein (1988) writes:

> "Serifs have an important role in the readability of type, providing...accentuation to the ends of strokes that may help the reader read faster and avoid fatigue."

Serifs might thus enhance legibility of individual letters by providing an additional cue to the location of stroke ends.

A third possible reason, possibly implied by the above quotation from Rubinstein, but not clearly articulated, is that those horizontal serifs that sit along the font baseline might conceivably enhance the ability of the reader to track the line of type with eye movements and hence may promote faster or more efficient reading.

On the other hand, there are also good reasons to believe that serifs have little effect on legibility. Being small relative to letter size, and generally being ornamental, rather than essential parts of the letter form, one might suspect that they would have little impact on letter identification. If they do affect legibility, it might be reasonable to suppose that they interfere with letter recognition, since to a simple letter-form template, they might simply act as a form of noise.

Empirical studies, also, have shown that spatial frequency information in letters, above 2–3 c/letter, is unnecessary for letter recognition (Ginsburg, 1981), and to support maximum reading speeds (Legge, Pelli, Rubin, & Schleske, 1985). Since serifs are largely comprised of such high spatial frequency information, one might suppose from these results, that they are irrelevant to legibility, especially at the acuity limit, where spatial frequencies higher than 2–3 c/letter are likely to be greatly attenuated by the optics of the eye.

Do fonts with serifs measurably enhance readability? We sought to determine whether or not these tiny features, which are clearly optional for basic letter recognition, have positive, negative, or no impact on legibility. Our criteria for demonstrating increased legibility were decreased size thresholds and increased reading speeds. Since the addition of serifs to a font increases the average inter-letter spacing of the font slightly (to accommodate the serifs), we explicitly varied inter-letter spacing as well, to independently assess its effects. And since illegible typography is a common complaint of people with low vision, we also included two observers with age-related maculopathy in our participant pool.

## 2. Methods

We assessed relative legibility of fonts with different size (or no) serifs, and with different inter-letter spacing using three different criteria for legibility:

1. Size thresholds (visual acuity) for letter identification, measured with five-letter, random, lower-case strings presented on a video monitor, using an up–down staircase (Levitt, 1971) with 0.05 log unit size steps. Size (or, inversely, distance) thresholds are probably the most common method of assessing text legibility (Tinker, 1963), and it is widely used in applied settings such as highway signage, with lower size thresholds indicating higher legibility.
2. Reading speeds using rapid serial visual presentation (RSVP). More legible fonts, by this criterion, allow faster reading, while less legible fonts prevent faster reading. We measured reading speed using RSVP with large letters (about seven times threshold size), and conventional mixed-case text from an expanded MNREAD (Legge, Ross, Luebker, & LaMay, 1989) corpus. Reading speed is a less common measure of legibility but it is perhaps more representative of ordinary reading than is size threshold. And because RSVP can support extremely high rates of reading, it has the potential to be more sensitive to subtle differences in legibility. RSVP reading was tested with individual sentences, whose speed was varied to determine the speed that supported a 50% correct reading rate.
3. Reading speeds using continuous reading of scrambled text passages using conventional text, printed on paper. We included this condition to address possible differences between reading speeds with RSVP on a computer monitor with those more commonly observed with continuous reading on paper. We used scrambled text to be able to compare performance on three different conditions within subjects while using text samples that have word frequency statistics that are representative of ordinary text, but which require reading of each individual word, rather than allowing context and inference to play a significant role in determining reading speed.

## 3. Stimuli

We constructed nine fonts using custom software (Arditi, 2004) that allows parametric font construction. Most of the font parameters are expressed as a proportion of the cap height, which is the height of an upper-case letter. The base font was constructed using strokes of uniform thickness that was 10% of the cap height. The fonts had serifs whose strokes were of the same 10% cap height thickness, and extended 0%, 5% or 10% of the cap height. Each of these three serif sizes had space added to their side bearings such that inter-letter spacing was 0%, 10%, or 40% of the cap height. This space was added only at the edges of the letter glyph so that the letter shape was unaltered by the manipulation of spacing. The full alphabet is displayed for three sizes of serifs (0%, 5%, and 10% cap height) in Fig. 1, and the three spacing conditions can be seen in Fig. 2. Other parameter values for the font that were constant for the entire set of nine fonts used in the experiment are: *x*-height: 55% cap height; and descent: 50% cap height. Parameter values other than serif size and spacing were chosen because they produce a reasonably natural appearing font, but are otherwise arbitrary. Most important, they are the same for all conditions of these experiments. In other words, the shapes of letter glyphs were unchanged over all conditions, except for the absence, presence, and size of serifs. All other published studies that have examined the effects of serifs have used existing, rather than custom fonts, and none have been able to conclusively separate effects of serifs from other font design characteristics.

The nine fonts were used for all text employed in these experiments, presented on both computer monitor and paper.

### 3.1. Size thresholds

In this experiment, random five-letter strings were presented centered on a SONY Multiscan 520GS monitor, as black (3.6 cd/m$^2$) letters on a white (129 cd/m$^2$) background. Normally sighted subjects viewed the screen optically folded through a front-surface mirror at an optical distance of 788.4 cm, so that letters were at least 100 pixels in height (from the top of an upper-case letter to bottom of the descent), or equivalently, for these fonts, 66.66 pixels in cap height. For these subjects, the letters were rendered in reverse on the screen to compensate for the mirror reversal. Subjects with low vision viewed the screen directly (i.e., with no mirror) at viewing distances of 106 (subject SM) and 58.4 cm (subject MG). The letter strings were sampled (with replacement) from the 26 lower-case letters of the English alphabet. Examples of such strings for the nine font conditions are illustrated in Fig. 2.

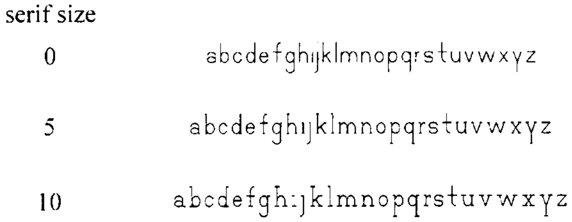

Fig. 1. The full font (alphabetic characters) used in the study. The letters are spaced with 10% cap height.

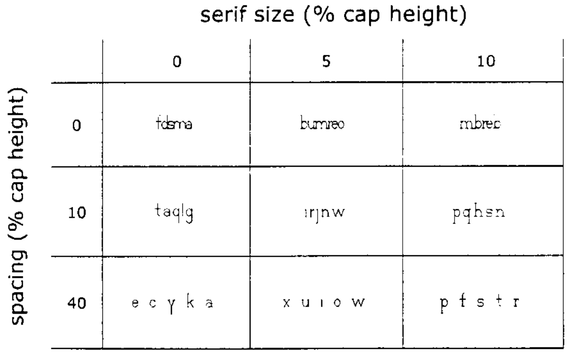

Fig. 2. Examples of lower-case fonts used in, and created for, the experiment. Fonts differed only in size of serifs and by inter-letter spacing. Both parameters are defined in units of percent of the height of a capital letter in the font, which is also equal to the distance from the top of a lower-case letter that has an ascending stroke, such as a "d," to the font baseline.

### 3.2. RSVP reading

We used custom software to present each word of a sentence centered vertically and horizontally on the computer monitor, for a constant time interval. Text was black on white, as with the size thresholds. The participant read aloud each sentence as it was presented, prior to presentation of the next sentence.

### 3.3. Continuous reading of scrambled text

Three text passages of roughly ninth grade-level reading difficulty, and length 376, 400, and 405 words, respectively, were used. The words of each passage were randomly permuted, and printed on ordinary letter size white paper, in 18 pt type. The subject read the text aloud continuously, while the experimenter timed the reading of the entire passage and recorded errors.

### 3.4. Participants

Normally sighted participants were Lighthouse research staff (JC, CC), one of whom is an author of this paper, or recruited from the Lighthouse International Volunteer Service (AG, IF). Participants with low vision, both of whom had age-related maculopathy, were recruited from the Lighthouse Low Vision Service (MG, SM). MG's distance acuity, measured with a trans-illuminated Lighthouse/ETDRS distance acuity chart, was 1.0 log MAR (20/200), while SM's was 0.6 (20/80). Participants were seated comfortably in a chair, with their head position fixed with a head and chin rest. All participants, except JC (who participated only in Experiment 1), were naïve to the purposes of the experiment.

## 4. Experiment 1: Size thresholds

### 4.1. Procedure

Size thresholds were measured using a staircase method (Levitt, 1971) in which correct identification of at least four of five letters (in correct order) was required for a decrease in letter size on the subsequent trial, while no more than three letters correct elicited a size increase on the subsequent trial. This procedure converges on the 68.6% correct point on the psychometric function. Subjects were required to give five-letter responses to all trials, and were encouraged to guess if they reported difficulty. On trials in which the size changed, the magnitude of the change was 0.05 log unit, half the size change from line to line on state-of-the-art visual acuity charts. Data prior to the 2nd reversal of each staircase were discarded, to concentrate the data used in the analysis close to the threshold.

To minimize sequence artifacts, the nine stimulus conditions were randomly permuted once for each subject. First, that random sequence of nine conditions was run in order, with each staircase terminating after 15 reversals. Next, the same sequence was run in reverse order with each staircase terminating after 30 reversals. Finally, the sequence was run in forward order again with termination after 15 reversals. Thus, each condition was run with a total of 60 staircase reversals, 30 in the forward randomized order and 30 in the reverse randomized order.

All responses were given verbally by the subject; the experimenter typed the responses into the computer, which then presented the next five-letter string whose size was contingent on the subject's performance. Subjects were thus able to change their responses if they did so prior to the experimenter's finalizing the response to that line. This procedure results in a negligible lapse or extraneous noise rate (Arditi, 2005).

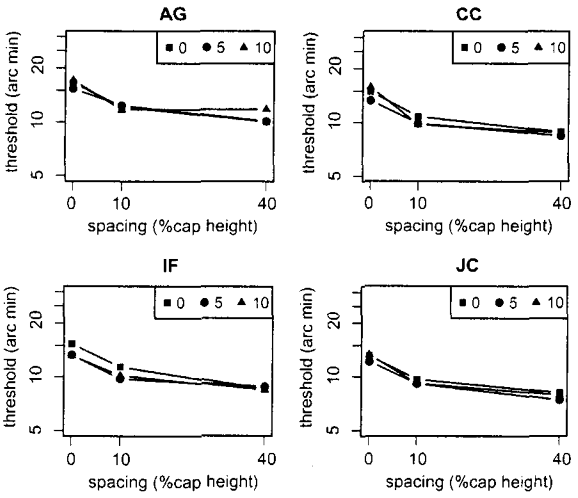

Fig. 3. Letter size threshold as a function of inter-letter spacing and serif size (squares: 0, circles: 5, and triangles: 10% cap height) for four normally sighted participants. Serif size has a nearly negligible impact on size threshold relative to spacing. Thresholds are plotted on log axis.

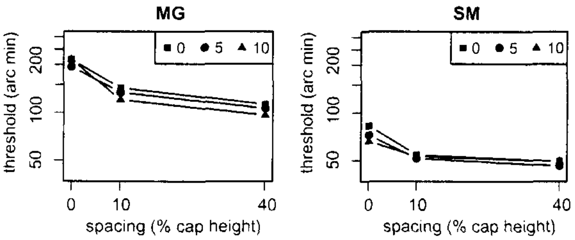

Fig. 4. Same as Fig. 3 but for two observers with age-related maculopathy. Note different scale from Fig. 3. Results are similar to those of normally sighted observers.

### *4.2. Results*

Size thresholds are shown as a function of serif size and inter-letter spacing for the four normally sighted participants in Fig. 3 and the two participants with low vision in Fig. 4. These thresholds are geometric means of all the staircase levels visited (after the second reversal of each run); the number of measurements on which the thresholds were based ranged from 69 to 107. Standard errors (SEs) about these means (which reflect accuracy of values in terms of proportion, rather than magnitude) were small; the maximum SE over all participants and all stimulus conditions was 0.0026.

All of the plots slope downward as spacing increases, indicating the presence of a large inter-letter spacing "crowding" effect, in which closely spaced letters result in higher size (acuity) thresholds. Also evidents are much smaller, but systematic effects of serif size on threshold, with the threshold for the 5% serif nearly always being lower than that of the smallest (zero) serif size. Averaged data are shown in Figs. 5 and 6, for normal and low vision, respectively, and in Fig. 7 for all subjects. Note that the results are essentially the same for the low vision subjects—those for whom, some might argue, serifs should make a difference.

The above observations were corroborated with an analysis of variance (ANOVA) performed on normalized thresholds. First, so that data from the low vision and normal vision groups could be combined, each subject's data were transformed by dividing each data point by that subject's minimum threshold, yielding a score normalized to the subject's best performance. The log of this ratio was then used as the dependent variable in an ANOVA with independent variables serif size, inter-letter spacing, and vision status (normal or low), and repeated measures on serif size, and inter-letter spacing. The only significant effects were spacing ($F[2,8] = 143.888$, $p = 0.000$) and serif size ($F[2,8] = 10.120$, $p = 0.006$).

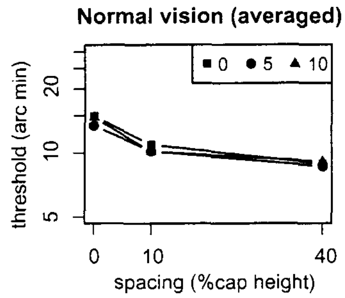

Fig. 5. Average (geometric mean) normal vision data from Experiment 1.

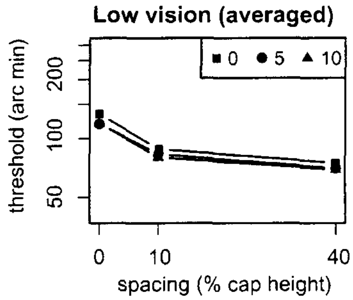

Fig. 6. Average (geometric mean) low vision data from Experiment 1.

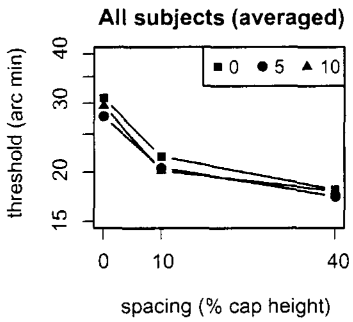

Fig. 7. Data of all subjects averaged (geometric mean) from Experiment 1.

## 5. Experiment 2: Rapid serial visual presentation reading

### 5.1. Procedure

In this experiment, we assessed the affect of serif size on reading using the RSVP reading technique. This technique, in which words are presented one at a time in the center of the computer monitor, allows reading at higher speeds than with continuous verbal reading (Rubin & Turano, 1994; Rubin & Turano, 1992), especially for normally sighted readers (Rubin & Turano, 1992), and therefore might plausibly be more sensitive to subtle differences in legibility. To further enhance this sensitivity, we used sentences from an expanded MNREAD corpus. These sentences are by design 56 characters long (including interior spaces) with comparable comprehensibility (See Mansfield, Ahn, Legge, & Luebkerr, 1993 for details). Since the sentences are very short, readers can store most or all of each sentence in short-term memory, and report the sentence verbally without needing to maintain a high rate of verbal output, which might otherwise limit speeds. Word presentation rate, which was controlled by a desktop computer, was varied only between sentences, by an amount that was contingent on reading error rate.

We compared only the three fonts with 10% cap height spacing using this technique, because we had a limited number of 56-character MNREAD sentences (357), and wanted to obtain error rates for a range of presentation rates. Subjects were given practice on 60-character MNREAD sentences prior to testing.

The experimenter determined informally during the practice phase the speed region in which the subject began to make errors, by increasing speed by 20% if no errors were made, and decreasing speed if errors were made. Once data collection began, the speed increments and decrements were reduced to 10%, and data collection proceeded in staircase fashion, such that if no errors were made, the speed was increased; if no words in the sentence were correctly identified, the speed was reduced. Our goal was thus to obtain nonzero error rates for several presentation speeds, sampling a wide range of the sloping portion of the psychometric function. We obtained estimates of between 5 and 10 speeds for each of the three conditions, for each subject. Error rates (in characters per 56-character sentence) were then fit by probit (Finney, 1971), to a cumulative Gaussian. Maximum reading speed was taken to be the speed in words per minute, at which 50% errors were made. Following the method of Carver (1976), speeds in words per minute were computed by assuming that each sentence was composed of 9.33 standard length words (each six letters in length) and dividing by the exposure time for the sentences.

Viewing distances and font sizes were chosen to approximate an acuity reserve of about seven, easily enough for comfortable reading (see Table 1).

Table 1
Viewing distance, font *x*-height, log minimum angle of resolution (log MAR) and acuity reserve for the four participants of Experiment 2

| Participant | Viewing distance (cm) | *x*-height (cm) | log MAR | Acuity reserve |
|---|---|---|---|---|
| SM | 50 | 2 | 0.6 | 6.9 |
| MG | 30 | 3 | 1.0 | 6.8 |
| AG | 100 | 0.9 | −0.1 | 7.8 |
| IF | 100 | 0.9 | 0.0 | 6.2 |

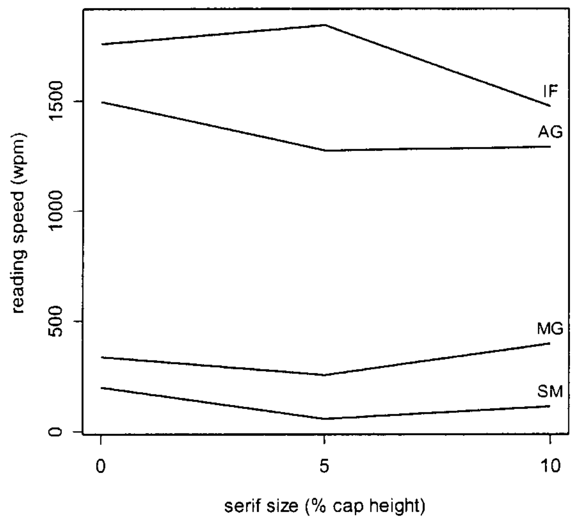

Fig. 8. RSVP reading speeds for 10% cap height letter spacing, as a function of serif size. Speeds correspond to 50% error rate, as fit by probit. Participants MG and SM have low vision, while IF and AG have normal vision.

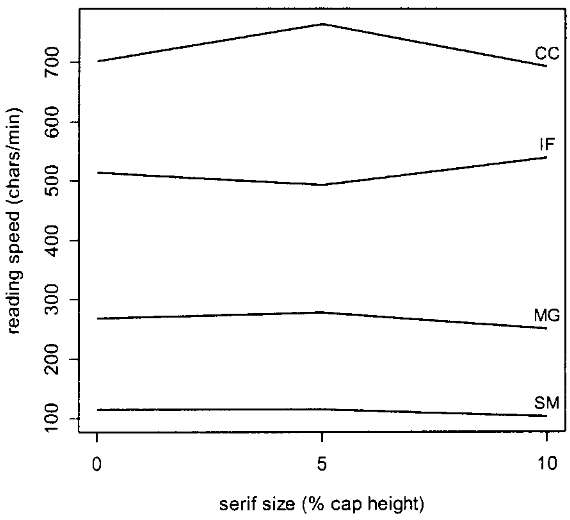

Fig. 9. Continuous reading speeds for text with 10% cap height letter spacing, as a function of serif size. Participants MG and SM have low vision, while IF and CC have normal vision.

### 5.2. Results

Fifty percent of correct RSVP speed thresholds for the four participants reading the three fonts are shown in Fig. 8. The data show no systematic effect of serif size on reading speed. This was corroborated by a repeated measures ANOVA, which resulted in no significant effects.

Note the high reading speeds measured for normally sighted subjects AG and IF. Very high speeds have previously been reported by Rubin and Turano (1992). Our use of short sentences may have made such high rates possible, since the reader could keep the entire sentence in short-term memory prior to reporting it. Also, the reading speeds we report (for computational convenience) correspond to an estimated 50% character error rate, which is a much higher error rate than would be tolerated in ordinary reading.

## 6. Experiment 3: Continuous reading on paper

### 6.1. Procedure

Participants were given the scrambled reading passages and asked to read them aloud as quickly and accurately as possible. The two subjects with low vision (MG and SM) used their customary optical reading aids, which were a 6× Eschenbach halogen illuminated stand magnifier (MG) and a 4× Eschenbach torch hand magnifier (SM). Participants were allowed to hold the passages in their hands, and no attempt was made to control or advise reading distance. Reading of the passages was timed with a stop watch and errors recorded. Credit was given for each whole word read correctly. Reading speed was taken as the number of characters within correctly read words divided by the time taken to read the passage.

### 6.2. Results

Reading speeds, in characters per minute, are shown for each subject in Fig. 9. Again, there are no systematic differences in reading speed as a function of serif size, and, as with RSVP reading, this was corroborated by failure to find any significant effect in a repeated measures ANOVA.

## 7. Discussion and conclusion

In Experiments 2 and 3, the presence or absence of serifs made no difference in reading speed, for all participants, both normally sighted and those with low vision. Only in Experiment 1, which used an acuity criterion of legibility, was a statistical effect of serif size observed. The size of the observed effect was extremely small, however. Looking at the average data of Fig. 7, the range of the size threshold fell within 3.14 arc min (or about 0.11 of the threshold) for the zero spacing condition, 1.76 arc min (0.08 threshold) for the 10 min spacing condition, and 0.14 arc min (0.01 threshold) for the 40 min condition, with the intermediate (5% cap height) serifs yielding the lowest thresholds, and highest legibility.

Note that a small degree of legibility enhancement would be expected for serifs due to the increased letter spacing that the addition of the serifs requires. In the fonts used in the current experiment, 14 of 26 of the letters have serifs along the baseline that add separation between the letters. On average, the increased separation is equal to 14/26 × serif size. For the 5% serif font, the increase in letter spacing is 2.69% cap height; for the 10% serif font, the increase is 5.38%. The average slope of the linear segment between 0 spacing and 10% cap height spacing is −2.56; that is, for each percent cap height increase in letter spacing, threshold decreases by 2.56 arc min. The 5% serif, then, should provide a $2.69 \times 2.56 = 6.88$ arc min reduction in size threshold, while the 10% serif should result in a $2.56 \times 5.38 = 13.77$ arc min reduction, on the basis of increased letter spacing alone. These reductions are far greater than those observed, and therefore we conclude that, at least at very small letter sizes, close to the acuity limit, serifs may actually interfere ever so slightly with legibility. This reduction is more than offset by an enhancement of legibility caused by the increased spacing that results from the addition of serifs, so the net effect is one of slightly enhanced legibility for the intermediate (5% serif) fonts.

This could also help explain why the slight enhancement of legibility due to increased spacing due to serifs is no longer seen in the 10% serif font, which has even wider spacing. It is certainly plausible to posit that in the case of the 5% serif, the serif and the additional letter spacing required to accommodate it has a legibility-enhancing effect that is stronger than any legibility-reducing effect of the serif. But in the case of the 10% serif, more inter-letter spacing does not outweigh the serif's stronger legibility-reducing effect, perhaps because the relief from crowding is greater when inter-letter separation is zero, while the serif's legibility-reducing effect may be independent of spacing. The idea that serifs might reduce legibility is also consistent with the recent finding of Morris, Aquilante, Yager, and Bigelow (2002), who found reductions in RSVP reading speed with seriffed but not sans-serif type at sizes close to the acuity limit (4 pt type at 40 cm), and not at larger sizes.

We wish to offer three concluding caveats. First, we have only studied a single font of our own parametric design. It is possible that serifs in other fonts, especially those designed with the critical eye of an expert font designer, may have more of an impact. On the other hand, while our font choices were to a degree arbitrary, we can think of no reason why they would bias our results against finding stronger serif effects on legibility.

Second, we have used a small sample of participants. It is certainly plausible that subtle differential legibility effects of legibility could emerge from a larger study. The present results are best taken to mean that substantial legibility effects are absent; we can conclude little about more subtle effects.

Third, while two subjects with AMD were included in the participant sample, no firm or general conclusions can be drawn about AMD or low vision, with respect to font legibility. Again, if such effects exist, they are either subtle enough to be undetected by our experimental methods, or they exist only within a subpopulation not well represented by our two subjects with AMD.

In sum, we did find a small effect of serifs on size thresholds, but it is unlikely to be of significance at typical print sizes viewed under normal conditions. While subtle effects on reading rate may emerge with larger subject samples, the miniscule differences we found with this small sample were apparent only with visually tiny print.

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