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Bolder print does not increase reading speed in people with central vision loss

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ABSTRACT

Patients with central vision loss are often advised by low vision rehabilitation professionals to read bolder print to ameliorate their reading difficulties. Is boldface print really effective in improving reading performance for people with central vision loss? In this study, we evaluated how reading speed depends on the stroke-width of text in people with central vision loss. Ten participants with long-standing central vision loss read aloud single, short sentences presented on a computer monitor, one word at a time, using rapid serial visual presentation (RSVP). Reading speed was calculated based on the RSVP word exposure duration that yielded 80% of words read correctly. Text was rendered in Courier and at six boldness levels, defined as the width of the letter-strokes normalized to that of the standard Courier font: 0.27, 0.72, 1, 1.48, 1.89 and 3.04× the standard. Reading speed was measured for two print sizes — 0.8× and 1.4× the critical print size (the smallest print size that can be read at the maximum reading speed). For all participants and both print sizes, reading speeds were essentially the same for text with stroke-width boldness ranging from 0.72 to 1.89× the standard, and were significantly lower for the thinnest and the boldest print. Most importantly, reading speed was not higher for bolder print than for the standard one. Despite the clinical wisdom that patients with central vision loss might benefit from bolder print, print with stroke-widths larger than the standard does not significantly improve reading speed for participants with central vision loss.

1. Introduction

Reading is arduous and slow for people with impaired vision, yet, it often ranks as the top most desired goal for low vision rehabilitation (Bullimore & Bailey, 1995; Elliott et al., 1997; Kleen & Levoy, 1981), cementing its importance as an activity of daily living. Reading is especially strenuous for people who lose their central vision due to eye diseases that affect the foveal or macular region of the eye, such as age-related macular degeneration (AMD). AMD is the leading cause of visual impairment in the elderly (Congdon et al., 2004; Friedman et al., 2004). As the lifespan of people is longer, the prevalence of AMD also rises, thus rehabilitation strategies targeting an improvement in reading performance is of prime importance in low vision rehabilitation.

In the clinic, patients with visual impairment are often advised to use the "3Bs" — making reading materials or written text bigger, brighter and bolder.[1] Making print or objects "bigger" can be achieved through magnification, either by bringing print or objects closer, or by using optical or electronic magnifiers. "Brighter" usually refers to the luminance or illumination, which can be achieved, for example, by using bright white text on a black background, or advising patients to use bright enough illumination. "Bolder" usually refers to the advice offered to patients to use dark felt-tipped pens when writing, or to choose boldface font when reading on an electronic screen. Previous research has focused primarily on the effects of magnification and luminance/illumination on reading, but limited work has been devoted to the understanding on how reading depends on boldness of font; therefore, in this study, we sought to evaluate the effect of boldness of print on reading speed in people with central vision loss.

Previous studies examining the effect of boldness of font on reading speed are scarce. Luckiesh and Moss (1940) compared reading speed using the Memphis font for four boldness levels (referred to as the "weights" in typography): Light (standard), Medium (20% bolder than standard), Bold (35% bolder than standard) and Extra Bold (69% bolder than standard), and found that reading speed was the highest for the

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[1] For example, see the webpages from Queensland Blind Association Inc. (https://qba.asn.au/living-with-blindness/making-the-most-of-your-site/), Fight for Sight (https://www.fightforsight.org.uk/about-the-eye/coping-with-sight-loss/), Associated Optical (https://www.associatedoptical.com/blog/an-insight-into-video-magnifiers-making-things-bigger-bolder-and-brighter).

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Medium and Bold setting, but the improvement was only 2–3% over the speed for the standard boldness. Paterson and Tinker (1940) compared reading speed for standard ("Roman") and boldface print in 200 college students and did not find any difference in reading speed. More recently, we evaluated reading speed in the fovea and periphery in a group of normally sighted young adults using Courier font rendered at six boldness levels, with widths of letter-strokes ranging from 0.27 to 3.04× the letter-stroke width of the standard Courier font, and failed to find any improvement in reading speed using font with letter-strokes bolder or thinner than the standard. However, when subjective legibility instead of reading speed was used as a performance measurement, Sheedy, Subbaram, Zimmerman, and Hayes (2005) reported that boldface letters (the authors tested several fonts but simply used the default of boldface for each font) enhanced legibility of letters and words, although the effects were modest (1–10%). Silver and Braun (1993) studied perceived readability (a rating given by observers) for warning labels, and found a higher perceived readability rating for boldface type over Roman type (averaged across several fonts: Helvetica, Times and Goudy), and for 10-point print over 8-point print. However, whether an enhanced legibility or an improved perceived readability leads to faster reading speed is unclear. To our knowledge, there is no report on whether print with thicker or bolder letterstrokes indeed improves reading speed for visually impaired persons, especially those with central vision loss. In this study, we sought to study the dependence of reading speed on stroke-width boldness of print in people with central vision loss, from which we could answer the question of whether boldface print indeed benefits reading for people with central vision loss.

2. Methods

Ten observers with central vision loss participated in the study. These included seven with AMD, two with Stargardt disease and one with toxoplasmic chorioretinitis. All had bilateral vision loss for at least 1.25 years (see Table 1). Each of our observers with central vision loss granted his/her written consent before the commencement of data collection. This research was approved by the Institutional Review Board at the University of California, Berkeley, and was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

After consent was obtained, we first measured best-corrected visual acuities and contrast sensitivities for each eye, and performed a brief fundus evaluation using a scanning laser ophthalmoscope. Best-corrected visual acuities, contrast sensitivities and other characteristics of the observers are given in Table 1. Best-corrected visual acuities were measured separately for each eye using the Bailey-Lovie Visual Acuity Chart. Contrast sensitivity given in the table refers to the peak contrast sensitivity of the contrast sensitivity function determined separately for each eye, using the method described in Chung and Legge (2016). In brief, we used a staircase method to determine each observer's contrast threshold for detecting the presence of a sine-wave grating presented on a computer monitor, for six to eight spatial frequencies. An asymmetric parabolic function was used to fit the data-set from which the peak contrast sensitivity was derived. Using this method, Chung and Legge (2016) reported that the averaged peak contrast sensitivity for normally sighted observers was 2.22 log units. Hence, all of our observers demonstrated a loss in visual acuity and contrast sensitivity. Fundus evaluations confirmed the presence of macular lesion(s) and the resultant loss of vision (scotoma) in the lesioned region(s) in each eye.

2.1. Stimuli and apparatus

The set of sentences used for measuring reading speed was the same as that used in our previous studies (e.g. Bernard, Kumar, Junge, & Chung, 2012; Chung, 2002, 2011; Chung, Legge, & Cheung, 2004; Chung, Mansfield, & Legge, 1998). Details of how the set of sentences was developed and the characteristics of the sentences are summarized in Chung et al. (1998). In brief, the set contained 2630 sentences extracted from nine novels, with the length of each sentence ranging between 8 and 14 words (mean = 10.9 ± 1.7 [SD] words). Words which appeared in these sentences were among the 5000 most frequently used words in normal written English usage (Kilgarriff, 1997). Throughout the experiment, none of the observers read any of the sentences more than once.

As summarized in Introduction, previous studies have used different fonts to investigate the effect of boldness of font on reading speed (mostly, in normally sighted subjects), arriving at a similar result that there was no large improvement in reading speed with bolder print. Therefore, the specific choice of font might not matter too much. In this study, we used Courier font for several reasons. First, it is a font with a uniform stroke-width (for a given letter size), which facilitated the creation of the font with different stroke-width boldness by adding or removing layers of pixels (see details below). Second, although Courier is not a widely used font in modern daily reading materials for people with normal vision, it is a font that is recommended to the visually impaired community because it allows readers to read smaller print sizes without compromising reading speed, when compared with other fonts (Mansfield, Legge, & Bane, 1996; Tarita-Nistor, Lam, Brent, Steinbach, & González, 2013). Mansfield et al. (1996) even reported that reading speed for small print could be 10% faster for Courier than for Times-Roman, a more widely used font in daily reading materials. Third, many previous studies that used similar psychophysical methods and reading mode to study the effects of various visual or stimulus factors on reading have used Courier, thus facilitating the comparison of results from this study with the literature.

To create text rendered in different letter stroke-width boldness, we used the freeware FontForge to add or remove layers of pixels around the letter-strokes of the standard Courier font, thus creating letters with thicker or thinner letter-strokes. The resultant stroke-widths were then normalized to that of the standard Courier font. Details of how this was

Table 1
Demographical and visual characteristics of observers.

Observer	M/F	Age	Diagnosis	Acuity (logMAR)		Contrast sensitivity (log units)		Years since onset	CPS (°)
				OD	OS	OD	OS		
A	M	84	AMD	0.56	0.70	1.10	1.13	8	1.77
B	F	75	AMD	0.32	1.10	1.95	1.53	5	0.79
C	F	84	AMD	0.54	0.58	1.92	1.87	11	0.68
D	M	72	AMD	0.80	0.80	1.69	1.70	1.25	1.72
E	F	74	AMD	0.70	0.52	1.74	1.77	8	1.73
F	F	76	AMD	0.54	1.16	1.17	1.06	6	4.03
G	F	73	AMD	1.10	1.40	1.11	1.12	3	4.84
H	M	51	Toxoplasmic chorioretinitis	0.86	0.98	1.24	1.19	37	1.62
I	F	43	Stargardt	1.08	0.86	1.81	1.83	29	1.56
J	M	58	Stargardt	1.10	1.10	1.70	1.84	41	3.26

Fig. 1. An example of a sentence rendered in different stroke-width boldness (from top to bottom): 0.27×, 0.72×, 1× (the standard), 1.48×, 1.89× and 3.04×.

accomplished are given in Bernard et al. (2012). Essentially, we created bolder or thinner Courier fonts with the following stroke-widths: 0.27×, 0.72×, 1× (the standard), 1.48×, 1.89× and 3.04× the standard stroke-width. Fig. 1 shows sample sentences rendered at each of the six stroke-width boldness.

Text stimuli were generated on a Macintosh G4 computer with software custom-written in MATLAB 7.7.0 (The MathWorks, MA), using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Stimuli were presented on a Sony color graphics monitor (model# GDM-17E21) with a refresh rate of 85 Hz, and at a resolution of 1280 × 1024 pixels (36.75 × 29.60 cm). Because some of our observers required larger print to read, the testing distances ranged between 20 and 40 cm, with the resulting pixel resolution of the monitor ranging between 2.48 and 4.95 arc min. Optical corrections were given to each observer to correct for his/her reading distance. Testing was binocular under normal office illumination.

2.2. Control experiments

The rationale and details of the control experiments are the same as for our previous paper examining the effect of stroke-width boldness on reading in normal central and peripheral vision (Bernard et al., 2012). In a nutshell, by adding or removing layers of pixels around letter-strokes of the standard Courier font to create fonts of different stroke-width boldness, at least three additional text characteristics were changed: (1) the actual x-height of the letters (defined as the topmost row to the bottommost row of black pixels of the lowercase letter x: Legge and Bigelow (2011)); (2) the root-mean square (RMS) contrast of the letters; and (3) the edge-to-edge spacing between letters. Table 2 lists the ratios of the x-height, ratios of RMS contrast and ratios of the edge-to-edge spacing between letters for letters rendered in the different stroke-width boldness relative to that of the standard Courier font, for the same *nominal* print size. It is well known that reading speed is affected by print size (Legge, Rubin, Pelli, & Schleske, 1985; Mansfield et al., 1996) and contrast (Rubin & Legge, 1989) for people with impaired vision. In addition, reading speed also shows a dependency on letter spacing. On one hand, when inter-letter spacing is small, crowding (the spatial interaction on an object (e.g. recognizing a letter) due to the presence of nearby objects) may lead to an adverse effect on letter recognition which may slow down reading. On the other hand, when inter-letter spacing is large, letters of a word may not be grouped efficiently thus affecting recognition of the word. To determine whether or not changes in reading speed for letters rendered at different stroke-width boldness could be explained by a change in the actual x-height, the RMS contrast of the letters, or the spacing between letters, we included additional conditions (each tested in a separate block of trials) to be tested along with the main experiment.

As shown in Table 2, the actual x-height of the thinnest (0.27×) and the boldest (3.04×) font were equivalent to 0.88× and 1.33× of the x-height of the standard Courier font. Therefore, we included two additional conditions — letters rendered at the standard boldness but at letter sizes equivalent to 0.88× and 1.33× of the standard Courier font.

To compensate for the changes in RMS contrast, our original plan was to test two other conditions in which the gray-levels of the standard Courier font (boldness of 1×) and the boldest font (boldness of 3.04×) were reduced such that the resultant RMS contrast matched that of the thinnest font (boldness of 0.27×). However, none of the observers were able to read the words (in some cases, not even the individual letters) when we reduced the gray-level of the boldest font to match the resultant RMS contrast of the thinnest font. As a result, that condition was tried but, in the end, discarded for all observers. Only the condition in which we reduced the gray-level of the standard font such that the RMS contrast matched that of the thinnest boldness was included.

Because our software presented text with letters at a center-to-center separation according to the standard Courier font, the "white space" or the edge-to-edge inter-letter spacing became larger for the font with the thinnest letter-strokes and smallest for the font with the thickest letter-strokes. To rule out the possibility that the impact on reading speed for fonts with the thinnest or the thickest letter-strokes was due to the change in the edge-to-edge inter-letter spacing, in a third control condition, we decreased the edge-to-edge inter-letter spacing for the font with the thinnest letter-strokes to match the standard edge-to-edge spacing for the standard font.

To summarize, in addition to the six different boldness levels, we tested four additional control conditions: (1) standard Courier font

Table 2
Ratios of the x-height, RMS contrast and edge-to-edge spacing for letters of different boldness relative to the standard. Cells with thick borders represent the ten testing conditions (including control conditions).

Boldness	0.27×	0.72×	1×	1.48×	1.89×	3.04×
actual x-height	0.88×	0.93×	1×	1.10×	1.18×	1.33×
RMS contrast	0.24×	0.72×	1×	1.52×	2.05×	3.05×
Edge-to-edge letter spacing	1.63×	1.38×	1×	0.88×	0.63×	0

rendered at 0.88× the nominal tested print size; (2) standard Courier font rendered at 1.33× the nominal tested print size; (3) standard Courier font rendered at a lower gray-level to match the RMS contrast of the font with the thinnest letter-strokes; and (4) font with the thinnest letter-strokes and reduced edge-to-edge letter spacing to match the spacing of the standard font. These 10 conditions are highlighted in Table 2 as cells with thick borders. The order of testing of the 10 conditions was randomized separately for each observer and for each nominal print size.

2.3. Reading speed measurement

Reading speed was assessed using the rapid serial visual presentation (RSVP) paradigm in which words were presented one at a time on the computer monitor (Chung, 2002; Chung et al., 1998, 2004; Rubin & Turano, 1992, 1994). This paradigm is ideal for the evaluation of physical text parameters on reading because it minimizes the necessity to make eye movements between words, and also because it presents words at localized retinal regions, thus minimizing the effect of different regional sensitivities of the retina, especially for observers with macular disease. In each block of trials (a given condition with a specific combination of print size and stroke-width boldness), we used the Method of Constant Stimuli to present words at one of six exposure durations. Observers were asked to read aloud each word as quickly and as accurately as possible. They were allowed to continue verbalizing the words after the last word disappeared from the computer monitor. In each block of trials, durations were chosen such that observers' word recognition accuracies for the block of trials ranged between 10–20% for the shortest duration and 90–100% for the longest duration, to facilitate the construction of a psychometric function from which the threshold reading speed was derived. Three sentences per duration were presented in a block of trials (18 sentences per block). Each condition (print size × stroke-width boldness) was tested twice. We then combined the data across two blocks of trials for each condition and fit a cumulative Gaussian function to the data. In other words, each duration for each condition was based on 6 sentences, with a total number of words presented ranging between 56 and 76 (average number of words presented per duration per condition per observer = 65.9). The threshold reading speed was calculated based on the word exposure duration that yielded 80% reading accuracy.

2.4. Experimental design and procedures

All observers attended five sessions of testing that were completed between two and five weeks. In the first session, reading speed was measured for five print sizes, so that we could determine the critical print size (CPS, the smallest print size that can be read at the maximum reading speed: Chung et al., 1998). A short practice session preceded the actual data collection. The goal of the practice session was to familiarize observers with the RSVP task and for them to try out a range of print sizes. Data collection only began after observers were comfortable with the task. On average, the practice session took approximately 30 min. The exact range of print sizes (increment of print size in steps of 1.414×) used to determine the CPS varied among different observers. Observers B & C were tested with print sizes ranging from 0.5° to 2°, while observers F, G and J were tested with print sizes ranging from 2° to 8°. The rest of the observers were tested with print sizes ranging from 1° to 4°. As expected (Chung et al., 1998), reading speed improved with print size up to the CPS, and reached a plateau for print sizes larger than the CPS. In other words, when print sizes were smaller than the CPS, reading speed was limited by print size; but when print sizes were larger than the CPS, reading speed was not limited by print size. To quantify the CPS, we fit each set of reading speed versus print size data with a two-line fit, in which the slope (on log–log axes) of the first line was free to vary while the slope of the second line was constrained to zero (Chung et al., 1998). The print size at which these two lines intersected was used to represent the CPS. Across our observers, the CPS ranged between 0.68° and 4.84° (see Table 1 for details).

To evaluate whether or not the effect of stroke-width boldness on reading speed depends on print size, we tested two nominal print sizes — one smaller than the CPS so that print size was a limiting factor on reading speed and another one larger than the CPS so that print size was not a limiting factor. We chose 0.8× CPS as the nominal "smaller" print size because we wanted to avoid the floor effect in our measurements and also to ensure that the print size was not so small that observers would find it exceedingly discouraging and frustrating to complete the testing. For the nominal "larger" print size, we chose 1.4× CPS so that it was close to twice the size of the smaller nominal size, but at the same time, allowed us to present text at the physical letter sizes required by several of our observers with poorer vision. The order of testing these two print sizes was counterbalanced across the ten observers. Considering the number of conditions tested for each print size (six stroke-width boldness and four control conditions), the testing for each print size was completed in two sessions, with each session testing one entire set of ten conditions and the second session repeating the testing of these conditions in a reverse order.

2.5. Statistical analyses

Statistical analyses were performed using the R software (R Development Core Team, 2016). We used a linear mixed-effects model to analyze our reading speed data using the lme4 (Bates, Maechler, Bolker, & Walker, 2015) and lmerTest packages (Kuznetsova, Brockhoff, & Christensen, 2015). Print size and stroke-width boldness are included as fixed effects, while observer is included as a random effect. Reading speed was log-transformed. Post-hoc analyses consisted of Tukey's pairwise comparisons were accomplished using the multcomp package (Hothorn, Bretz, & Westfall, 2008).

3. Results

Reading speed (words per minute, wpm) measured using RSVP, is plotted as a function of the stroke-width boldness of text in Fig. 2 for each observer, and for the two nominal print sizes. First, as expected, reading speeds are generally higher for print size of 1.4× CPS than for 0.8× CPS ($F_{(1,9)} = 67.8$, $p < 0.0001$). This is not surprising given that reading speed depends on print size for print sizes smaller than the CPS (Chung et al., 1998; Mansfield et al., 1996). However, the important point is how reading speed depends on boldness of text, and whether this dependence differs between smaller and larger print. Despite some individual differences, all observers essentially showed a very similar trend — reading speed was the lowest for text with the thinnest (boldness of 0.27×) and the thickest (boldness of 3.04×) letter-strokes, and did not seem to differ substantially among the other four boldness levels. Indeed, there is a significant effect of stroke-width boldness on (log) reading speed ($F_{(5,45)} = 94.7$, $p < 0.0001$). However, the effect of stroke-width boldness on reading speed does not depend on print size ($F_{(5,45)} = 1.1$, $p = 0.37$), as shown in Fig. 3. Post-hoc analyses showed that for either print size, reading speeds for the thinnest and the thickest letter-strokes are significantly different from the reading speeds for all other boldness. In addition, reading speeds for the middle four boldness levels, *viz.*, 0.72×, 1×, 1.48×, 1.89×, are not statistically different from one another. Importantly, none of the boldness levels yields significantly higher reading speed than that for the standard (1×) boldness. These results are the same for the two nominal print sizes; again, implying that there is no interaction between the effects of print size and boldness level.

To evaluate the effect of boldness on reading speed more clearly, we normalized the reading speeds obtained for the different boldness relative to the reading speed for the standard boldness. This was performed for each observer and for each print size separately. Fig. 3 shows the group-averaged normalized reading speeds for the different

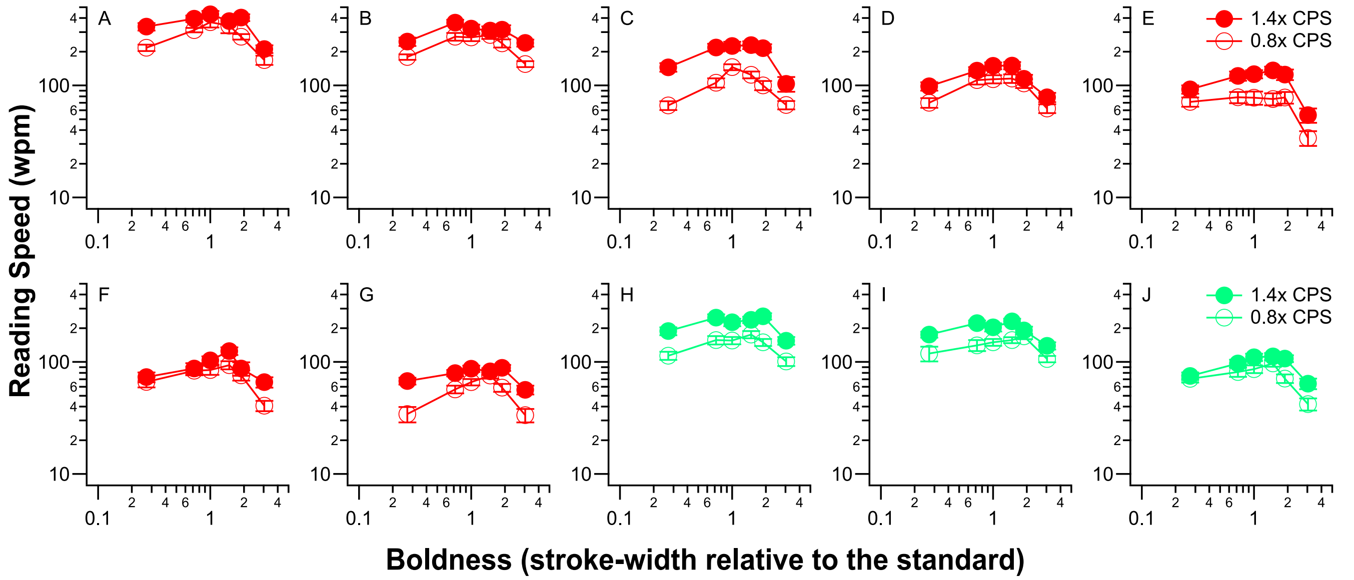

Fig. 2. Reading speed (words per minute, wpm) is plotted as a function of stroke-width boldness of text (relative to the standard Courier font). Each panel shows the data for one observer (red: AMD; green: other diagnoses). Unfilled and filled symbols represent reading speeds obtained for 0.8× CPS and 1.4× CPS, respectively. Error bars represent ± 1 SEM. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

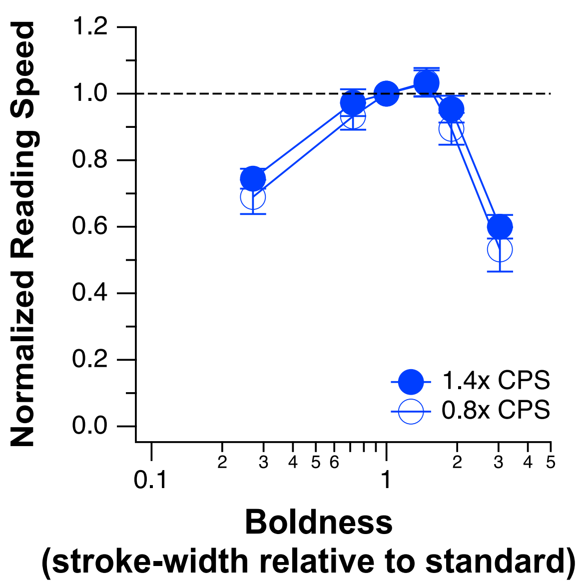

Fig. 3. Normalized reading speed (reading speed for a given stroke-width boldness normalized to that of the standard boldness), averaged across the ten observers, is plotted as a function of stroke-width boldness of text. Unfilled and filled symbols represent reading speeds obtained for 0.8× CPS and 1.4× CPS, respectively. Error bars represent ± 95% confidence intervals.

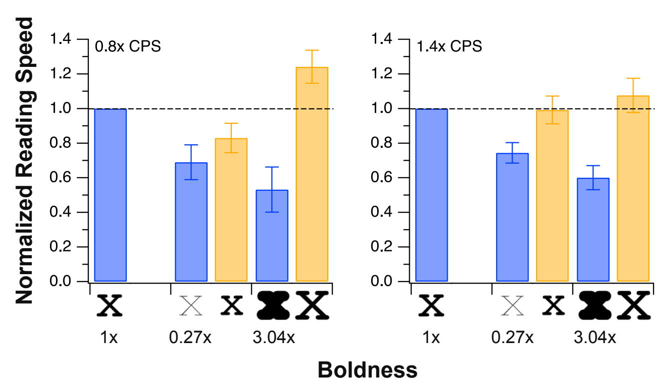

Fig. 4. Normalized reading speed (reading speed for a given stroke-width boldness normalized to that of the standard boldness), averaged across the ten observers, is plotted for the thinnest and the thickest letter-stroke boldness (blue bars) and for print rendered at the standard boldness but matched in the physical letter size as the print with the thinnest and thickest letter-strokes (yellow bars). Results are plotted separately for the two nominal print sizes (0.8× and 1.4× CPS). Error bars represent ± 95% confidence intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

boldness, and for the two print sizes. A normalized value greater than 1 means that reading speed is higher than that for the standard font. Although the reading speed at 1.48× stroke-width boldness appeared to be higher than that for the standard font, the 95% confidence intervals of the group-averaged reading speed included the value of 1, implying that the reading speeds are not different between 1.48× stroke-width boldness and the standard. Also note that the trend of how normalized reading speed depends on boldness is very similar for the two print sizes.

3.1. Control experiments

Fig. 3 clearly shows that reading speed was significantly slower for fonts with the thinnest and thickest letter-strokes than for other boldness levels. However, as we stated in Methods, changing the widths of the letter-strokes leads to concurrent changes in the physical letter size, RMS contrast and edge-to-edge inter-letter spacing. To ensure that the slower reading speeds obtained for the thinnest and thickest letter-strokes were primarily due to the changes in the width of letter-strokes, we measured reading speeds for several control conditions.

Fig. 4 compares the average normalized reading speed (reading speed obtained for a given condition normalized to that of the standard boldness) for the standard boldness (1×), the thinnest letter-strokes (0.27×) and the thickest letter-strokes (3.04×) of the same nominal size (blue bars), with letters rendered at the standard boldness but at an equivalent actual physical size (number of row of black pixels from the topmost to the bottommost row of the lowercase letter, yellow bars). Results are plotted separately for the two nominal print sizes (0.8× and 1.4× CPS). If the reduction in reading speed was due to the concurrent changes in the actual physical letter size, then each pair of blue and yellow bars should yield the same normalized reading speed. This is not

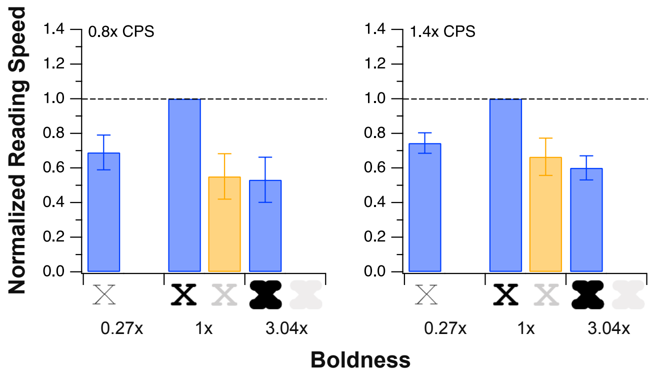

Fig. 5. Normalized reading speed (reading speed for a given stroke-width boldness normalized to that of the standard boldness), averaged across the ten observers, is plotted for the thinnest and the thickest letter-stroke boldness at the original RMS contrast (blue bars) and for print matched in the RMS contrast (yellow bars) as the print with the thinnest letter-strokes. For both nominal print sizes (0.8× and 1.4× CPS), none of the observers were able to read the RMS contrast-matched, thickest letter-stroke print. The images given on the x-axis are for illustration purpose and the gray levels of the RMS contrast-matched print displayed are not the actual gray levels used during testing (much lower during testing). Error bars represent ± 95% confidence intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

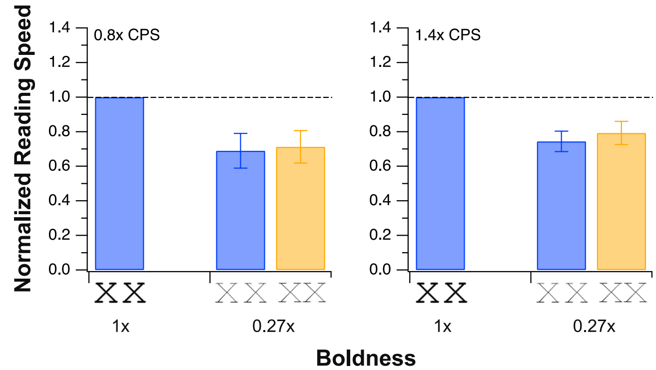

Fig. 6. Normalized reading speed (reading speed for a given stroke-width boldness normalized to that of the standard boldness), averaged across the ten observers, is plotted for the standard and the thinnest letter-stroke boldness at the original letter spacing (blue bars), and for print rendered in the thinnest letter-strokes but matched in the edge-to-edge letter spacing (yellow bars) as that of the standard font. Error bars represent ± 95% confidence intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the case. Instead, reading speeds obtained with standard boldness (yellow bars) were generally higher than those with the thinnest or thickest letter-strokes, even when the physical letter sizes were matched. These results suggest that the lower reading speed for the thinnest and the thickest letter-strokes observed in the main experiment could not be explained by the small changes in print size, but was indeed a stroke-width boldness effect.

The effect of a change in RMS contrast of print rendered at the thinnest and the thickest letter-strokes is summarized in Fig. 5. Blue bars represent the averaged normalized reading speeds obtained for the thinnest and the thickest letter-strokes in the main experiment. Yellow bars represent normalized reading speeds when the pixel luminance of letters of the standard boldness text was reduced to match the RMS contrast of that of the thinnest boldness rendered at the original contrast (note that we were not able to measure reading speed when the luminance of the font with the thickest letter-strokes was reduced to match the RMS contrast of the font with the thinnest letter-strokes). If the reduction in reading speeds for the thinnest and the thickest letter-strokes was primarily due to the concurrent changes in the RMS contrast of letters, then reading speeds should be similar once the RMS contrast was matched, even for fonts of different stroke-widths. Although the yellow bars in Fig. 5 (for font rendered in standard boldness but reduced pixel luminance) in both panels are not statistically different from their respective comparisons — the leftmost blue bar in each panel (at a p-value of 0.05, given the overlapping confidence intervals), the fact that reading speed could not be measured for the thickest letter-strokes for the RMS contrast-matched conditions implies that the changes in reading speeds with letter-stroke boldness are not simply a RMS contrast effect.

Fig. 6 compares averaged normalized reading speeds for fonts rendered in the standard and the thinnest letter-strokes at the normal letter spacing in the main experiment (blue bars), with font rendered in the thinnest letter strokes but with edge-to-edge spacing reduced to match that of the standard font (yellow bars). If the slower reading speed for the thinnest letter-strokes was due to the differences in edge-to-edge letter spacing, then by matching the spacing, reading speed for the thinnest letter-strokes should reach that of the standard boldness. Clearly, that is not the case here. Instead, reading speeds for the thinnest letter-strokes were very similar for the two edge-to-edge letter spacings. This finding suggests that the slower reading speed obtained for the thinnest letter-strokes in the main experiment was not due to the larger edge-to-edge letter spacings.

4. Discussion

Despite the popular belief that patients with central vision loss benefit from reading bolder print, and that there is a subjective preference for patients to choose bolder print over standard print (Silver & Braun, 1993), we did not find a significant improvement in reading speed for print with letter-strokes bolder than the standard. The lack of an improvement is unlikely to be due to an insufficient increase in stroke-width boldness tested in this study, because we tested three letter-strokes thicker than the standard, and we did not find any significant improvement in reading speed relative to the standard boldness for any of the three. More importantly, reading speed for the thickest letter-strokes is significantly lower than that for the standard boldness, which means that thicker letter-strokes could be detrimental to reading for people with central vision loss.

Previously, we evaluated whether reading boldface print improves reading speed in the normal fovea and/or in the normal periphery (Bernard et al., 2012). We used the same paradigm as used in the present study to measure RSVP reading speed for text rendered at the same range of stroke-width boldness in a group of six young adults with normal vision. Like in the present study, we found that letter-strokes bolder than the standard did not lead to a significant improvement in reading speed in the normal fovea and the periphery. Therefore, our finding that bolder print does not significantly improve reading speed is likely to be a general finding, instead of one that is specific to people with central vision loss. These findings are consistent with that of Paterson and Tinker (1940) who failed to find a difference in reading speed for boldface and regular print in 200 (likely to be normally sighted) readers; and that of Luckiesh and Moss (1940) who reported a mere 2–3% higher reading speed for print with letter-strokes 69% thicker than the regular print. In the present study, for letter-strokes 48% thicker than the standard print, mean reading speed was 3–4% higher than that for standard print, but this modest improvement is not significantly different from the reading speed for the standard boldness print. As we speculated in our earlier paper, printed text has existed since at least 1455 (Meggs, 1998), therefore, various typographic characteristics of font might have already been optimized to provide the highest legibility and/or readability for the standard or regular version of the font. Apparently, this optimization of typographic characteristics of print applies not only to readers with normal vision, but also to those with central vision loss. Additionally, an adult, assuming an average page reading speed of 300 wpm and who spends approximately 30 min per day reading, reads approximately 9000 words, or approximately 45,000 letters (the average word length for common English words is ~5 letters (Norvig, 2013)) per day. Considering the high volume of letters to which an adult is exposed, we might have already adapted to the specific characteristics of the font, akin to perceptual learning. Either or both of these factors may account for why it seems difficult, if not impossible, to improve reading speed using bolder print. However, if adaptation to the standard font is indeed a reason why we did not observe an improvement in reading speed using bolder print, one may ask whether or not training to read bolder print (e.g. with letter stroke-width of 1.48 × the standard) could lead to significantly higher reading speed. This question may be tested in future studies.

Several considerations should be taken into account when interpreting our findings. First, as we stated earlier, one of the primary reasons for using Courier font in this study was because of the uniformity of its stroke-width. We do not know for sure if the lack of a benefit in reading bolder print would apply to other fonts, in particular, fonts with variable stroke-widths such as Times-Roman. However, based on the handful of previous studies that had measured reading speed, legibility, or subjective readability using various fonts, even if an improvement in reading speed were to be found, the magnitude of the improvement would likely to be small. Second, our results were obtained while observers read aloud single sentences presented using RSVP. Whether or not the results would generalize to silent reading or when reading longer passages would need to be evaluated in future studies. On one hand, it is possible that bolder letters and words offer some advantages in normal page reading that we could not observe here. A larger ink density could, for instance, help patients with central vision loss more easily localize lines of text and consequently, guide their eye movements more efficiently. This potential benefit might not have manifested itself in our study because RSVP would have minimized the need to make intra-word saccades during reading. However, recall that people with macular disease are known to have erratic eye movements, therefore it is unclear how much of an advantage the increase in ink density would help in guiding their eye movements. When reading longer passages, readers may opt for fonts that provide a higher "comfortability", which was not something we measured in this study. Occasionally, readers may show a strong preference for one font over other fonts, while the font does not offer the best reading performance (Beier & Larson, 2013). The subjective preference of a bolder font, compared with its Roman counterpart, could be due to the fact that bolder fonts appear to bring more comfort during reading or an increase in *perceived* readability, despite the fact that there is no improvement in reading performance. On the other hand, based on the literature that has compared reading speed, legibility or readability for different font types (various type faces or, bold versus Roman versions of the same font) using a passage reading paradigm, the advantage of reading "bolder" fonts or print, if any, has been small. Therefore, we believe that our results are likely to be generalizable to the more conventional form of passage reading. Third, our results were obtained from ten observers with central vision loss, which clearly could not represent the entire spectrum of people with central vision loss. However, given the ranges of visual acuities, peak contrast sensitivities and reading speeds of our observers, the consistent lack of a sizeable benefit in reading speed when reading bolder print indicates that the clinical wisdom of patients with central vision loss benefiting from reading bold print may not be as general as the community of low vision rehabilitation professionals once thought. We do not know whether or not the same result would apply to people with central vision loss whose vision is worse than our observers', but the slowest reader in this study had a maximum RSVP reading speed of 87 wpm, which corresponded to a passage reading speed of 60 wpm based on the mean RSVP gain (ratio of reading speed between RSVP and passage reading) of 1.54 as reported by Rubin and Turano (1994). A passage reading speed of 60 wpm, according to the guidelines suggested by Whittaker and Lovie-Kitchin (1993), is quite low and can only support spot reading (e.g. reading price-tags while shopping), not fluent reading (which requires a minimum of 80 wpm). Therefore, even if a benefit could be observed with bolder print for readers with even lower reading speed, it is unlikely that the benefit would be practical for the readers to engage in a serious reading task, when considering the magnitude of improvements of reading bolder print that we have observed in this study or in previous studies.

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