Reading difficulty is a major consequence of vision loss for more than four million Americans with low vision. Difficulty in accessing print imposes obstacles to education, employment, social interaction and recreation. In recent years, research in vision science has made major strides in understanding the impact of low vision on reading, and the dependence of reading performance on text properties. The ongoing transition to the production and distribution of digital documents brings about new opportunities for people with visual impairment. Digital documents on computers and mobile devices permit customization of print size, spacing, font style, contrast polarity and page layout to optimize reading displays for people with low vision. As a result, we now have unprecedented opportunities to adapt text format to meet the needs of visually impaired readers.

Keywords

low vision, reading, readability, legibility, digital typography, typography

Typographic variables for digital low vision reading:

- Print size and display size matter: magnification is usually necessary.
- High contrast is often essential.
- Bright displays and contrast reversal are desirable.
- Inter-line and inter-word spacing may help.
- Font effects are small, but fixed width fonts may be helpful when reading near the acuity limit.
1 Introduction

The term low vision was coined in the 1950s by eye-care clinicians to convey the idea that vision can vary between the extremes of Sighted and Blind. Low vision refers to any chronic form of vision impairment not correctable by glasses or contact lenses that adversely affects everyday function. The boundary between normal vision and low vision is sometimes based on the inability to read newsprint at a standard viewing distance of 40 cm (16 inches) with best optical correction. This definition is used because most people with low vision have problems with reading texts designed for people with normal vision (Elliott et al., 1997; Owsley et al., 2009).

Letter acuity is the traditional clinical measure of vision, dating from the eye chart introduced by the Dutch ophthalmologist Herman Snellen in 1862. Four notable values on the Snellen scale of print size illustrate the range of reading vision. A Snellen acuity of 20/20 is the conventional standard for normal vision, and refers to letter sizes at the acuity limit subtending 5 minutes of arc (min-arc) of visual angle.

At a reading distance of 40 cm, an x-height of 0.58 mm subtends 5 min-arc. Typical newspaper print has an x-height of about 1.45 mm, just 2.5 times larger than acuity letters, the font size that a person with 20/20 vision can just barely see. One criterion for low vision is an acuity less than 20/60, meaning the acuity letters for 20/60 vision are more than three times larger than the standard for normal vision, and larger than typical newspaper print. The criterion for legal blindness is 20/200 or less (acuity letters at least 10 times larger than the normal limit). With high magnification, people with acuities as low as 20/2000 (acuity letters 100 times larger than 20/20 letters) can read. This wide range of reading acuities emphasizes that low vision, even very low vision, is compatible with reading, provided that adequate magnification is available.

The World Health Organization (2014) estimated that there are 285 million people worldwide with vision impairment, 39 million blind1 and 246 million with low vision. These figures include many people in less developed countries whose impaired vision is due to uncorrected refractive errors or untreated cataracts. According to the National Eye Institute (2014), there are between 3.5 and 5 million Americans with low vision, and the number is rising as the U.S. population ages. Because the leading causes of visual impairment in the United States are age-related eye diseases—macular degeneration, glaucoma, diabetic retinopathy and cataract—the prevalence of impaired vision rises steeply with age. Reading poses problems for almost everyone with low vision because the print size in everyday text is too small.

Traditional hard copy reading is not inclusive of people who are blind or have low vision. Marshall McLuhan (1962) in his famous essay

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1. The World Health Organization defines people with acuities less than 20/400 as “blind,” but, as indicated above, some people with acuities as low as 20/2,000 can read visually, given high magnification.

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This quotation was brought to my attention by Cattaneo & Vecchi (2011).
synthetic speech. A major development in nonvisual text accessibility has been the inclusion of synthetic speech software (VoiceOver) as a standard component in Apple’s iOS and Mac operating systems.

In short, the migration of text into digital formats brings with it enormous opportunities for enhancing text accessibility for people with impaired vision.

2 From Paper to Screens

Prior to the digital age, the primary method for facilitating low-vision reading was magnification, and the primary technology was optics. Optical magnification continues to be an important part of low-vision reading rehabilitation. Table 1 lists some highlights in the development of low-vision reading technology in the pre-digital era.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1270</td>
<td>Marco Polo discovered older people in China using magnifying glasses for reading.</td>
</tr>
<tr>
<td>1637</td>
<td>First magnifying aid for visual defects; René Descartes described a solid glass cone with a plano front surface and a concave back surface.</td>
</tr>
<tr>
<td>1829</td>
<td>Louis Braille published his invention of a tactile code for reading.</td>
</tr>
<tr>
<td>1908</td>
<td>The Myope School in London was the first class for children with low vision.</td>
</tr>
<tr>
<td>1909</td>
<td>Moritz von Rohr, employed by Carl Zeiss, designed a telescopic lens to correct high myopia.</td>
</tr>
<tr>
<td>1913</td>
<td>Edward Allen, Director of Perkins Institute, opened the first U.S. class for children with low vision.</td>
</tr>
<tr>
<td>1916</td>
<td>The Clear Type Publishing Company produced a series of books in 36 point font.</td>
</tr>
<tr>
<td>1924</td>
<td>The American Foundation for the Blind began supplying telescopic lenses and referring clients to eye-care practitioners.</td>
</tr>
<tr>
<td>1947</td>
<td>The American Printing House for the Blind began regular publication of large print books.</td>
</tr>
<tr>
<td>1969</td>
<td>Samuel Genensky and colleagues at the Rand Corporation reported on their development of a closed circuit television magnifier for low vision.</td>
</tr>
</tbody>
</table>

There are three general forms of magnification for reading—enlarge the print size on the page, reduce the viewing distance, and use a magnifier. Some published materials are available in “large print” formats. It is recommended that large print materials should be at least 16 to 18 points (Arditi, 1999). The vast majority of published material is not available in large print. Even when large-print publication is an option, there are practical limitations on the sizes of pages and books. For this reason, large print rarely exceeds 20 pt. For many people with low vision, 20-pt print provides insufficient magnification.

The simplest method of magnification is to reduce viewing distance. Since angular character size (and, correspondingly, retinal image size) is inversely related to viewing distance, reduction of the viewing distance by a factor of N accomplishes N-fold magnification. For instance, viewing the newspaper from 20 cm rather than 40 cm (a factor of two) is equivalent to magnifying print size by a factor of two. But this approach requires the reader to focus for the nearer distance. Young people who have a wide range of accommodation, or people who are myopic (short-sighted), may be able to focus at distances of 10 or 20 cm. Most people, especially older people with presbyopia (the absence of accommodation, encountered by almost everyone over 50), will require a lens to focus print at short viewing distances. Lenses used for this purpose are termed magnifiers.

Optical magnifiers for reading come in three general types—hand-held, spectacle-mounted or stand magnifiers that rest on the page. Enlargement of the characters in a local region of text by a magnifier brings about the need to move the magnifier across the lines of text. This process is sometimes termed page navigation and imposes demands on eye or head movements and manual dexterity. For reviews of properties and principles for prescribing low-vision magnifiers, see Bailey, Bullimore, Greer and Mattingly (1994) and Sloan (1977).

Optical magnifiers are effective reading aids for people with mild forms of low vision. For people with acuities of less than 20/100, requiring magnification of 6X or more, optical magnifiers become difficult to use because of the restricted field of view and the increasing demands of page navigation.
A major step in alleviating the problems associated with high-power optical magnifiers was to move text from small print on a page to highly magnified print on a television screen (Genensky, 1969). Figure 1 illustrates the display of text on a closed-circuit TV (CCTV) magnifier for a reader with very low acuity. The device includes a video camera, pointed downward, imaging a page of text lying on a moveable X-Y table. The camera zoom is adjustable, allowing for high magnification, up to 64 times or more (ratio of character size on the screen to character size on the hard copy page.) The user can view different portions of the page by moving the table left/right or forward/back beneath the camera. In the example shown, the user has adjusted magnification so that the x-height on the screen is 1.3 inches, about 19 times larger than the characters on the page (Courier 10 pt). This user views the screen from a distance of 13 inches, with the result that the angular character size is almost 6°.

Notice that this low-vision reader prefers bright letters on a dark background rather than the conventional dark letters on a white background. Some people with low vision have higher acuity and read better with reversed-contrast text. CCTV magnifiers are designed to include options for reversing contrast polarity.

The original CCTV magnifiers were desktop devices. A recent development has been the advent of portable electronic magnifiers. An example is shown in Figure 2. These are handheld devices with a built-in LCD screen, a range of zoom, and the capability for contrast reversal. The user moves the magnifier across a page containing text. There are now many portable electronic magnifiers on the market.

The American Foundation for the Blind (AFB) lists technology resources for people with vision loss at [http://www.afb.org/info/living-with-vision-loss/using-technology/12](http://www.afb.org/info/living-with-vision-loss/using-technology/12). In a review of low-vision reading aids, Virgili et al. (2013) found that there is some limited evidence that desk-mounted or hand-held electronic reading aids yielded faster reading than stand or hand-held optical magnifiers.

The CCTV magnifiers are devices for magnifying hardcopy print. They deal with text in analog form. A big leap forward toward accessibility of digital text for low vision was the advent of computer software for screen magnification. Figure 2 shows text magnified by the software program ZoomText on a computer display. Like the CCTV magnifiers, screen magnification software is designed with a wide range of zoom and the capacity for contrast reversal. The user scrolls through the text by moving the mouse or by taking advantage of the program’s auto scrolling capability.

There is growing evidence that people with low vision are taking advantage of digital displays for reading. In an internet-based survey of 132 people with impaired vision (26% with no vision and 74% with low vision), Crossland et al. (2014), found that 81% used a smartphone. Of the smartphone users, 51% used the camera and screen for magnification. Gill et al. (2013) studied 27 subjects with stable age-related macular degeneration. They compared reading speeds for matched print size on paper, an Apple iPad and a Sony eReader. Reading speeds were slightly faster on the iPad than paper, and slightly faster on paper than the eReader. The authors attributed the differences to the bright, high-contrast display of the iPad. Morrice et al. (2015) compared the reading speeds of 100 low-vision subjects on a CCTV magnifier, and apple iPad and the subject’s preferred optical magnifier. Reading speeds did not differ significantly across the three conditions. The authors emphasized the significance for rehabilitation of the use of a mainstream technology (the iPad) for low-vision reading magnification.

Once text is in digital form and of sufficient print size, we can ask how other text properties affect low-vision reading.

### 3 Measuring Reading Vision

If we want to measure the impact of text properties on reading, we need a method for measuring visual reading ability. Miles Tinker long ago introduced reading speed as a metric. For a review of his many contributions to understanding the effects of typographic variables on normally sighted reading, see Tinker (1963). A great deal of recent psychophysical research on reading has used reading speed because it is straightforward to measure objectively, is sensitive to changes in both eye condition and text properties, and is functionally significant to readers. For a discussion of methods of measuring reading speed and a comparison to other metrics for measuring reading performance, see Legge (2007, Ch. 2). For a review of clinical tests for assessing visual aspects of reading, see Rubin (2013).

Figure 3 shows the MNREAD reading-acuity chart designed by my colleagues and me (Mansfield et al., 1993; Mansfield & Legge, 2007). The chart is printed on two sides, and is composed of 19 sentences in a progression of print sizes differing by about 26% (0.1 log unit) per step. At 40 cm viewing distance, print sizes range from 20/400 to 20/6. 20/6 letters are more than 3 times smaller than 20/20 letters, tinier text than anyone can read. For low-vision testing requiring letters larger than 20/400, shorter viewing distances can be used (20 cm or even 10 cm) yielding corresponding increases in angular print size. Sentences on the chart are matched for geometric layout (each sentence is formatted on three lines with the same aspect ratio), and linguistic properties including high-frequency vocabulary. There are exactly 60 characters in each MNREAD sentence. The sentences have been pilot tested to ensure uniform readability.
My father takes me to school every day in his big green car.

Everyone wanted to go outside when the rain finally stopped.

They were not able to finish playing the game before dinner.

In the test, subjects are instructed to read the sentences aloud as quickly and accurately as possible. They are timed with a stopwatch, and errors are recorded. These measurements are converted to reading speed in words per minute as a function of print size.

Figure 4 shows sample data for a normally sighted subject (A) and a low-vision subject (B). Reading speed in words/minute is plotted as a function of print size on a log scale.

Note that print size may be expressed as a physical measure on the page in units of mm or points (1 pt = 1/72 inch), or as the visual angle subtended in units of degrees (°) or minutes of arc (min-arc). Angular print size takes into account both the physical size of the characters and the viewing distance. Representing print size in terms of visual angles makes sense for vision researchers because angular size determines retinal-image size. Acuity letters on the 20/20 line of an eye chart subtend 5 min-arc. The "logMAR" unit represents angular print size as the logarithm (base 10) of print size divided by the size of 20/20 letters. This means that print sizes of 20/20, 20/200, and 20/2000 have logMAR values of 0, 1.0 and 2.0 respectively.

The curves in Figure 4 exhibit a typical form characterized by the subject’s Reading Acuity (RA), Critical Print Size (CPS) and Maximum Reading Speed (MRS). RA is the smallest print that can be read. CPS is the inflection point in the curve, indicating the smallest print that can be read at maximum reading speed. MRS is the reading speed on the plateau, 225 words/minute for subject A with normal vision in Figure 5. As discussed in the next section, low-vision subjects often have larger values of RA and CPS, due to their lower acuity, and also lower maximum reading speed (42 words/minute for subject B in Figure 4).

Figure 4 also illustrates the computation of a summary parameter called the Reading Accessibility Index (ACC). It is the average reading speed, computed over the print size range from 0.4 to 1.3 logMAR, normalized by the mean value of 200 words/minute for a group of normally sighted, young adults (Calabrese et al, 2016). This range of print sizes encompasses the vast majority of print encountered in contemporary texts (Legge & Bigelow, 2011). The ACC is intended as a single-valued measure of the accessibility of print and depends on both the subject’s range of visible print sizes and the speed of reading within the visible range. An average normally sighted reader would have an ACC value of 1.0. In Figure 4, subject A has an ACC value of 1.12, representing performance slightly better than the normal mean. Subject B with low vision has an ACC value of 0.12, representing severely reduced reading accessibility. Perhaps subject B’s range of visible print and/or speed could be improved with an optical or electronic magnifier, thereby increasing the reading accessibility value.

4 Impact of Text Variables on Low-Vision Reading

The impact of many text variables on low-vision reading has been studied. For a review, see Legge (2007). According to an online publication by the American Council of the Blind (2011), the most important text variables are print size, spacing, contrast and font style. All of these are modifiable by digital devices.
Print Size:

First, let's consider how print size affects reading speed for people with normal vision. This information can serve as a baseline for understanding deficits associated with low vision.

Figure 5 presents data from several experiments showing how print size affects reading speed for people with normal vision. Reading speed is plotted vertically against print size, measured as x-height in degrees of visual angle over a wide range. The curves rise steeply at the small-print end to a critical print size, then flatten out for an intermediate range of print sizes, and then decline more slowly for very large print sizes.

The key result is that there is a large range (10-fold) of print size for which people with normal vision can achieve maximum reading speed—extending from the critical print size of 0.2° to 2°.

This range corresponds to x-heights from 4 points to 40 points at a reading distance of 40 cm. We refer to this as the fluent range of print size. Legge & Bigelow (2011) presented evidence supporting the hypothesis that the distribution of print sizes in historical and contemporary published works falls within this behaviorally-defined fluent range of print size. For reasons of economy and space, production of text has favored the small print end of the fluent range. The challenge for low vision is the lack of accessibility of print in this fluent range, especially toward the small-print end.

Figure 6 illustrates the impact of print on reading speed in low vision, measured with the MNREAD chart.

The red curves in the four panels show reading speed measurements for individual subjects with age-related macular degeneration (AMD), the commonest form of low vision in the United States. The upper white curves show the average data from a group of 15 age-matched normally sighted older adults (mean age 70 years). There are two important things to notice in the figure. First, the AMD subjects have larger critical print sizes (CPS), to achieve their maximum reading speed; this means they need magnified print for reading. The extent of the difference in CPS between the normal controls and the AMD subject can guide a clinician in deciding how much magnification is required for a reading magnifier.

Second, even with adequate magnification, the AMD subjects do not achieve normal reading speeds; the flat portions of the red curves lie below the normal curves. Several causes of this reduction of maximum reading speed in AMD have been explored, including instability of eye fixations (Crossland et al., 2004) and reduced visual span for reading (Cheong et al., 2008).

To achieve magnification of digital text, people with low vision often use large computer displays and/or screen magnification software. But what about the visual accessibility of text on portable digital devices with small displays?

Table 2 summarizes some measurements of print size on portable devices. Based on recommendations for large print books, a font...
size of at least 18 to 20 pt is required for low vision. This corresponds to roughly 9 pt x-height in this table. Values near or above this value are highlighted in red.

Bababekova et al. (2011) surveyed the font sizes and reading distances of more than 100 young normally sighted cell phone users for text messaging and web browsing. On average they held the phones a little closer than the standard 40 cm, 36 and 32 cm respectively. The corresponding angular x-heights of the cell phone print were close to the critical print size (CPS) for normally sighted readers of 0.2°, and the font point size of the print was much smaller than recommended for large print applications.

Houston et al., (2011) evaluated print sizes on six types of cell phones. Only the iPhone 4c in its 2X mode generated text that might be viable for low vision. They did their testing in the landscape orientation. For text messaging and web browsing, the print was 8.6 pt in x-height, not far from the 9-pt minimum x-height for large print. For symbols on the phone keypad, the print size was 15.4 point.

Charles Bigelow (personal communication) measured e-reader print sizes on the Nook GlowLight Plus (e-paper display at 300 pixels per inch), and also on the iPhone 6s Plus (Retina HD LCD display at 401 pixels per inch). Both e-readers offer at least 10 user-selectable font sizes. Using the Georgia font, and depending somewhat on the particular book, the Nook’s smallest print size x-height is approximately 1.1 mm (equivalent to 6.5 pt font size), less than the CPS for normal vision for a 40 cm viewing distance, and its largest print size x-height is approximately 10.0 mm (equivalent to 60 pt font size), almost three times the low-vision guideline for large type. On the iPhone 6s Plus iBooks e-reader, also using the Georgia font, the smallest print size x-height is approximately 0.9 mm, less than the CPS for normal vision and the largest print size x-height is approximately 3.9 mm (equivalent to 23 pt font size) which meets the low-vision guideline.

Keep in mind two additional user strategies for dealing with print size: First, small devices can be held closer to the eye, thereby increasing the angular print size, but with the added demand for near focus. Second, these devices generally allow pinch to zoom to provide larger print. But, because of their limited screen real estate, magnification is constrained by the number of large characters that can be displayed.

For many people with low vision, reduced acuity means that the required print size is much larger than a font size of 20 points, even with a short viewing distance. The small size of displays on mobile devices poses a major challenge. Four interacting factors may determine the viability of reading with such displays—print size, number of characters per line, line separation and font. Figure 7 illustrates these interactions in the case of a sample low-vision reader.

**Figure 7**
This figure simulates 2° text displayed on an iPad 3 and an iPhone 5 at viewing distances of 16” (top row) and 8” (bottom row). Only the iPad at 8” exceeds 12 characters per line and 10 words per screen for both Times (left panel) and Courier (right panel).

Spacing

Spacing has been of interest in studies of low-vision reading because of the crowding phenomenon. Crowding refers to the interfering effects of one target on the identification of a nearby target in the visual field. The spatial extent of crowding increases in peripheral vision (Bouma, 1970), meaning that target stimuli need to be farther apart for recognition. Crowding is a major cause of the reduced visual span in peripheral vision (Pelli et al., 2007; He et al., 2013). Macular degeneration, the leading cause of low vision in the United States, can result in the development of blind spots (scotomas) in central vision extending 5° or more and including the fovea. People with this condition must use peripheral vision for reading. It is reasonable to suspect that increased spacing between letters, words or lines would help their reading by reducing crowding.

Measurements of reading speed for normally sighted subjects have varied letter-letter spacing in a fixed-width font (Courier) from half of standard spacing to twice standard spacing (Chung, 2002; Yu et al., 2007). These studies found that reading speed peaks at the standard spacing. But does extra spacing help in low vision? In a limited experiment, Legge et al. (1985) tested two normal and four low-vision subjects. They read highly magnified text (6” or larger), with normal spacing, and 1.5x and 2x normal spacing. For all of the subjects, reading speed was highest for standard spacing and declined for extra spacing. Chung (2012) conducted a more
extensive test with 14 subjects with central-vision loss, and found essentially
the same result.

What about interline spacing? Two recent studies with low-
vision subjects found either no benefit of extra line separation (Chung et
al., 2008) or a very small advantage (Calabrese et al., 2010). But Blackmore-
Wright et al. (2013) found that combining double line spacing and
double between-word spacing was beneficial for subjects with macular
degeneration.

Overall, the evidence indicates that increasing spacing between
letters is not helpful, but extra-wide spacing between lines or words may
have some benefits for some readers with low vision.

Figure 8
Losses of resolution in low vision. Samples of text
are shown in six fonts. A blurring filter simulates
viewing the samples in 18 pt type, at a viewing
distance of 40 cm (16") with four levels of declining
acuity (standard sharpness followed by three increasing
amounts of blurring). Which font appears to have best
visibility as acuity declines?

<table>
<thead>
<tr>
<th>Font Style</th>
<th>20/120</th>
<th>20/160</th>
<th>20/200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Courier</td>
<td>A quick brown</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courier Bold</td>
<td>A quick brown</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Times New Roman</td>
<td>A quick brown fox</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arial</td>
<td>A quick brown fox</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verdana</td>
<td>A quick brown f</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tiresias LP</td>
<td>A quick brown fr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The advantage of Courier may relate to space around narrow letters. The
simulation in Figure 9 appears to confirm that Times is less tolerant to acuity
reduction than Courier. Tarita-Nistor et al. (2013) tested 24 AMD subjects on
the MNREAD test with four fonts—Times Roman, Arial, Courier and Andale.
Near the acuity limit, performance was best with Courier and worst with
Arial. The poorer performance with Arial was a surprise; it is a sans-serif font.
The prevailing opinion has been that sans serif fonts are slightly more legible
than serif fonts for low vision. The Guidelines for Large Print recommend
Verdana and Arial.

It is widely held that bold print is desirable for low vision. In
Figure 8, is Courier Bold more tolerant to blur than Courier? Bernard et al.
(2013) measured reading speed (RSVP method) in central and peripheral
vision for subjects with normal vision. They rendered their text in Courier,
but varied the stroke thickness from 0.27 to 3.04 times the standard stroke
width for the font. Contrary to expectation, stroke thickness greater than
the standard value did not help reading, and excessively bold strokes
resulted in slower reading. It remains to be determined empirically how
stroke width affects low-vision reading.

Tiresias was designed specifically for low vision. It emphasizes
space around narrow letters. Does it appear more tolerant to blur in Figure
8? Rubin et al. (2006) compared four fonts including Tiresias and Times
Roman, for people with mild forms of low vision. The Tiresias font had a
slight advantage in speed for fonts equated for nominal font point size, but
when equating fonts for actual horizontal and vertical space occupied, the
difference disappeared.

A review by Russell-Minda et al, (2007) concluded that there is
little empirical evidence for an optimally legible font for low vision. In my
book (Legge, 2007, Ch. 4), I concluded that
“… type designers have developed several commonly used
fonts that are roughly comparable in terms of reading performance
for normal vision, at least when angular character size is greater than some
critical print size. For low vision, fixed-width fonts may yield faster reading,
possibly because low-vision reading often occurs near the acuity limit.”

Recently, Bernard et al. (2016) reported on the design of a font
to enhance legibility for peripheral vision by reducing crowding between
adjacent letters. Such a font might be helpful for people with central-field
loss from macular degeneration. Bernard et al. designed their fixed-width
font, named Eido (Figure 9), based on three principles: reduce the image
similarity between letters, reduce the complexity of the letters, and retain
letter shapes that are familiar to readers. They compared Eido with Courier,
matched for inter-letter spacing and x-height, in tests of reading speed,
letter recognition, word recognition and reaction time for lexical decisions.
Tests of flanked letter recognition indicated that Eido was successful in
reducing crowding. But when they tested reading speed on normally
sighted subjects with simulated central scotomas, they found no significant
There is evidence that some people with low vision benefit from brighter illumination of text than normally sighted readers. For a review, see Legge (2007, Ch. 4). Bowers et al. (2001) measured reading speed as a function of print size at six illumination levels (from 50 to 5,000 Lux) for 20 subjects with AMD. They found significant improvements in reading acuity, critical print size and maximum reading speed over this range, with most of the improvement occurring for 2,000 Lux or less. They reported that 2,000 Lux is substantially higher than typical values of 50 Lux for page illumination in the home, and 500 Lux in the eye clinic. Their findings confirm that AMD patients frequently benefit from elevated lighting while reading.

Ambient lighting can, however, have adverse effects on digital reading. The contrast of text on a display can decrease due to veiling light from windows, sunshine or other bright lights. The brighter the display, the less the contrast will be diluted by glare sources. So, bright digital displays are better for low vision than dimmer displays.

In short, people with low vision have reduced contrast sensitivity, and a more pressing need for high-contrast text. Reading will often benefit from a brighter display, and from care in controlling veiling light from external glare sources.
5 Conclusions

To summarize the impact of text variables on low-vision reading:

Print size and display size matter. Magnification is usually necessary.

High contrast is often essential.

Bright displays and contrast reversal are desirable.

Inter-line and inter-word spacing may help.

Font effects are small, but fixed width fonts may be helpful when reading near the acuity limit.

Marshall McLuhan famously proclaimed that “the medium is the message.” For people with low vision, the digital medium for displaying text is indeed the message; digital reading has the potential to enhance access to print for people with low vision.

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