C H A P T E R

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# Typography, Print Legibility, and Low Vision

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## Key Terms

- legibility
- reading acuity
- typography
- letter stroke width
- letter aspect ratio
- letter spacing
- crowding
- Americans with Disabilities Act

The loss of ability to read is well known to be one of the most disabling functional problems experienced by those with low vision,[1] and providing renewed access to text after vision loss is a focal task of vision rehabilitation.

Most methods for remediating reduced access to text in low vision employ magnification, because increasing optical size of letter and word patterns and distributing their information over a larger retinal area is highly effective in increasing the ability to identify visual patterns. Magnification may be done optically at the eye, or environmentally at the text stimulus (as with large print and signage).

It is so effective and consistent a visual aid that pattern processing capability itself is often characterized by the amount of image magnification an individual requires for effective visual processing. Thus using standard letter optotypes as patterns, *letter acuity* measurements identify the minimum retinal size an individual requires for reliable letter identification. Similarly, *reading acuity* measurements use standard fonts to identify the minimum retinal size an individual requires for reading. In this way, relative magnification of just discriminable standard stimuli is used to characterize the visual resolving capabilities of patients.

Magnification can also be used in a similar way to characterize the relative discriminability, legibility, or readability of text fonts and optotypes. In other words, rather than using standard optotypes and fonts to assess observers, visual acuity itself can be used to access relative legibility, by comparing acuities obtained under different typographic conditions within research subjects. Compared to other measures of legibility such as reading speed,[2,3] reading acuity is an appropriate measure of legibility in the context of low vision, since so many low vision patients must read letter by letter, at their acuity limit.

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Using such acuity methods, we have recently begun to identify general characteristics of letter forms and typography that make text more or less readable, and optotypes more or less legible. Previous attempts to study text legibility parametrically have lacked generality, using only one or two numeral forms at a time, and testing perceptibility[4-6] or exposure duration[7] rather than letter discrimination.

We use a font design program, written in the METAFONT[8] computer language, whose parameters may be independently adjusted to produce a family of fonts that vary in selected ways thought to have strong effects on legibility: stroke width, letter spacing, and width-to-height (aspect) ratio. This program also generates the Sloan letters used in the Lighthouse/ETDRS acuity chart and the British letters used in the Bailey-Lovie chart with suitable adjustment of parameters. The Sloan letters are among those in the upper row of Figure 11-1.

Generally, our methods are to present random five-letter text strings using the fonts of interest on an optically minified CRT, which brings the text on the display close to the acuity limit. If the observer

| Sample | stroke | width:height | spacing |
|---|---|---|---|
| ABCDEFGHIJKLM NOPQRSTUVWXYZ | 1/5 | 1:1 | 1/10 |
| ABCDEFGHIJKLM NOPQRSTUVWXYZ | 3/10 | 1:1 | 1/10 |
| ABCDEFGHIJKLM NOPQRSTUVWXYZ | 1/20 | 1:1 | 1/10 |
| [illegible] | 1/10 | 1:5 | 1/10 |
| ABCDE FGHIJ PQRST KLMNO UVWXYZ | 1/10 | 5:1 | 1/10 |
| ABCDEFGHIJKLM NOPQRSTUVWXYZ | 1/10 | 1:1 | 1/20 |
| A B C D E F G H I J K L M N O P Q R S T U V W X Y Z | 1/10 | 1:1 | 3/5 |

**FIGURE 11-1** Font samples illustrating several typographic parameters. The first three samples differ only in stroke width; the fourth and fifth samples differ only in width-to-height ratio; the sixth and last samples differ only in interletter spacing. Stroke width and spacing are expressed in units of letter height.

identifies all five letters correctly, the text is reduced in size by 0.05 log unit; if at least one letter is incorrectly identified, the letter size is increased by 0.05 log unit. After 24 reversals of this psychophysical staircase, the average text size of letters presented is computed, and represents the 90% correct identification threshold. For comparison to visual acuity data, this size can be presented as the minimum angle of resolution (MAR), conventionally defined as $\frac{1}{5}$ the letter height.

## Letter Stroke Width

Figure 11-2 shows how legibility (as measured by letter acuity) varies as a function of stroke width for each of five subjects, and for each of three letter spacings (parameter).[9] The fonts used were among the family shown in Figure 11-1 with 1:1 width-to-height ratio. For the widest spaced letters (triangles), legibility is an inverted U-shaped function of stroke width, with very thin and very thick letters being more difficult to identify. It is reasonable to suppose that the thickest stroked letters become less legible because gaps and other features that distinguish the letters are more difficult to resolve (Figure 11-1, row 2). Effects of letter spacing on thinner stroked letters are discussed later.

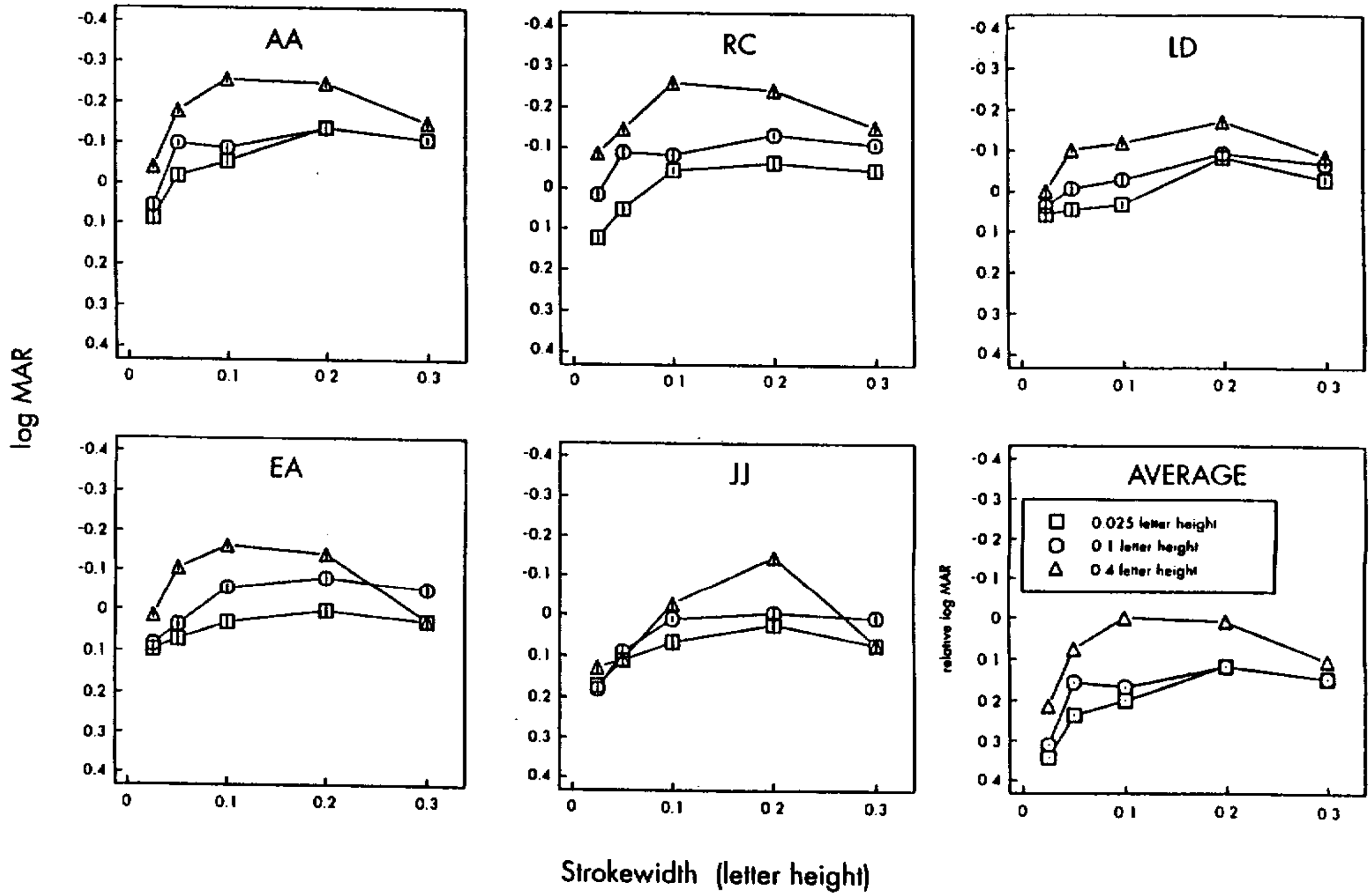


**FIGURE 11-2** Legibility expressed as log MAR, as a function of letter stroke width for five subjects and three spacings (shown in the inset in the lower right panel). Average data are shown as departures from maximum legibility. Standard error bars are shown only for individual subject's data. (From Arditi A et al: Letter strokewidth, spacing, and legibility. In *Vision science and its applications*, vol 1, OSA Technical Digest Series, Washington, DC, 1995, Optical Society of America, 324-327.

One of the most interesting aspects of these data is that there is a range encompassing at least an octave (0.1 to 0.2 letter height) of stroke widths in which there is little (less than 0.1 log MAR, equivalent to one chart line) variation in legibility. While this seems to be true for these normal observers, low vision patients, especially those with reduced contrast sensitivity due to ocular media opacities and reduced retinal illuminances, may have particular difficulty with thinly stroked letter forms,[10] because they contain less contrast energy than do thickly stroked letters.

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## Letter Form Aspect Ratio

The width-to-height ratio of letter forms also has a strong impact on legibility as defined by minimum discriminable size (Figure 11-3).[11] In this case, where the aspect ratio varies, minimum size is not easily characterized. In the figure, the data are plotted in three ways: column A as a function of minimum vertical size, column B minimum horizontal size, and column C minimum vertical or horizontal size, whichever is greater. Expressed as in *A*, legibility increases with width-to-height ratio throughout the range of aspect ratios from 0.2 to 5, whereas it decreases throughout the same range, when expressed as in *B*. Both *A* and *B* indicate that adding horizontal *or* vertical extent to letter forms has an effect on legibility throughout this range of aspect ratios, although the direction of the effect depends on what measure of letter size is used. Rows 4 and 5 of Figure 11-1 illustrate the extremes of the aspect ratios tested in Figure 11-3. In this experiment, each aspect ratio tested other than unity had a counterpart with reciprocally-valued aspect ratio that was also tested (e.g., 0.2 and 5).

Figure 11-3 exhibits an interesting asymmetry, most apparent in the right-hand column of the graphs. Fonts with width-to-height ratios less than unity are consistently more legible than their counterparts

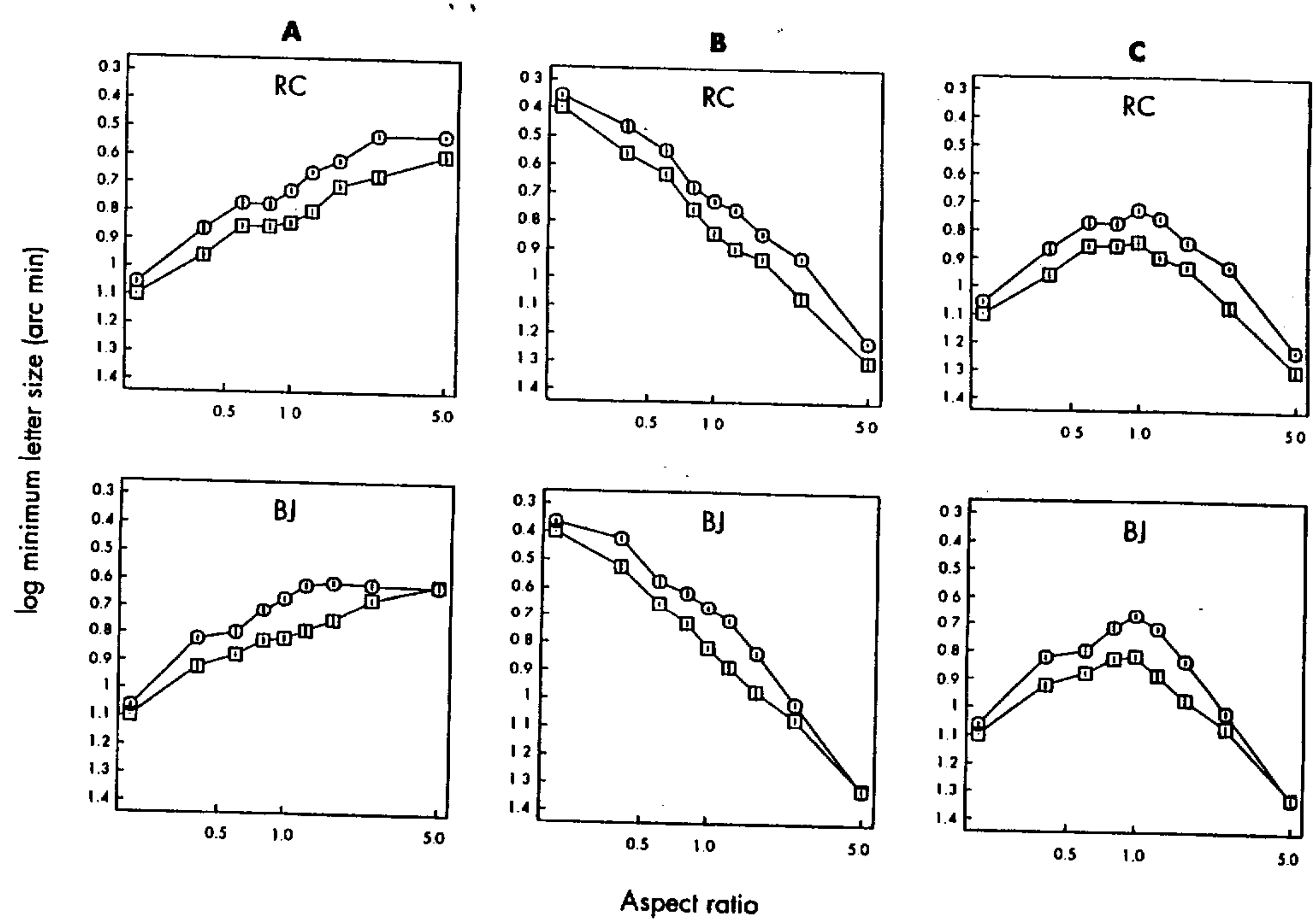


**FIGURE 11-3** Legibility measured as log minimum letter size, as a function of letter width-to-height ratio, for two subjects, at two interletter spacings (squares: 0.05 letter height, circles: 2 letter height). **Column A,** plots log minimum vertical size of letters. **Column B,** plots log minimum horizontal size of letters. **Column C,** plots log minimum size of the larger (vertical or horizontal) dimension.

with reciprocal aspect ratio. This may be due to the greater amount of vertical than horizontal information distinguishing uppercase letters in the spatial-frequency bands used in the acuity discrimination.

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## Letter Spacing

A third typographic variable of interest is that of interletter spacing. Acuity for letters or optotypes presented in close proximity to other letters [2,12,13,14,15] or other contours [13,16] is widely known to be significantly worse than it is for isolated letter or optotype forms. Such deficits, known as "crowding" phenomena, have been found to be worse in amblyopia and in disorders of the central visual field,[13,15,16,17,18] and thus may have special relevance to low vision.

Close spacing has also been shown to reduce reading speed at letter sizes close to the acuity limit,[2] but not with larger letters.[2,3] With larger letters, close spacing actually improves reading speeds,[19] probably because eye movement requirements for reading such text are more modest.[2]

Given the substantial literature on crowding phenomena, it is not surprising that close spacing also results in reduced acuity for text strings. This is demonstrated in Figure 11-2, which also plots effects of stroke width on acuity. What is of particular interest about these data is that for the two closer and less legible spacings shown in the figure (0.1 and 0.025 letter height), legibility does not suffer so much when letters are very thickly stroked, as it does for the wider spacing (0.4 letter height). With close spacing, small gaps probably do not serve as such effective marks to distinguish letters since they exist between and within letters. Additionally, with close spacing the letters are more difficult to localize than they are when separated by more space.

Figure 11-4 shows the same data as Figure 11-2, replotted to emphasize effects of spacing on legibility. In general the effects of spacing (crowding) are similar for all stroke widths except the thickest, where wide spacing fails to offer an advantage.

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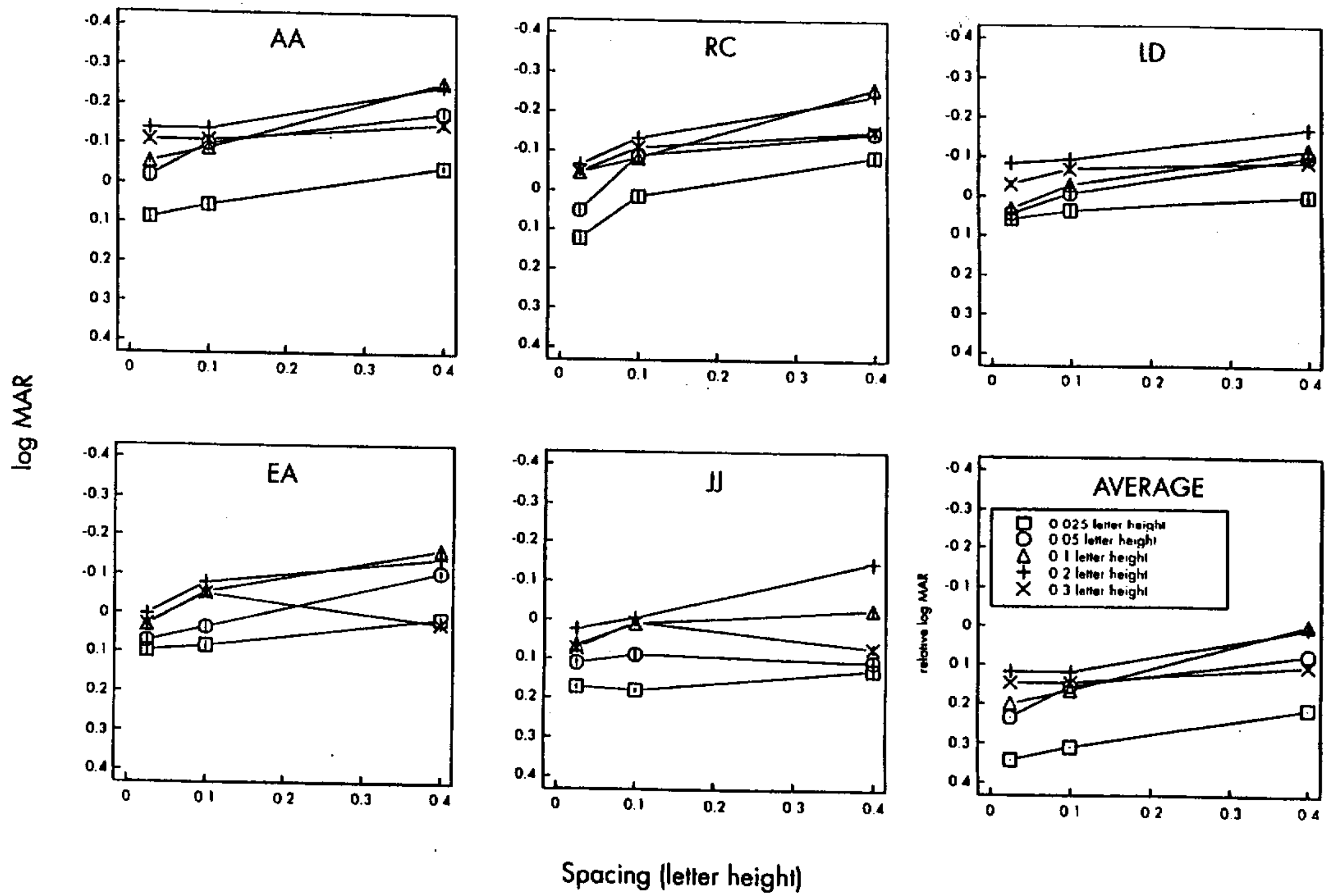


**FIGURE 11-4** The same data as Figure 11-2, replotted as a function of spacing to show effects of letter spacing. (From Arditi A et al: Letter strokewidth, spacing, and legibility. In *Vision science and its applications*, vol 1, OSA Technical Digest Series, Washington, DC, 1995, Optical Society of America, 324-327.

At ARVO in 1993[20] and at the International Low Vision Conference in 1993,[10] we proposed that crowding phenomena were simply an instance of lateral masking of the target letter by neighboring contours. We hypothesized that since spatial masking occurs predominantly within spatial-frequency bands, crowding phenomena should depend on the spectral composition of the target and neighboring forms. Since the Fourier spectra of thickly stroked letters have more energy at lower object spatial frequencies than do thinly stroked letters, they can exert a masking influence over a larger neighboring region. Our finding that crowding effects are no greater for thickly stroked than for thinly stroked letters suggests that contrary to our earlier beliefs, crowding is not an instance of spatial-frequency dependent lateral masking. It is also possible that crowding is an instance of lateral masking, but that information critical to letter identification at the acuity limit exists within a fixed object spatial-frequency band.

As to potential interactions between aspect ratio and letter spacing, the data of Figure 11-3 do not show any evidence for them. That is, spacing and aspect ratio seem to have independent effects on legibility.

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## Other Typographic Variables

There are many other typographic variables that can affect legibility of text. Arditi, Knoblauch, and Grunwald[2] found proportionally spaced fonts to be more legible than fixed space fonts at most character sizes, but found fixed space fonts to be more legible at retinal sizes close to the acuity limit. Morris et al.[21] also found proportionally spaced fonts to be superior to fixed space at sufficient sizes, and Mansfield et al[22] replicated Arditi et al's results at the acuity limit.

Italics, slanted fonts, and decorative/ornate styles are all thought to be less legible,[23,24] but this probably has less to do with their physical characteristics than with readers' relative lack of familiarity with the letter forms.

Many studies of reading performance have focused on the role of contrast.[3,25,26] All are consistent with the views that increasing contrast never decreases legibility, and that it generally increases legibility for patients with effective contrast reductions due to pathology, and for normally-sighted individuals viewing low contrast text. In addition, there is some evidence that for patients who report significant problems with glare, white text on a black background is more legible than the reverse, presumably because the amount of light entering the eye in the region of the text is lower in the former case than in the latter. Thus for designers of text displays, maximum legibility for the largest proportion of the normally-sighted and visually impaired population seems to be achieved with the highest feasible contrasts, using white letters on a dark background.

What color combinations result in the highest text readability? The few studies that have addressed this issue[27,28] have in general found that the most important chromatic determinant of readability is the luminosity contrast component of the color combination comprising the letters and background of the text display. In other words, for the standard observer (with a standard spectral luminosity function), hue and saturation per se are irrelevant—the luminance contrast between the colors chosen for letters and background alone determines the readability. Of course, relative to the standard observer most low vision patients have some color defect, either congenital or acquired through aging or disorders producing spectrally nonuniform ocular media opacities or selective cone losses. These color defects often result in luminosity functions that differ markedly from the standard observer. As a result, some color combinations produce higher effective contrasts and hence higher readability than others for these observers.

Further discussion of this issue and a set of three simple rules for optimizing color contrast are contained in a chapter by Arditi and Knoblauch entitled *Effective color contrast and low vision* that appears in the companion to this volume.[29] Also, nontechnical brochures describing 10 guidelines for increasing print legibility and how to compose effective color contrasts for partially-sighted individuals are available free from The Lighthouse Inc.[23,30]

## The Role of Typography in Vision Rehabilitation

As noted earlier, amelioration of vision loss may be provided proximally to the eye, as with an optical or optoelectronic magnifier, or environmentally, by large print or large signage. Proximal vision aids that increase the retinal size of the visual stimulus are generally more portable and more easily adjustable to the patient's individual needs as far as focus, field of view, lighting level, etc.

But magnification alone is often insufficient to provide successful access to text in some reading situations, particularly outside the home (e.g., reading signs) where adjustments of light, magnification, and viewing distance cannot be easily controlled by the patient. Although telescopic aids can be used in such situations, they are difficult to use effectively and often require a great deal of skill and training.[31] Furthermore, magnification range is generally more limited since the devices must be handheld or headmounted and are therefore more susceptible to hand and head tremor. Increasing text size environmentally may also be infeasible due to limited sign space or economic constraints (e.g., size and/or number of pages in a large print book).

The Americans with Disabilities Act (ADA) of 1990 has recognized the importance of visual signage enhancement in its Title III Guidelines for Buildings and Facilities (ADAAG) published July 21, 1991.[32] The ADAAG, which addresses public accommodations and commercial facilities,* has, for various types of signs, requirements that are intended to provide increased legibility by means of specifying ranges of type style, letter size, proportion and stroke width, sign finish, and a recommended contrast minimum. Unfortunately, these guidelines were written without sufficient research to specify such ranges with confidence.

One reason why such research has been lacking is that until recently, ability to vary typographic parameters was costly, and there was little need to specify in general terms the effects of typographic variation on legibility. With the advent of computerized typography,[33] infinite variations of typefaces are very easy to implement. This makes it easy to abuse typography, and at the same time allows the study of how general typographic parameters affect text legibility, and the potential for customizing typography for maximum legibility for persons with low vision.

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* These terms have technical meanings that are too lengthy to describe here, but which cover a wide range of privately operated and privately owned business facilities, and facilities that provide goods and services to the public.

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