



Vision Performance Institute

Technical Report

Individual character legibility

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The purpose of this study was to investigate the factors that influence the legibility of individual characters. Previous work in our lab [2], including the first study in this sequence, has studied the relative legibility of fonts with different anti-aliasing techniques or other presentation medias, such as paper. These studies have tested the relative legibility of a set of characters configured with the tested conditions. However the relative legibility of individual characters within the character set has not been studied. While many factors seem to affect the legibility of a character (e.g., character typeface, character size, image contrast, character rendering, the type of presentation media, the amount of text presented, viewing distance, etc.), it is not clear what makes a character more legible when presenting in one way than in another. In addition, the importance of those different factors to the legibility of one character may not be held when the same set of factors was presented in another character. Some characters may be more legible in one typeface and others more legible in another typeface. What are the character features that affect legibility? For example, some characters have wider openings (e.g., the opening of "c" in Calibri is wider than the character "c" in Helvetica); some

letter g's have double bowls while some have single (e.g., "g" in Batang vs. "g" in Verdana); some have longer ascenders or descenders (e.g., "b" in Constantia vs. "b" in Courier New); and some are smaller while some are bigger (e.g., in most fonts, "m" is wider than "n"; Verdana letters tend to be wider than the same letter of equal point size in other font types). How do these and other character features affect the legibility of a character? Will the importance of these features differ when presenting with different medias (e.g., onscreen vs. Hardcopy)?

In this study 10 characters configured in 12 different fonts were presented either on screen or in print. The 10 characters and the 12 font types were chosen for relative legibility testing by a group of font designers and experts in Microsoft Corp. These 10 characters were: a, c, e, m, n, o, r, s, v, w; and the 12 font types were Baskerville, Bodoni, Centaur, Consolas, DIN, Frutiger, Futura, Garamond, Georgia, Helvetica, Rockwell, and Verdana. These letters were selected to represent different basic character shapes: o, a, c, e are circular; m, n, w, are more rectangular; v is triangular; r and s represent unique shapes. In addition, a, c, e, and s seem to be the most difficult characters to make legible for font designers due to their more horizontal lines. The 10 characters were also selected to be without ascenders or descenders, thereby eliminating such factor in identification and facilitating the testing protocol.

The 12 fonts were chosen to represent different typographic categories that can influence a character's physical attributes (e.g., size, shape, line and form). While there are more font types than selected here, this study focuses on three main categories: Serif, Sans Serif, and Monospace. Other categories such as Blackletters, Script, and Decorative/Display-type, were not included due to their extreme forms (e.g., Script) or limited application (e.g., Decorative font types). Serif is a font group identified by smaller decorative strokes or flourishes that are added to the end of a

character's main strokes, used to characterize individual characters. Depending on the features of these serifs (slab, wedge, or hair; bracketed or unbracketed; etc.) and the forms of the characters (thicker vertical or equal stroke width, rectangle or round shape, etc.), serif fonts can be further categorized into different family groups, such as Humanist/Venetian, Garamond, Transitional, Modern/Didone, Slab-serif/Contemporary, and others [8-12]. These families further categorize the physical features of a serif typeface, mostly influenced by the printing techniques or the popular art style in the era when the typeface was created. It has been suggested that these serifs improve letter identification in reading by leading the eye along the line of main stroke while highlighting a character with those serifs [10]. Hence, serif fonts have been thought to be best used for body text. Sans serif fonts developed relatively late (first appeared around 1815-1817) [8, 9]. In contrast to serif typefaces, they have no flourishes ("sans" means "without" in Latin) with simpler letterforms, relatively uniform stroke weight, and tend to be shaped in round or other basic geometric shape. The forms of earlier sans serif typefaces tended to have heavy stroke widths which made them difficult to follow for general reading. They were often used in big font size for headlines or road signs, sometimes paired with the use of a serif font in the body text. However, the descendant sans serif fonts have quickly evolved a wide range of styles designed to be used in different contexts, even in body text (e.g., Verdana). Sans serif can also be categorized into different families (e.g., Slab-serif, Humanist, Geometric, etc.). Monospace (or Typewriter) typefaces have the same amount of space for each character, often used in computer programming codes. The uniform letter size and letter spacing takes up more room and are thought less artful and harder to separate as word groups, so they are less preferred for text presentation. Table 12 describes the main features of the selected typefaces in more detail by category and family.

Table 12.
Description of the twelve selected typefaces.

Typeface	Category	Family	Feature Description	Examples
Consolas	Monospace	Mono-space	<p>Description:</p> <ul style="list-style-type: none"> • A monospace typeface newly developed by Microsoft, used mostly in programming environments; • Closer inter-letter-spacing and careful hinting resulted in better readability than traditional monospace fonts (e.g., Courier); • Perform well on both letter and word legibility tests in Study 1. <p>Main features:</p> <ul style="list-style-type: none"> • Rectangular shape; • Equal letter width for all letters; • Closer inter-letter-spacing; • Relatively larger x-height. 	a c e m n o r s v w
Futura	Sans Serif	Geometric	<p>Description:</p> <ul style="list-style-type: none"> • First presented in Germany in 1928; • Emphasize “form follows function”, reflect the radicalism of the font; • Have essential forms with strictly geometric outline, no serifs or superfluous segments; • Opposed to earlier sans-serif designs, the strokes are of even weight (e.g., o) and almost-perfect geometric shape, as drawn with compasses and rulers; • Have relatively long ascenders and descenders, hence require more line spacing. <p>Main feature:</p> <ul style="list-style-type: none"> • Minimal number of strokes; • Bold form; • Constant line thickness (no weight); • Straight lines; • Almost perfectly circled round strokes and arcs. 	a c e m n o r s v w

Helvetica	Sans Serif	Neo-Grotesque	<p>Description:</p> <ul style="list-style-type: none"> • Helvetica refers to “Swiss” in Latin. The font was developed in 1957 by Swiss graphic designer Max Miedinger for metal type machine; • Rigid, simple, clean and no-nonsense design; • Only essential forms of the main strokes, no decorative serifs; • Have more variation in weight and more strokes in glyph when compared to the geometric fonts, but the strokes are relatively uniform (hence lack of significant contrast) when compared to other fonts. <p>Main features:</p> <ul style="list-style-type: none"> • Bold form with uniform strokes; • Minimalistic but less extreme than Geometrics. 	a c e m n o r s v w
Frutiger	Sans Serif	Humanist	<p>Description:</p> <ul style="list-style-type: none"> • Named after its Swiss designer Adrian Frutiger, first developed in 1968 for use in road and airport signs and directional systems, soon adopted for use in print and advertising; • Belong to sans serif, but softened with humanist letterforms (i.e., a pen-drawn look), based on the shapes of Renaissance text types, with more liberal styles; • Only essential forms without serifs; • Generally uniform strokes with subtle variation in weight to smooth out the too-harsh edges of sans serif fonts; • Less rigid curves than the Geometrics; • Bolder than original typesetting fonts to offer better clarity in poor lighting conditions. <p>Main features:</p> <ul style="list-style-type: none"> • Bold form; • Uniform (but not as strong as Futura) strokes with more relaxed look; • Wide open counters. 	a c e m n o r s v w

DIN	Sans Serif	German interstate sign	<p>Description:</p> <ul style="list-style-type: none"> In 1936, it was chosen for typeface used in technology, traffic, administration and business in Germany (DIN stands for "Deutsches Institute fur Normung", the German Institute for Industrial Standards). <p>Main features:</p> <ul style="list-style-type: none"> Larger x-height (taller shape); Wide open counters (e.g., "c", "U"). 	a c e n o r s v w
Verdana	Sans Serif	Legible	<p>Description:</p> <ul style="list-style-type: none"> Lately developed by Matthew Carter and hinted by Tom Rickner for Microsoft Corp., released in 1996, intended for onscreen reading at small font sizes (default 10-pt); Bearing similarities to humanist sans-serifs, such as Bell Centennial, Tahoma, and Frutiger, but designs originated from onscreen pixels rather than from the pen, the brush, or the steel. Contain only essential elements, no serifs; To improve onscreen readability at small sizes, Verdana has large x-height, wide proportions, loose letter-spacing, large counters, balanced separation between lines, and designed distinctive parts between similarly-shaped characters, therefore it always appears larger and slightly more open than other fonts of the same point size, which also gives it a typewriter-like look on paper (due to the wide width and spacing); The most legible typeface for both letter and word stimuli in Study 1. <p>Main features;</p> <ul style="list-style-type: none"> Large x-height and; Extended x-width (wider proportions); Large counters & open space with minimal curve (e.g., c, s); Large inter-letter spacing; Emphasized distinctions between similarly-shaped characters (e.g., 1, i, l). 	a c e m n o r s v w

Centaur	Serif	Humanist / Renaissance / Venetian Old style	<p>Description:</p> <ul style="list-style-type: none"> • Designed by Bruce Rogers in 1916 as a titling design for signage in the Metropolitan Museum; • Based on very traditional styles, dating back to Renaissance humanism in 15th - 16th century; <p>Main features:</p> <ul style="list-style-type: none"> • Constant width of all strokes and serifs (hence <i>low contrast</i>); • Complex, non-linear shapes of strokes; • Well defined, bracketed serifs with rounded join to the main strokes of the glyph; • Emphasize diagonal horizontal lines, such as a sloped cross-bar on the lower-case "e", in an attempt to imitate handwriting back then. 	a c e m n o r s v w
Garamond	Serif	Renaissance / Garamond / Italic faces / Baroque Old style	<p>Description:</p> <ul style="list-style-type: none"> • Developed in 17th century, a leading typeface of the renaissance and early Baroque, also influenced by Renaissance Humanism, but has more contrast, more slope of italic, and somewhat variable axis; • Slightly increased linearity and contrast in thickness between thick and thin strokes; • Upper wedge shaped serifs of the minuscules (e.g., b); • Slightly variable axis and more slope of italic. <p>Main features:</p> <ul style="list-style-type: none"> • Relatively more contrast between strokes; • Slightly diagonal lines; • Bracketed serif, connected to main strokes with rounded transitions. 	a c e m n o r s v w
Baskerville	Serif	Transitional / Baroque old style	<p>Description:</p> <ul style="list-style-type: none"> • A transition between Renaissance old style and modern typefaces, with the change from the woodcut to copperplate engravings in the 17th century; 	a c e m n o r s v w

			<ul style="list-style-type: none"> Compared to Old Style fonts, it has greater variety and higher level of contrast (thicker strokes and thinner horizontal lines). <p>Main features:</p> <ul style="list-style-type: none"> Letter axis is vertical or barely inclined (e.g., h, t); Serifs are flat and bracketed, sloping above and horizontal below (e.g., f, y). 	
Bodoni	Serif	Modern / New Antiqua / Didone	<p>Description:</p> <ul style="list-style-type: none"> Arose with the distribution of cooper and steel engraving techniques in 1700s; Strongly influenced by the typesetting techniques, the appearance is technical exact; Have more characters, attitudes and better contrast than old style fonts; Emphasize vertical strokes, in contrast by the attached fine horizontal lines; Serifs with long, fine hairlines and short transitions attached perpendicular to the main stroke to reveal strong contrast. <p>Main features:</p> <ul style="list-style-type: none"> Wide open counters; High contrast between heavy, thick vertical lines and light, thin horizontal hairlines; Thin and light hairy serifs, perpendicularly connected to the main stem (e.g., j, n, p, q, y). 	a c e m n o r s v w
Rockwell	Serif	Slab Serif / Egyptian / Contemporary	<p>Description:</p> <ul style="list-style-type: none"> Arose in early 19 century, for attracting attention to advertisement, posters, flyers, business and private printed matters; Have an artificial look with almost rectangular shapes; The appearance is uniform (Geometric) between letters; The striking serifs are also shaped in rectangle, sticking out horizontally or vertically. 	a c e m n o r s v w

			Main feature: <ul style="list-style-type: none"> Rectangle shape with uniform strokes, lack of contrast. 	
Georgia	Serif	Legible	Description: <ul style="list-style-type: none"> Recently designed by Matthew Carter and hinted by Tom Rickner, released in 1996, to provide optimal readability onscreen with small fonts; Designed with a special purpose for onscreen reading, the glyph started with bitmap fonts, no outlines. Relatively large x-height (but not as big as Verdana) and wider letter spacing; Have a slightly old-style feeling but are still lining. Main feature: <ul style="list-style-type: none"> Large x-height (but less than Verdana); Wider and regular spacing; Rectangle shape with uniform strokes, lack of contrast. 	a c e m n o r s v w

Information in this table derived from references [8-12].

Methods

The same visual acuity method used in Study 1 was used to test the legibility of the 10 letters across the 12 selected fonts. The letters were presented either on a LCD monitor displayed in grayscale or printed out on paper hanging on the same LCD monitor.

Subjects. The two groups of subjects (age 18 to 35 years) tested in Study 1 were recruited to participate in this study. Each group of 30 subjects was tested with only one presentation type: onscreen or in print. The study protocol was approved by the Ohio State University Institutional Review Board.

Stimuli and procedure. Visual acuity measurement procedures were the same as in the first study. The stimuli were presented in 12-pt font size, either rendered in grayscale on a LCD monitor (SONY SDM-M61) or printed on a piece of letter-sized paper hanging on the LCD monitor. Onscreen or imprint, the stimulus was designed in the same way. Each chart consisted of 6 testing pages as in Study 1, with each page being read at a different distance. For each page, 5 out of the 10 letters were randomly selected to be presented and the other 5 letters were presented on the same page of a companion chart. With the two paired charts, each of the 10 letters appeared once at each viewing distance for each font. To average out the random errors, each letter was tested 4 times (rounds) with each font at each of the six distances, hence 48 chart pairs (i.e., 96 charts) were needed. In total, each subject was tested with 96 charts, with 8 charts for each of the 12 fonts and 6 pages in each chart. To balance the effect of testing order between fonts, the 12 fonts were tested in a Latin Square order; In addition, two orders of the 48 charts within each font were created by splitting the charts in each pair to balance the effect of testing order between letters. Half of the subjects were tested in one order and the other half in the other order.

Data analysis. The identification accuracy of each character was recorded. The legibility was calculated separately for each letter in each font. Since each letter was tested 4 times at each size and for each font, each correctly identified letter contributed 25% of an acuity line or 0.025 logMAR. Depending on the subject's vision, if testing began with a 20/40 line, the logMAR of each letter for each font was calculated as:

$$\mathbf{\logMAR = 0.4 - (0.025) \times (\text{the number of correct identifications});}$$

If testing began with a 20/32 line, the logMAR of each letter for each font was calculated as:

$$\mathbf{\logMAR = 0.3 - (0.025) \times (\text{the number of correct identifications}).}$$

Each logMAR value was transformed into Standard Relative Legibility ($1/\text{MAR}$). Further comparison was performed to examine the effect of font type and presentation mode.

As in Study 1, even though all fonts were in 12-point, the character size expressed in height and width varied across characters and fonts as shown in Table 13. The character size in the onscreen conditions was measured on screen directly by counting subjectively the number of pixels occupied by a letter and then transforming the value into metric unit in millimeters. The character size in the hardcopy condition was measured directly with a measuring magnifier. While there may be some arguments in the exact character size as some subjective criteria involved in the measuring process, in general, characters in Verdana, Helvetica, Rockwell, Georgia, and Frutiger tend to be larger than in other fonts, and characters in Centaur and Bodoni tend to be smaller. An increased character size by itself will enhance the relative legibility of a character, hence the Standard Relative Legibility calculated directly from the experimental results contained the effects of size. In order to factor out the size effect on relative legibility, we compensated for the size difference with Height-, Width/Height- and Area-Adjusted Relative Legibility, as in Study 1. Then the adjusted MARs were transformed into logMARs for data analysis to avoid the non-linear transformation problem. The derived results were transformed to Relative Legibility ($1/\text{MAR}$) for report.

Table 13.

The size (Width x Height) of each letter across different font types and presentations.

Presentation Category	Font	Letters size (width x Height, unit: mm)										Average W x H	Average Area	
		a	c	e	m	n	o	r	s	v	w			
GrayScale	Monospace	Consolas	1.5 x 2	1.5 x 2	2 x 2	2 x 2	1.25 x 2	2 x 2	1.5 x 2	1.5 x 2	2 x 2	2 x 2	1.65 x 2	3.30
	Sans serif	Verdana	2 x 2.5	2 x 2.5	2 x 2	3.5 x 2	2 x 2	2 x 2	1.5 x 2	2 x 2.5	2 x 2	3 x 2	2.2 x 2.15	4.73
	Sans serif	Helvetica	2 x 2	1.5 x 2.5	2 x 2	2.5 x 2.5	1.5 x 2	1.5 x 2	1 x 2.5	1.5 x 2.5	2 x 2.5	2.5 x 2	1.8 x 2.25	4.05
	Sans serif	Futura	2 x 2	1.5 x 2	2 x 2	3.5 x 2	1.75 x 2	2 x 2	1.5 x 2	1.5 x 2	2 x 2	3.5 x 2	2.13 x 2	4.25
	Sans serif	Fruitger	1.5 x 2	1.5 x 2	2 x 2.5	3.5 x 2.5	2 x 2.5	2 x 2.5	1 x 2	1 x 2.5	2 x 2	3 x 2.5	1.95 x 2.3	4.49
	Sans serif	DIN	1.5 x 2	2 x 2	1.5 x 2.5	3 x 2	2 x 2	1.5 x 2.5	1.5 x 2.5	1.5 x 2	2 x 2	3 x 2	1.95 x 2.15	4.19
	Serif	Rockwell	2 x 2.5	2 x 2.5	2.5 x 2.5	3.5 x 2.5	2 x 2.5	2.5 x 2.5	1.5 x 2.5	1.5 x 2.5	2.5 x 2.5	3.5 x 2.5	2.35 x 2.5	5.88
	Serif	Georgia	2 x 2	1.5 x 2	1.75 x 2	3.5 x 2	2 x 2	2 x 2	1.5 x 2	2 x 2	2 x 2	3 x 2	2.13 x 2	4.25
	Serif	Garamond	1.5 x 1.5	1.5 x 2	1.5 x 1.5	3 x 2	2 x 1.5	1.5 x 2	1 x 1.5	1 x 1.5	2 x 2	3 x 2	1.8 x 1.75	3.15
	Serif	Centaur	1.5 x 1.75	1 x 1.75	1.25 x 1.75	2.5 x 1.5	1.75 x 1.5	1.75 x 1.5	1.25 x 1.5	1 x 1.5	1.75 x 1.5	2.5 x 1.75	1.63 x 1.6	2.60
	Serif	Bodoni	1.5 x 1.5	1.5 x 2	1.5 x 1.5	3 x 2	2 x 2	1 x 2	1 x 1.5	1.25 x 1.5	2 x 1.5	2.5 x 1.5	1.73 x 1.7	2.93
	Serif	Baskerville	2 x 2	1.5 x 2	1.5 x 2	3.5 x 2	2.5 x 2	2 x 2	1.5 x 2	1.5 x 1.5	2 x 2	2.5 x 1.5	2.05 x 1.9	3.90
	HardCopy	Monospace	Consolas	1.8 x 2.2	1.6 x 2.2	1.8 x 2.2	1.9 x 2.2	1.6 x 2.2	1.3 x 2.2	1.7 x 2.2	1.6 x 2.2	1.9 x 2.2	2.1 x 2.2	1.73 x 2.2
Sans serif		Verdana	1.9 x 2.5	1.8 x 2.5	2 x 2.5	3.2 x 2.5	1.8 x 2.5	2.1 x 2.5	1.4 x 2.5	1.8 x 2.5	2.1 x 2.5	3 x 2.5	2.11 x 2.5	5.28
Sans serif		Helvetica	2 x 2.2	1.9 x 2.2	2 x 2.2	2.9 x 2.2	1.8 x 2.2	2 x 2.2	1 x 2.2	1.8 x 2.2	2 x 2.2	2.9 x 2.2	2.03 x 2.2	4.47
Sans serif		Futura	2 x 2	1.7 x 2	1.9 x 2	2.6 x 2	1.6 x 2	2.1 x 2	1 x 2	1.3 x 2	1.9 x 2	3.3 x 2	1.94 x 2	3.88
Sans serif		Fruitger	1.9 x 2.2	1.5 x 2.2	1.9 x 2.2	3 x 2.2	1.6 x 2.2	1.9 x 2.2	1.7 x 2.2	1.6 x 2.2	1.9 x 2.2	2.1 x 2.2	1.91 x 2.2	4.20
Sans serif		DIN	1.6 x 2.2	1.6 x 2.2	1.7 x 2.2	2.9 x 2.2	1.6 x 2.2	1.7 x 2.2	1.2 x 2.2	1.7 x 2.2	1.7 x 2.2	2.8 x 2.2	1.95 x 2.2	4.29
Serif		Rockwell	1.9 x 2	1.9 x 2	2 x 2	3.4 x 2	2.1 x 2	2.1 x 2	1.6 x 2	1.7 x 2	2.3 x 2	3.3 x 2	2.23 x 2	4.46
Serif		Georgia	1.9 x 2	1.8 x 2	1.8 x 2	3.4 x 2	2.2 x 2	2 x 2	1.6 x 2	1.6 x 2	2.2 x 2	3.3 x 2	2.18 x 2	4.36
Serif		Garamond	1.6 x 1.7	1.5 x 1.7	1.5 x 1.7	3.1 x 1.7	1.8 x 1.7	2.1 x 1.7	1.2 x 1.7	1.3 x 1.7	1.9 x 1.7	3.3 x 1.7	1.93 x 1.7	3.28
Serif		Centaur	1.5 x 1.6	1.3 x 1.6	1.3 x 1.6	2.9 x 1.6	1.8 x 1.6	1.7 x 1.6	1.3 x 1.6	1 x 1.6	1.5 x 1.6	2.3 x 1.6	1.66 x 1.6	2.66
Serif		Bodoni	1.7 x 1.6	1.5 x 1.6	1.5 x 1.6	3.1 x 1.6	2.1 x 1.6	1.7 x 1.6	1.4 x 1.6	1.2 x 1.6	2.2 x 1.6	2.8 x 1.6	1.92 x 1.6	3.07
Serif		Baskerville	1.8 x 1.8	1.5 x 1.8	1.5 x 1.8	3.1 x 1.8	2 x 1.8	1.9 x 1.8	1.5 x 1.8	1.2 x 1.8	1.7 x 1.8	2.6 x 1.8	1.88 x 1.8	3.38
Average Width x Height			1.81x1.99	1.61x2.05	1.77x2.01	3x2.04	1.86x2	1.85x2.04	1.37x2	1.44x2	1.98x2	2.83x1.99		
Average Area			3.7	3.3	3.55	6.13	3.73	3.77	2.74	2.88	3.96	5.62		

*An invisible box (3.4 x 4.2 mm, W x H) of 12-pt font is used as the base for size adjustment.

Results

As in Study 1, We examined the size effect before presenting the size-adjustment results. Table 14 shows that, for each of the 10 tested letters, the actual character size explained 55%~82% of variance in most conditions, except for letter e (27.4%) and letter m (39.6%) in the Grayscale conditions. In other words, the measure of Standard Relative Legibility was greatly affected by their actual character size (height always, width most of the time, together they may cover the effect of area therefore sometimes area has no net-effect on Standard RL). Therefore, in the following report, we presented results of relative legibility comparison with and without size adjustment, for each individual letter and for the overall comparisons across fonts and across letters.

Table 14.

Summary of size effect on Standard RL across letters with different presentation media.

	<i>Onscreen</i>					<i>Hardcopy</i>				
	<i>R-Square</i>	<i>subject</i>	<i>height</i>	<i>width</i>	<i>area</i>	<i>R-Square</i>	<i>subject</i>	<i>height</i>	<i>width</i>	<i>area</i>
a	0.670	17.02	133.96	4.16	32.28	0.550	8.96	129.72	5.22	4.62
		<.0001	<.0001	0.0423	<.0001		<.0001	<.0001	0.023	0.0324
c	0.578	13.67	41.25	0.71	10.1	0.741	17.45	426.88	2.8	0.97
		<.0001	<.0001	0.4003	0.0016		<.0001	<.0001	0.0952	0.3264
e	0.274	3.02	12.79	6.15	17	0.711	12.73	419.31	12.05	2.17
		<.0001	<.0001	0.0137	<.0001		<.0001	<.0001	<.0001	0.1417
m	0.396	3.89	38.75	62.54	0.84	0.786	22	13.3	469.54	79.72
		<.0001	<.0001	<.0001	0.3597		<.0001	<.0001	<.0001	<.0001
n	0.754	26.94	123.27	26.23	74.12	0.738	19.77	346.53	0.33	0.91
		<.0001	<.0001	<.0001	<.0001		<.0001	<.0001	0.5687	0.3414
o	0.742	25.18	32.35	158.14	20.05	0.737	24.97	152.42	34.45	3.16
		<.0001	<.0001	<.0001	<.0001		<.0001	<.0001	<.0001	0.0763
r	0.749	28.3	153.87	2	0.36	0.732	21.23	272.7	2.61	2.06
		<.0001	<.0001	0.1582	0.5467		<.0001	<.0001	0.1072	0.1525
s	0.808	30.26	61.15	54.67	26.96	0.823	25.19	785.56	6.38	0.02
		<.0001	<.0001	<.0001	<.0001		<.0001	<.0001	0.012	0.8793
v	0.695	22.36	84.61	0.27	10.26	0.795	25.85	447.17	73.35	0.62
		<.0001	<.0001	0.6034	0.0015		<.0001	<.0001	<.0001	0.4305
w	0.683	19.54	98.91	35.72	2.18	0.728	18.78	265.06	57.09	7.02
		<.0001	<.0001	<.0001	0.1407		<.0001	<.0001	<.0001	0.0084

Legibility of individual letters across fonts.

The relative legibility values for each of the 10 tested letters are presented in Tables 15-24, one for each letter, with the top panel for Onscreen presentation and the bottom panel for Hardcopy presentation. All of the 4 types of relative legibility values are presented, including Standard (un-adjusted) RL, Height-Adjusted RL, Width/Height-Adjusted RL, and Area-Adjusted RL. Values in each legibility category are sorted in descending order and an example of the letter in each font is presented to assist subjective visual inspection. Figures 16-25 are presented in accompany to Tables 15-24, respectively, as graphical presentations of the Area-Adjusted RL, with left panel for the Onscreen display and the right panel for the Hardcopy display. In

each of the stacked bar chart, the blue bar represents the lower-bound of the 95% confidence interval and the red cap at the end of each bar indicates the 95% confidence range. If the red cap of one font overlaps with another, the two measures are considered to be statistically not different from each other.

As in Study 1, the Height adjustment increased RL, the Width/Height Adjustment decreased RL, and the Area-Adjustment which have effect from both height and width, and was hence have RL in between Height- and Width/Height-adjusted values.

Letter a.

For letter a, Verdana, Frutiger, Helvetica and Consolas had the highest Standard RLs, which may seem to benefit from their relative large x-height; however, after size adjustment (e.g., area adjustment), Verdana, Frutiger and Consolas remained strong while Helvetica drops lower on the list. These first three fonts have relatively distinctive lower bowl sticking out and a small but clear cap on the top. In contrast, the two parts stay about equal and closely connected in Helvetica, which may decrease the legibility from distance. Futura "a" (note: all exemplar letters are in 12-pt size as in the study) represents another paradigm, with only a light-weighted circle hanging against a strong vertical stroke. This kind of design seems to be less legible than the two-segment paradigm (like Consolas "a"), and easier to be confused with letters o, q or number 0. Another paradigm is letter "a" in DIN, whose legibility performance was better in the onscreen condition than in the hardcopy condition. A possible explanation for the difference is that DIN 12-pt a (and other characters) look significantly darker than other fonts onscreen, but it does not appear so when displayed on paper or in other font sizes. For fonts emphasizing detailed segments within a small character size (e.g., Garamond, Centaur, and

Bodoni), their relative legibility tended to be low, and this cannot be compensated with size adjustment.

In short, for letter a, a design with distinctive lower bowl under a clear cap with large character size seems to be more legible.

Table 15.
Relative legibility under different size adjustment: Letter a.

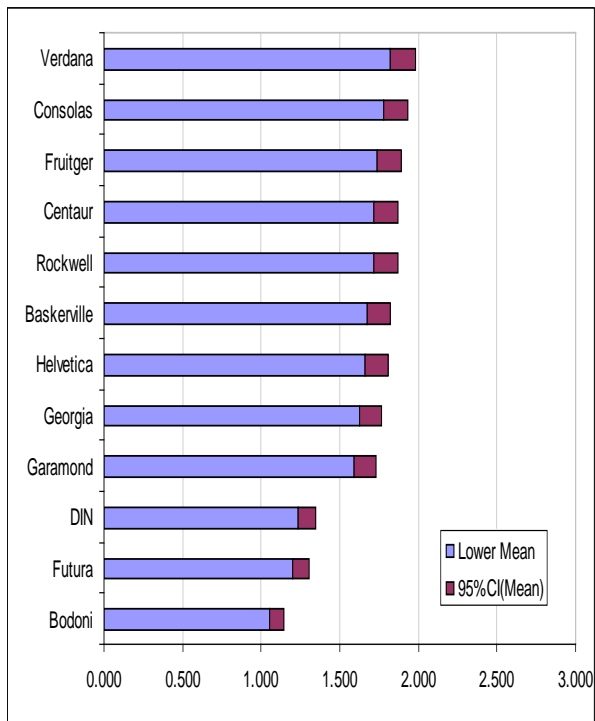
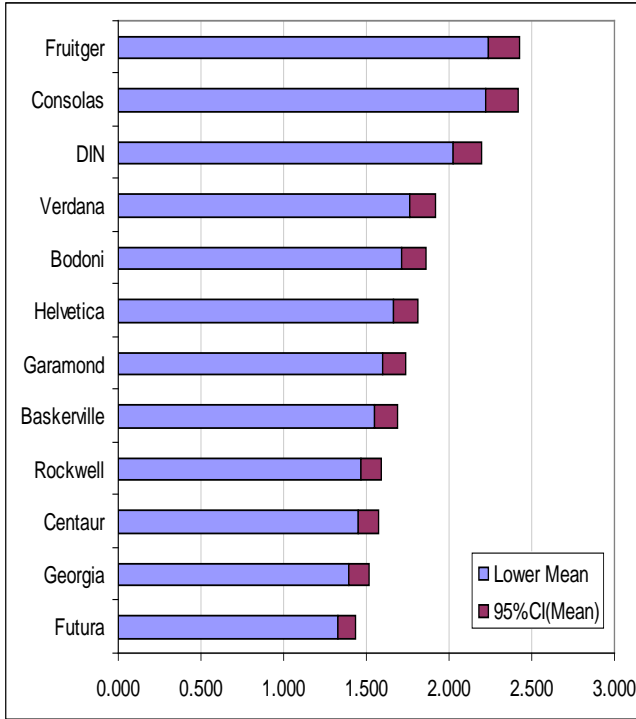
(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
a	Verdana	1.193	a	Bodoni	2.235	a	Fruitger	1.094	a	Fruitger	2.330
a	Fruitger	1.059	a	Fruitger	2.185	a	Consolas	1.087	a	Consolas	2.317
a	Helvetica	1.045	a	Helvetica	2.172	a	Verdana	1.080	a	DIN	2.109
a	Consolas	1.045	a	Consolas	2.172	a	DIN	0.990	a	Verdana	1.841
a	Baskerville	0.888	a	Garamond	2.086	a	Rockwell	0.896	a	Bodoni	1.788
a	DIN	0.842	a	Baskerville	2.023	a	Helvetica	0.815	a	Helvetica	1.738
a	Rockwell	0.777	a	DIN	1.977	a	Baskerville	0.760	a	Garamond	1.669
a	Georgia	0.693	a	Verdana	1.841	a	Georgia	0.682	a	Baskerville	1.619
a	Futura	0.615	a	Georgia	1.817	a	Futura	0.648	a	Rockwell	1.528
a	Bodoni	0.576	a	Futura	1.725	a	Bodoni	0.629	a	Centaur	1.513
a	Garamond	0.491	a	Centaur	1.621	a	Centaur	0.621	a	Georgia	1.454
a	Centaur	0.392	a	Rockwell	1.528	a	Garamond	0.587	a	Futura	1.380

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
a	Verdana	1.142	a	Bodoni	2.315	a	Verdana	1.115	a	Verdana	1.901
a	Helvetica	1.041	a	Baskerville	2.184	a	Consolas	0.957	a	Consolas	1.854
a	Frutiger	1.027	a	Rockwell	2.127	a	Frutiger	0.937	a	Frutiger	1.815
a	Rockwell	0.996	a	Centaur	2.099	a	Helvetica	0.895	a	Centaur	1.792
a	DIN	0.961	a	Georgia	2.012	a	Rockwell	0.840	a	Rockwell	1.791
a	Consolas	0.953	a	Helvetica	1.971	a	Georgia	0.795	a	Baskerville	1.747
a	Georgia	0.876	a	Frutiger	1.959	a	Baskerville	0.738	a	Helvetica	1.734
a	Baskerville	0.831	a	Garamond	1.950	a	Centaur	0.673	a	Georgia	1.694
a	Bodoni	0.724	a	DIN	1.904	a	DIN	0.665	a	Garamond	1.657
a	Centaur	0.578	a	Consolas	1.897	a	Garamond	0.661	a	DIN	1.289
a	Garamond	0.561	a	Verdana	1.806	a	Futura	0.587	a	Futura	1.252

a	Futura	0.491	a	Futura	1.564	a	Bodoni	0.412	a	Bodoni	1.098
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(Onscreen display)

(Hardcopy display)

Figure 16. Onscreen (left) vs. Hardcopy (right) for letter “a”

Letter c.

For letter a, Verdana, Frutiger, Futura and Consolas had higher legibility, both onscreen and in print, before and after size adjustment. A common feature of those fonts is the wide opening of the cup, which generally required a relative higher x-height. In addition, some variations in the stroke seems to be beneficial (e.g., thicker in the vertical stroke and lighter around the curves). These feature seem to make the letter more legible than designs with closer opening (e.g., Helvetica “c” and Rockwell “c”) and equal-weight strokes (e.g., Helvetica “c” and DIN “c”, though Futura “c” seems more legible). Fonts with small actual size, especially those with small decorative parts, tend to have lower legibility, even after size compensation.

In short, for letter c, a wide opening in the cup and big x-height seem to be effective designs.

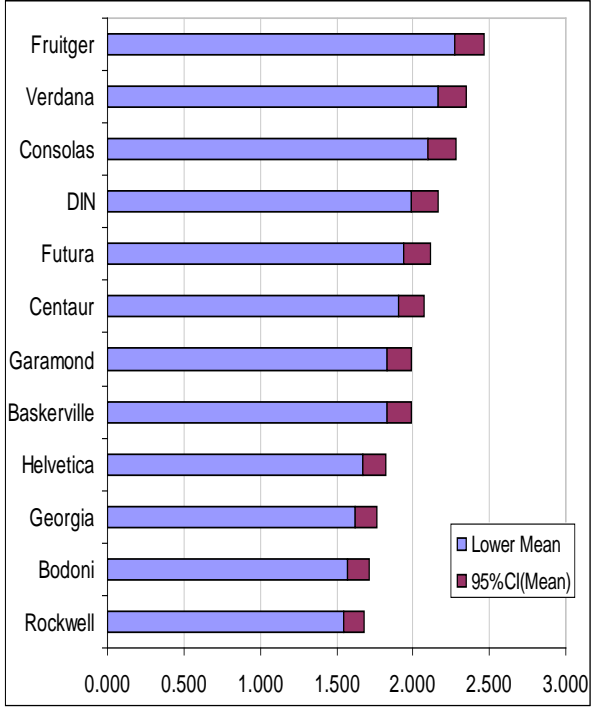
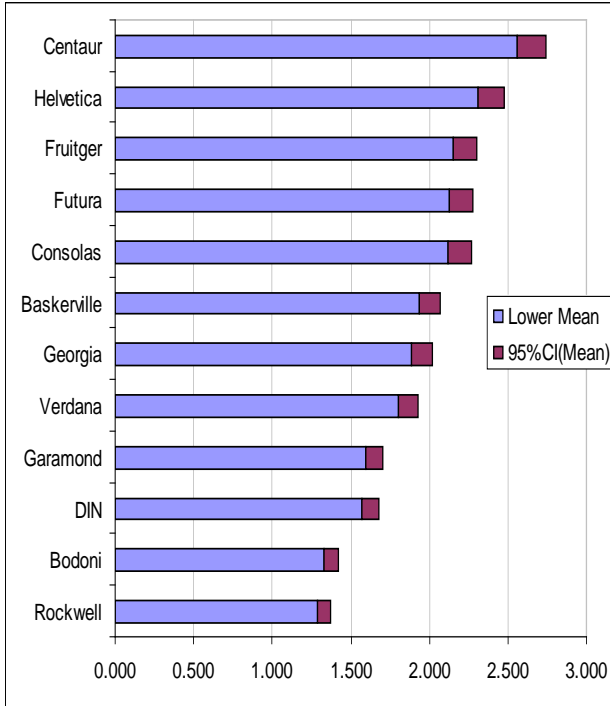
Table 18.
Relative legibility under different size adjustment: Letter c.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
c	Verdana	1.225	c	Frutiger	2.090	c	Helvetica	1.404	c	Centaur	2.651
c	Helvetica	1.127	c	Futura	2.062	c	Verdana	1.092	c	Helvetica	2.394
c	Frutiger	0.957	c	Consolas	2.058	c	Centaur	1.089	c	Frutiger	2.230
c	Futura	0.928	c	DIN	2.027	c	Frutiger	1.046	c	Futura	2.200
c	Consolas	0.924	c	Centaur	1.894	c	Futura	1.032	c	Consolas	2.196
c	DIN	0.891	c	Baskerville	1.874	c	Consolas	1.030	c	Baskerville	1.999
c	Baskerville	0.744	c	Verdana	1.862	c	Baskerville	0.938	c	Georgia	1.949
c	Georgia	0.702	c	Georgia	1.828	c	Georgia	0.915	c	Verdana	1.862
c	Rockwell	0.563	c	Helvetica	1.795	c	Rockwell	0.779	c	Garamond	1.646
c	Centaur	0.561	c	Garamond	1.544	c	Garamond	0.773	c	DIN	1.622
c	Garamond	0.476	c	Rockwell	1.328	c	DIN	0.761	c	Bodoni	1.375
c	Bodoni	0.314	c	Bodoni	1.289	c	Bodoni	0.645	c	Rockwell	1.328

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
c	Verdana	1.495	c	Futura	2.151	c	Verdana	1.323	c	Frutiger	2.366
c	Frutiger	1.097	c	Garamond	2.101	c	Frutiger	1.222	c	Verdana	2.255
c	Consolas	1.064	c	Verdana	2.030	c	Consolas	1.130	c	Consolas	2.189
c	Futura	1.022	c	Frutiger	2.017	c	DIN	1.071	c	DIN	2.074
c	DIN	0.940	c	Centaur	2.017	c	Futura	0.950	c	Futura	2.025
c	Helvetica	0.936	c	Consolas	1.990	c	Helvetica	0.900	c	Centaur	1.986
c	Rockwell	0.784	c	Baskerville	1.984	c	Baskerville	0.805	c	Baskerville	1.905
c	Georgia	0.767	c	Bodoni	1.922	c	Georgia	0.792	c	Garamond	1.905
c	Baskerville	0.666	c	Rockwell	1.917	c	Garamond	0.760	c	Helvetica	1.743
c	Garamond	0.666	c	Georgia	1.899	c	Rockwell	0.758	c	Georgia	1.688
c	Centaur	0.527	c	DIN	1.886	c	Centaur	0.745	c	Bodoni	1.640
c	Bodoni	0.472	c	Helvetica	1.882	c	Bodoni	0.616	c	Rockwell	1.615



(Onscreen display)

(Hardcopy display)

Figure 17. Onscreen (left) vs. Hardcopy (right) for letter "c"

Letter e.

For letter e, Verdana, Frutiger and Georgia e e e e e had higher legibility, both onscreen and in print, before and after size adjustment. Again, the opening in the lower cup in those fonts is wider. In contrast, Rockwell “e”, Helvetica “e” and Futura “e” are less legible despite of their big height and width. Centaur, Bodoni, Garamond and Baskerville are serif fonts with small character size. These fonts usually have lower Standard RL; Their detailed artful design seem to paid off after size adjustment.

Overall, as in letter c, a wide opening seems to be the most important designing factor for letter e. Details help only under the premise of enough character size.

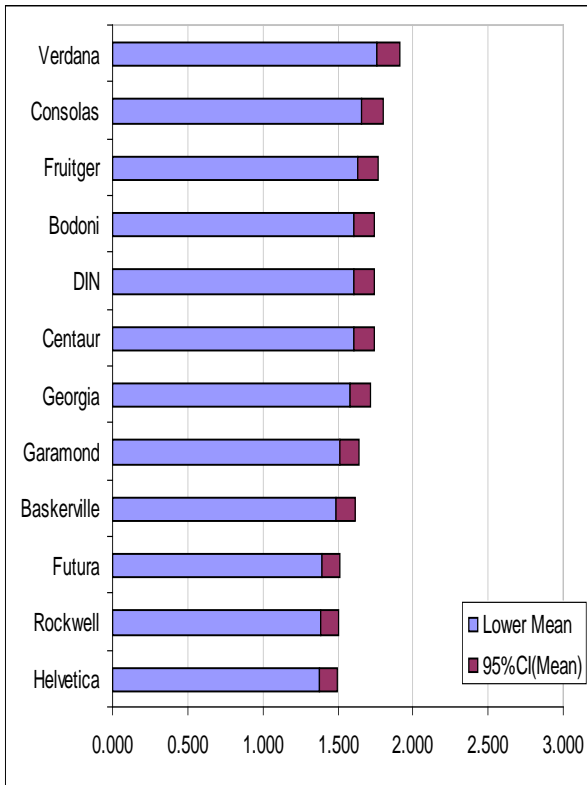
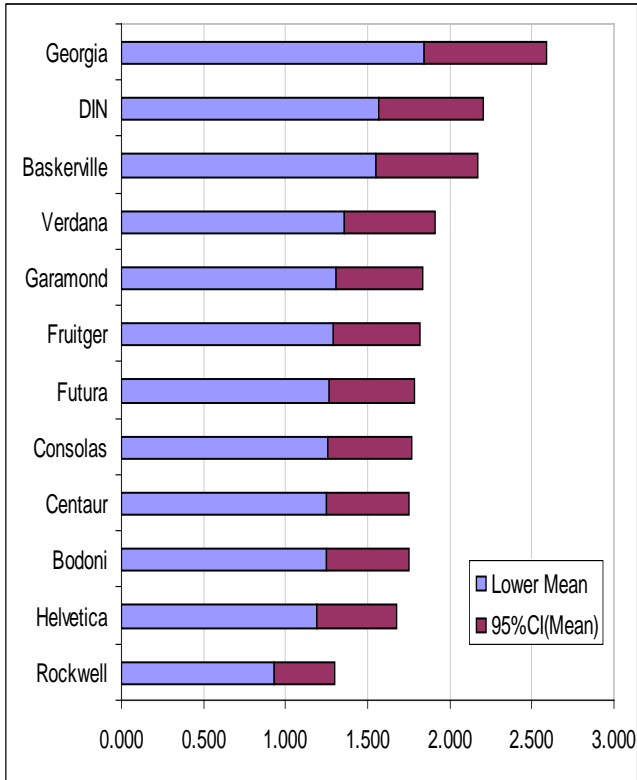
Table 19.
Relative legibility under different size adjustment: Letter e.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
e	Georgia	1.298	e	Georgia	2.386	e	DIN	1.090	e	Georgia	2.182
e	Verdana	0.876	e	Verdana	2.012	e	Georgia	1.024	e	DIN	1.858
e	Frutiger	0.784	e	Garamond	1.932	e	Frutiger	0.900	e	Baskerville	1.833
e	Futura	0.750	e	Futura	1.881	e	Baskerville	0.860	e	Verdana	1.609
e	Consolas	0.737	e	Consolas	1.867	e	Verdana	0.755	e	Garamond	1.545
e	Helvetica	0.651	e	Bodoni	1.845	e	Futura	0.706	e	Frutiger	1.534
e	DIN	0.629	e	Helvetica	1.769	e	Consolas	0.701	e	Futura	1.505
e	Baskerville	0.610	e	Baskerville	1.719	e	Helvetica	0.664	e	Consolas	1.493
e	Rockwell	0.607	e	Frutiger	1.534	e	Rockwell	0.644	e	Centaur	1.479
e	Garamond	0.411	e	DIN	1.394	e	Centaur	0.607	e	Bodoni	1.476
e	Bodoni	0.370	e	Rockwell	1.372	e	Garamond	0.544	e	Helvetica	1.415
e	Centaur	0.244	e	Centaur	1.320	e	Bodoni	0.520	e	Rockwell	1.098

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
e	Verdana	1.188	e	Bodoni	1.959	e	Verdana	1.078	e	Verdana	1.837
e	Frutiger	0.880	e	Georgia	1.852	e	Consolas	0.893	e	Consolas	1.731
e	Consolas	0.812	e	Verdana	1.837	e	Frutiger	0.876	e	Frutiger	1.697
e	Georgia	0.724	e	Frutiger	1.832	e	DIN	0.863	e	Bodoni	1.672
e	Rockwell	0.678	e	Rockwell	1.800	e	Georgia	0.773	e	DIN	1.671
e	Helvetica	0.675	e	Consolas	1.770	e	Helvetica	0.742	e	Centaur	1.671
e	DIN	0.657	e	Garamond	1.740	e	Futura	0.681	e	Georgia	1.646
e	Futura	0.612	e	Futura	1.722	e	Rockwell	0.676	e	Garamond	1.578
e	Bodoni	0.493	e	Centaur	1.697	e	Baskerville	0.654	e	Baskerville	1.548
e	Garamond	0.431	e	Helvetica	1.633	e	Garamond	0.629	e	Futura	1.450
e	Baskerville	0.413	e	DIN	1.614	e	Bodoni	0.628	e	Rockwell	1.440
e	Centaur	0.354	e	Baskerville	1.613	e	Centaur	0.627	e	Helvetica	1.437



(Onscreen display)

(Hardcopy display)

Figure 18. Onscreen (left) vs. Hardcopy (right) for letter "e"

Letter m.

For letter m, wide width improves Standard RL, but it does not seem to be the most critical factor, as the big width does not seem to increase the legibility of Georgia and Baskerville (and Rockwell in print). Still, Consolas suffers from the narrow width, but its legibility was improved after size compensation. Compared to serif fonts, sans serif fonts seem to be more legible in letter m. Their relatively smaller x-height and the more closed stroke ending at the bottom (due to their serifs) could be the cause of lower legibility.

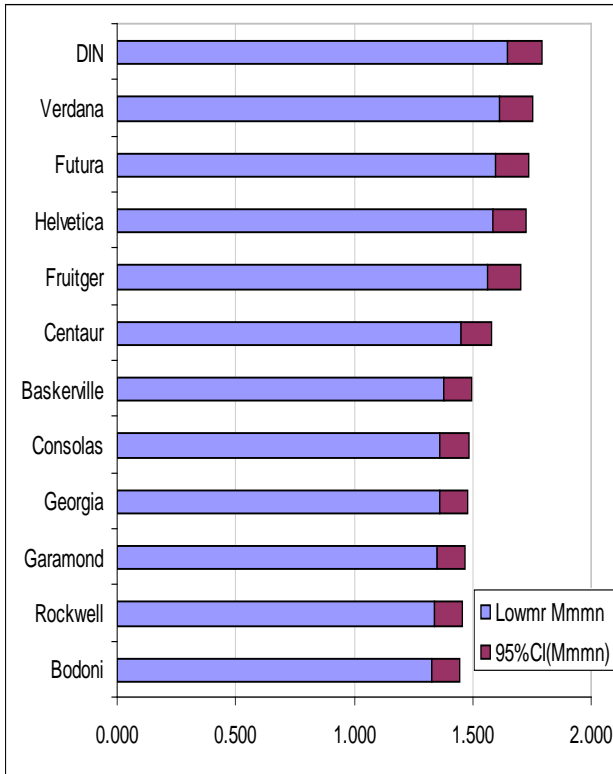
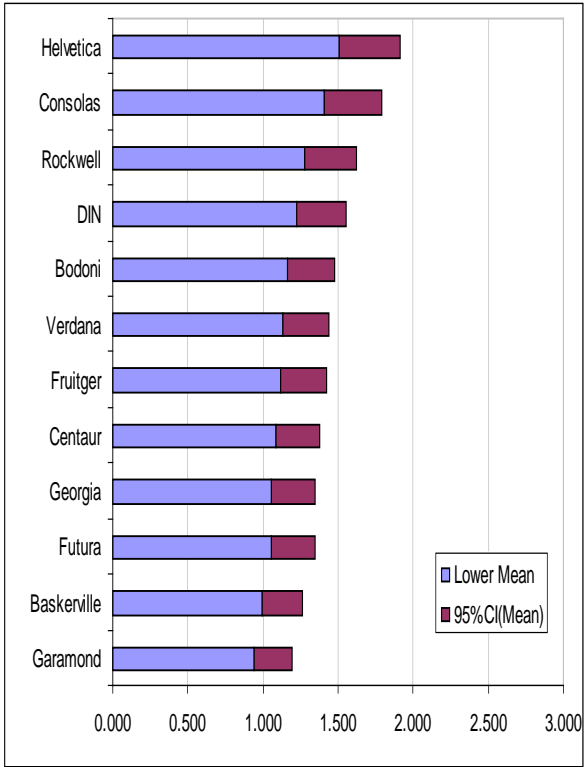
Table 20.
Relative legibility under different size adjustment: Letter m.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
m	Rockwell	2.452	m	Verdana	2.787	m	Helvetica	0.998	m	Helvetica	1.700
m	Verdana	1.856	m	Futura	2.611	m	Rockwell	0.844	m	Consolas	1.591
m	Frutiger	1.816	m	Georgia	2.611	m	Consolas	0.747	m	Rockwell	1.438
m	Helvetica	1.662	m	DIN	2.586	m	Frutiger	0.740	m	DIN	1.379
m	Futura	1.597	m	Centaur	2.552	m	DIN	0.647	m	Bodoni	1.312
m	Georgia	1.597	m	Rockwell	2.516	m	Bodoni	0.616	m	Verdana	1.274
m	DIN	1.562	m	Bodoni	2.461	m	Verdana	0.598	m	Frutiger	1.262
m	Bodoni	1.393	m	Baskerville	2.451	m	Futura	0.560	m	Centaur	1.225
m	Baskerville	1.381	m	Frutiger	2.209	m	Georgia	0.560	m	Futura	1.194
m	Garamond	0.853	m	Helvetica	2.125	m	Baskerville	0.526	m	Georgia	1.194
m	Centaur	0.781	m	Garamond	1.989	m	Garamond	0.498	m	Baskerville	1.121
m	Consolas	0.440	m	Consolas	1.491	m	Centaur	0.431	m	Garamond	1.061

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
m	Verdana	2.862	m	Centaur	3.431	m	Verdana	0.987	m	DIN	1.719
m	DIN	2.398	m	Bodoni	3.353	m	DIN	0.887	m	Verdana	1.682
m	Frutiger	2.305	m	Georgia	3.211	m	Helvetica	0.854	m	Futura	1.663
m	Garamond	2.225	m	Baskerville	3.091	m	Frutiger	0.843	m	Helvetica	1.654
m	Helvetica	2.196	m	Garamond	3.016	m	Futura	0.781	m	Frutiger	1.633
m	Rockwell	2.138	m	Rockwell	2.964	m	Consolas	0.734	m	Centaur	1.514
m	Baskerville	1.848	m	DIN	2.832	m	Garamond	0.666	m	Baskerville	1.436
m	Centaur	1.792	m	Frutiger	2.784	m	Rockwell	0.655	m	Consolas	1.423
m	Georgia	1.768	m	Helvetica	2.726	m	Baskerville	0.606	m	Garamond	1.419
m	Futura	1.730	m	Futura	2.703	m	Centaur	0.569	m	Georgia	1.409
m	Bodoni	1.699	m	Verdana	2.691	m	Georgia	0.562	m	Rockwell	1.395
m	Consolas	0.586	m	Consolas	1.536	m	Bodoni	0.520	m	Bodoni	1.384



(Onscreen display)

(Hardcopy display)

Figure 19. Onscreen (left) vs. Hardcopy (right) for letter "m"

Letter n.

Similar to letter m, letter n also benefit from bigger x-height, wider width, and wider opening at the bottom (usually no serifs), especially the x-height. In addition, wider inside-space between the two vertical strokes makes some san serif letter n's (e.g., Frutiger "n" and Verdana "n") more legible than others.

A noticeable difference between onscreen and hardcopy condition is that, serif fonts seemed to more legible after size adjustment in the onscreen conditions, but not in the hardcopy condition. We have no particular explanation so far.

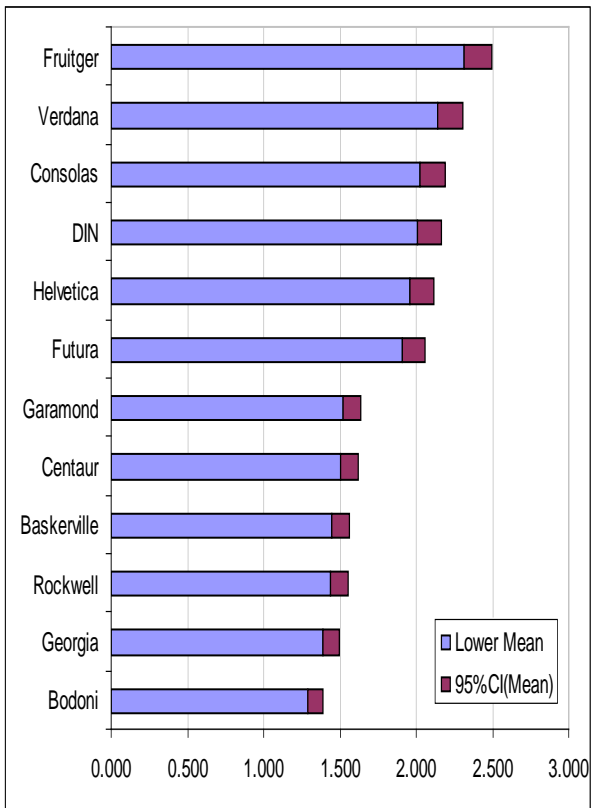
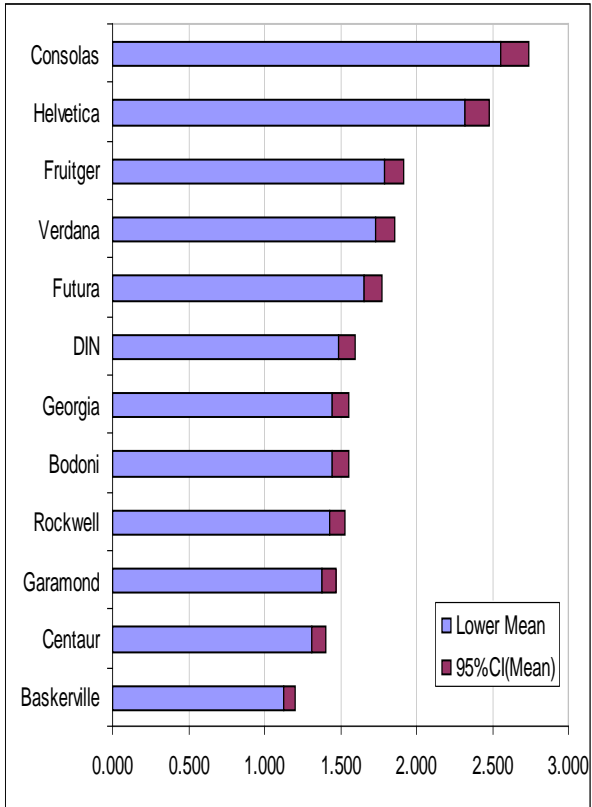
Table 21.
Relative legibility under different size adjustment: Letter n.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
n	Baskerville	0.693	n	Baskerville	1.817	n	Baskerville	0.546	n	Baskerville	1.817
n	Bodoni	0.744	n	Bodoni	1.874	n	Bodoni	0.703	n	Bodoni	1.874
n	Centaur	0.436	n	Centaur	1.981	n	Centaur	0.478	n	Centaur	1.981
n	Consolas	0.932	n	Consolas	2.066	n	Consolas	1.241	n	Consolas	2.066
n	DIN	0.791	n	DIN	1.925	n	DIN	0.723	n	DIN	1.925
n	Frutiger	1.209	n	Frutiger	1.851	n	Frutiger	1.086	n	Frutiger	1.851
n	Futura	0.744	n	Futura	1.874	n	Futura	0.804	n	Futura	1.874
n	Garamond	0.660	n	Garamond	2.372	n	Garamond	0.501	n	Garamond	2.372
n	Georgia	0.744	n	Georgia	1.874	n	Georgia	0.703	n	Georgia	1.874
n	Helvetica	1.132	n	Helvetica	2.248	n	Helvetica	1.126	n	Helvetica	2.248
n	Rockwell	0.721	n	Rockwell	1.479	n	Rockwell	0.868	n	Rockwell	1.479
n	Verdana	1.127	n	Verdana	2.244	n	Verdana	0.843	n	Verdana	2.244

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
n	Verdana	1.443	n	Centaur	2.198	n	Verdana	1.303	n	Frutiger	2.198
n	Frutiger	1.321	n	Bodoni	2.194	n	Frutiger	1.241	n	Verdana	2.194
n	Helvetica	1.178	n	Frutiger	2.186	n	Consolas	1.087	n	Consolas	2.186
n	Consolas	0.974	n	Garamond	2.089	n	DIN	1.077	n	DIN	2.089
n	DIN	0.953	n	Baskerville	2.086	n	Helvetica	1.050	n	Helvetica	2.086
n	Georgia	0.849	n	Helvetica	2.080	n	Futura	0.930	n	Futura	2.080
n	Futura	0.845	n	Verdana	1.999	n	Rockwell	0.700	n	Garamond	1.999
n	Rockwell	0.823	n	Georgia	1.985	n	Georgia	0.677	n	Centaur	1.985
n	Baskerville	0.747	n	Futura	1.981	n	Baskerville	0.634	n	Baskerville	1.981
n	Garamond	0.657	n	Rockwell	1.958	n	Garamond	0.630	n	Rockwell	1.958
n	Centaur	0.643	n	Consolas	1.915	n	Centaur	0.587	n	Georgia	1.915
n	Bodoni	0.640	n	DIN	1.897	n	Bodoni	0.502	n	Bodoni	1.897



(Onscreen display)

(Hardcopy display)

Figure 20. Onscreen (left) vs. Hardcopy (right) for letter “n”

Letter o.

For letter o, Verdana, Frutiger, and Rockwell in standard RL; after area adjustment, however, Rockwell quickly descended while Frutiger and Verdana remained high. It suggests that, in addition to x-height, the shape of the circle also matters. In this case, a more rectangular-shaped circle (e.g., Frutiger “O” and DIN “o”) seems to be better than a round-looking one (e.g., Rockwell “O”).

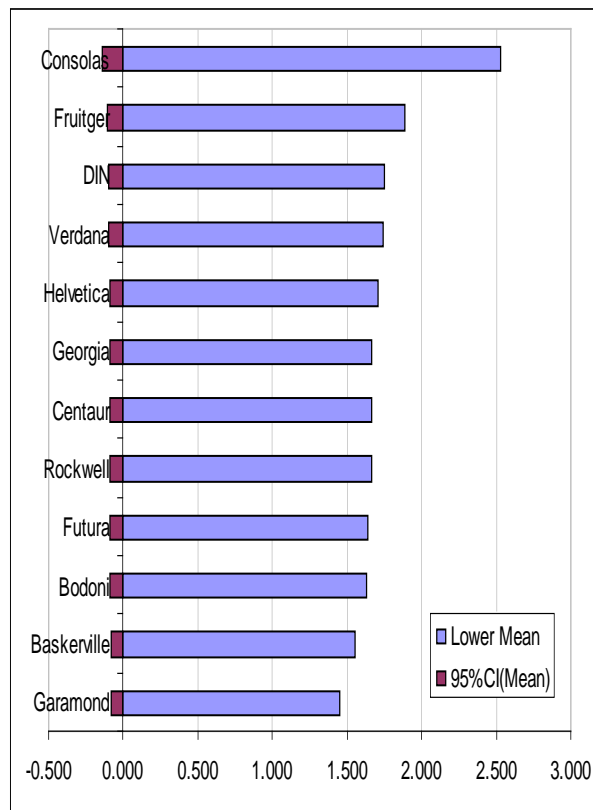
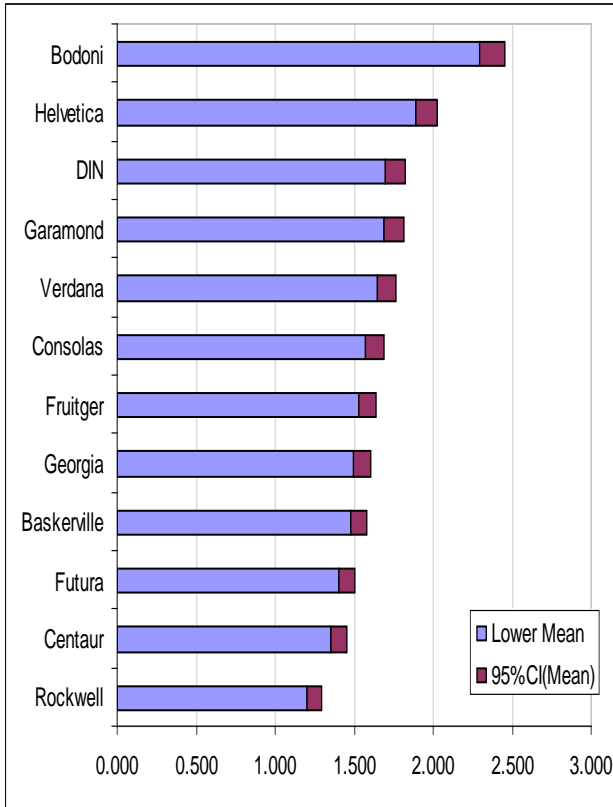
Table 22.
Relative legibility under different size adjustment: Letter o.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted	
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font
o	Verdana	0.996	o	Verdana	2.127	o	Bodoni	1.113	o	Bodoni
o	Consolas	0.899	o	Centaur	2.046	o	DIN	1.033	o	Helvetica
o	Frutiger	0.845	o	Consolas	2.035	o	Frutiger	0.930	o	DIN
o	Rockwell	0.812	o	Georgia	1.936	o	Helvetica	0.918	o	Garamond
o	Georgia	0.802	o	Baskerville	1.910	o	Garamond	0.822	o	Verdana
o	Baskerville	0.777	o	Helvetica	1.835	o	Verdana	0.798	o	Consolas
o	Helvetica	0.708	o	Futura	1.821	o	Consolas	0.764	o	Frutiger
o	Futura	0.696	o	Garamond	1.641	o	Rockwell	0.731	o	Georgia
o	DIN	0.556	o	Frutiger	1.585	o	Georgia	0.727	o	Baskerville
o	Garamond	0.548	o	Rockwell	1.558	o	Baskerville	0.717	o	Futura
o	Centaur	0.470	o	Bodoni	1.483	o	Futura	0.684	o	Centaur
o	Bodoni	0.434	o	DIN	1.321	o	Centaur	0.494	o	Rockwell

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted	
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font
o	Verdana	1.132	o	Garamond	2.204	o	Consolas	1.283	o	Consolas
o	Frutiger	1.078	o	Centaur	2.169	o	Verdana	1.005	o	Frutiger
o	Rockwell	1.013	o	Rockwell	2.143	o	Frutiger	0.957	o	DIN
o	Futura	0.974	o	Bodoni	2.128	o	DIN	0.886	o	Verdana
o	Helvetica	0.965	o	Futura	2.106	o	Helvetica	0.867	o	Helvetica
o	Georgia	0.907	o	Georgia	2.043	o	Georgia	0.767	o	Georgia
o	Consolas	0.884	o	Baskerville	2.007	o	Rockwell	0.766	o	Centaur
o	Garamond	0.744	o	Frutiger	2.001	o	Futura	0.753	o	Rockwell
o	DIN	0.699	o	Helvetica	1.908	o	Baskerville	0.643	o	Futura
o	Baskerville	0.684	o	Consolas	1.836	o	Centaur	0.613	o	Bodoni
o	Centaur	0.623	o	Verdana	1.799	o	Bodoni	0.602	o	Baskerville
o	Bodoni	0.596	o	DIN	1.658	o	Garamond	0.569	o	Garamond



(Onscreen display)

(Hardcopy display)

Figure 21. Onscreen (left) vs. Hardcopy (right) for letter “o”

Letter r.

For letter r, the key features to better legibility seem to be bigger x-height, clear strokes in the two segments, no decorative serifs and no over-emphasized horizontal segment. In other word, simple and essential is the key to legible letter r. For this reason, bold form with uniform strokes, such as Helvetica “r” and Frutiger “r” seem to be better than Consolas “r” and other serif fonts.

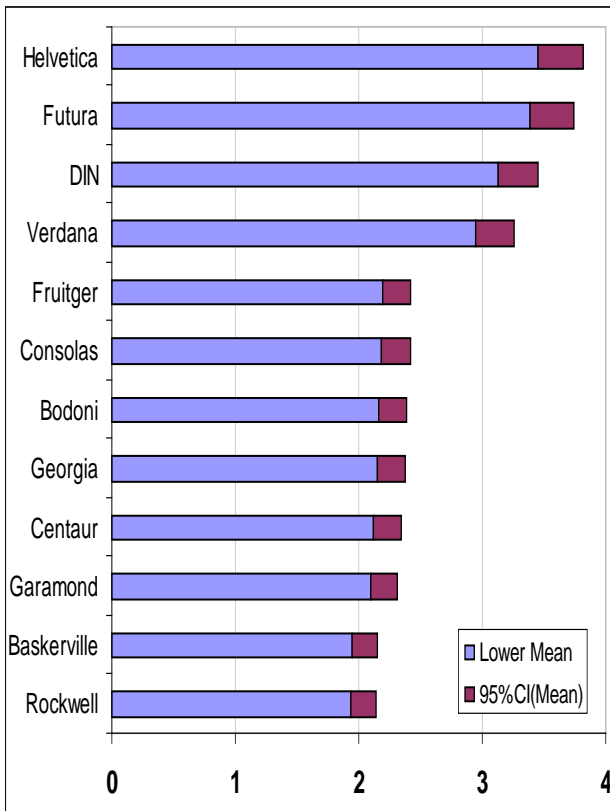
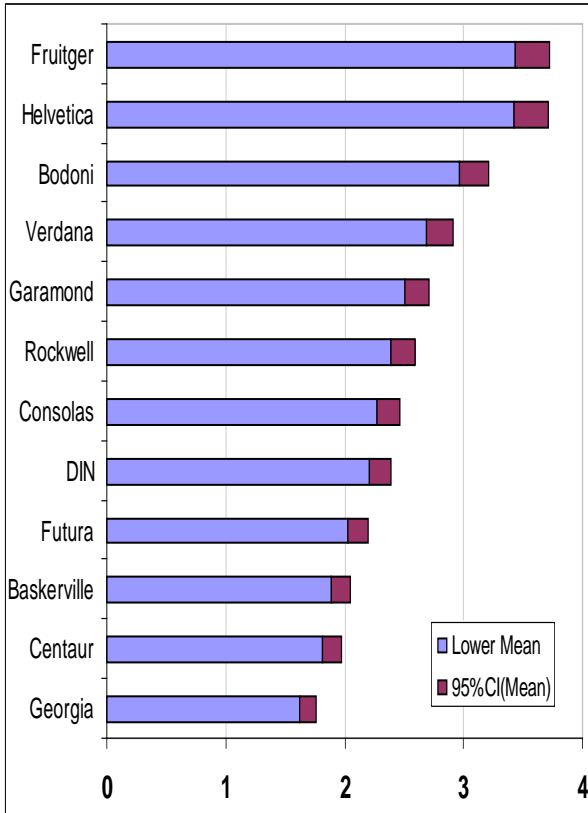
Table 23.
Relative legibility under different size adjustment: Letter r.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted	
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font
r	Verdana	1.611	r	Verdana	2.621	r	Helvetica	2.090	r	Frutiger
r	Rockwell	1.236	r	Bodoni	2.571	r	Frutiger	1.679	r	Helvetica
r	Frutiger	1.117	r	Frutiger	2.235	r	Rockwell	1.462	r	Bodoni
r	Helvetica	1.107	r	Consolas	2.223	r	DIN	1.349	r	Verdana
r	Consolas	1.102	r	Garamond	2.172	r	Verdana	1.312	r	Garamond
r	DIN	1.027	r	Georgia	2.114	r	Consolas	1.113	r	Rockwell
r	Georgia	0.982	r	Futura	1.977	r	Bodoni	1.086	r	Consolas
r	Futura	0.842	r	Centaur	1.969	r	Futura	0.990	r	DIN
r	Bodoni	0.795	r	Rockwell	1.869	r	Baskerville	0.924	r	Futura
r	Baskerville	0.718	r	Baskerville	1.845	r	Garamond	0.917	r	Baskerville
r	Garamond	0.539	r	Helvetica	1.782	r	Georgia	0.794	r	Centaur
r	Centaur	0.430	r	DIN	1.724	r	Centaur	0.665	r	Georgia

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted	
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font
r	Verdana	1.745	r	Bodoni	2.481	r	Helvetica	1.875	r	Helvetica
R	DIN	1.399	r	Centaur	2.263	r	Verdana	1.819	r	Futura
R	Frutiger	1.375	r	Georgia	2.257	r	DIN	1.697	r	DIN
R	Consolas	1.368	r	DIN	2.241	r	Futura	1.669	r	Verdana
R	Helvetica	1.157	r	Frutiger	2.224	r	Frutiger	1.189	r	Frutiger
R	Georgia	1.142	r	Futura	2.223	r	Consolas	1.186	r	Consolas
R	Futura	1.102	r	Consolas	2.220	r	Georgia	1.059	r	Bodoni
r	Rockwell	0.899	r	Verdana	2.171	r	Rockwell	0.955	r	Georgia
r	Bodoni	0.849	r	Baskerville	2.134	r	Garamond	0.879	r	Centaur
r	Baskerville	0.788	r	Helvetica	2.064	r	Baskerville	0.866	r	Garamond
r	Centaur	0.687	r	Rockwell	2.035	r	Bodoni	0.852	r	Baskerville
r	Garamond	0.556	r	Garamond	1.943	r	Centaur	0.836	r	Rockwell



(Onscreen display)

(Hardcopy display)

Figure 22. Onscreen (left) vs. Hardcopy (right) for letter "r"

Letter s.

For letter s, Verdana, Consolas, Frutiger, and DIN had higher legibility, both onscreen and in print. The legibility seems mainly resulted from their big character size. After size adjustment, those small-sized serif fonts (e.g., Centaur "s" and Bodoni "s") tended to improved, especially in the hardcopy condition. In general, wider opening seems to work better (e.g., Frutiger "S" and Centaur "s") than closer ones (e.g., Rockwell "S" and Bodoni "s"), but the case is not as clear in Verdana "S" and Helvetica "S" in the onscreen condition.

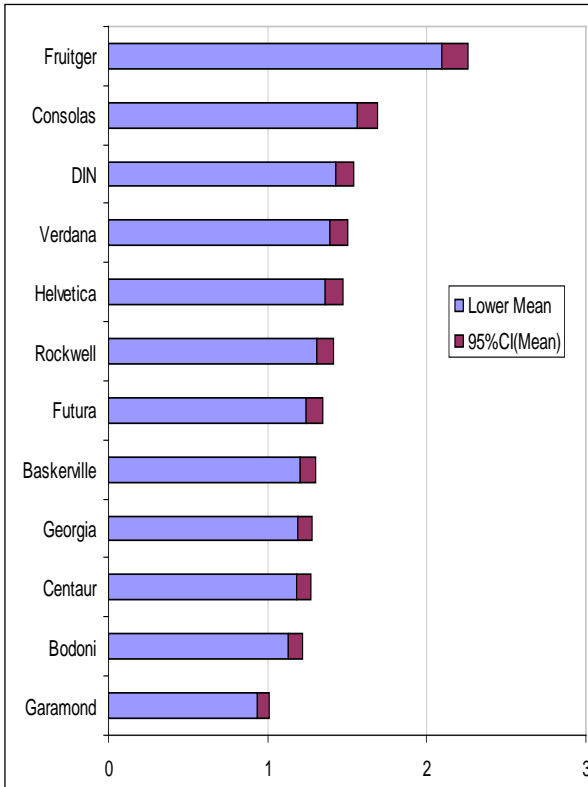
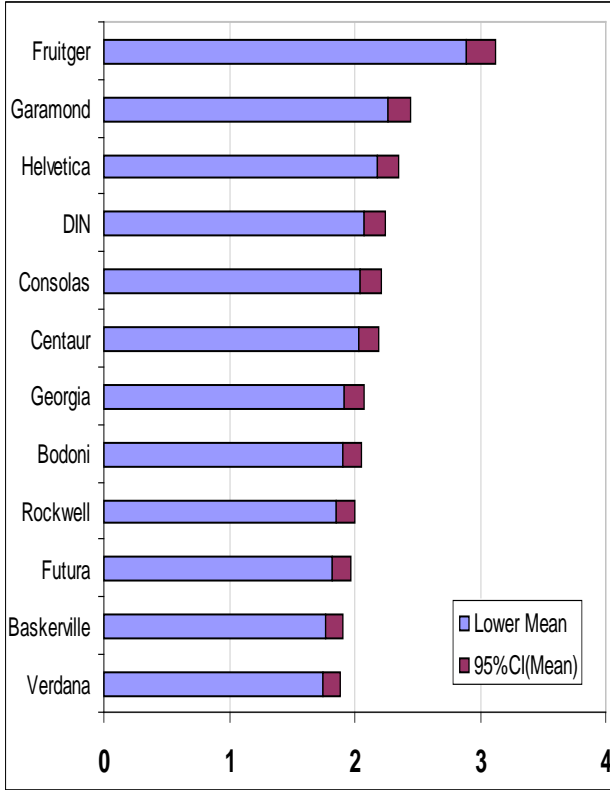
Table 24.
Relative legibility under different size adjustment: Letter s.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
s	Verdana	1.157	s	Baskerville	2.296	s	Frutiger	1.762	s	Frutiger	1.762
s	Helvetica	0.991	s	Bodoni	2.058	s	Helvetica	1.328	s	Garamond	1.328
s	DIN	0.884	s	DIN	2.019	s	Rockwell	1.128	s	Helvetica	1.128
s	Consolas	0.857	s	Consolas	1.992	s	Verdana	1.065	s	DIN	1.065
s	Frutiger	0.747	s	Garamond	1.958	s	DIN	1.011	s	Consolas	1.011
s	Georgia	0.737	s	Georgia	1.867	s	Consolas	0.997	s	Centaur	0.997
s	Rockwell	0.681	s	Verdana	1.816	s	Georgia	0.934	s	Georgia	0.934
s	Futura	0.654	s	Futura	1.772	s	Futura	0.887	s	Bodoni	0.887
s	Baskerville	0.612	s	Centaur	1.758	s	Garamond	0.827	s	Rockwell	0.827
s	Bodoni	0.476	s	Helvetica	1.698	s	Centaur	0.743	s	Futura	0.743
s	Garamond	0.424	s	Frutiger	1.502	s	Bodoni	0.695	s	Baskerville	0.695
s	Centaur	0.331	s	Rockwell	1.443	s	Baskerville	0.647	s	Verdana	0.647

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL	
letter	Font	Mean	letter	Font	Mean	letter	Font	Mean	letter	Font
s	Verdana	1.242	s	Consolas	1.875	s	Verdana	1.221	s	Centaur
s	Consolas	0.928	s	Verdana	1.873	s	Consolas	1.065	s	Futura
s	DIN	0.888	s	DIN	1.839	s	Frutiger	1.040	s	Baskerville
s	Frutiger	0.880	s	Frutiger	1.832	s	Futura	1.020	s	Verdana
s	Helvetica	0.827	s	Centaur	1.804	s	DIN	0.983	s	Consolas
s	Futura	0.649	s	Helvetica	1.784	s	Baskerville	0.903	s	Frutiger
s	Georgia	0.643	s	Baskerville	1.782	s	Helvetica	0.900	s	DIN
s	Rockwell	0.599	s	Futura	1.766	s	Centaur	0.867	s	Bodoni
s	Baskerville	0.520	s	Georgia	1.759	s	Georgia	0.825	s	Georgia
s	Centaur	0.408	s	Bodoni	1.733	s	Rockwell	0.753	s	Garamond
s	Garamond	0.395	s	Rockwell	1.706	s	Garamond	0.699	s	Helvetica
s	Bodoni	0.372	s	Garamond	1.675	s	Bodoni	0.694	s	Rockwell



(Onscreen display)

(Hardcopy display)

Figure 23. Onscreen (left) vs. Hardcopy (right) for letter "s"

Letter v.

For letter v, the features affecting legibility are more clear: bigger x-height, clear and uniform strokes and wide opening increase legibility (e.g., Helvetica “v” and Verdana “v”), while serifs, and smaller x-height, unequal stroke weight decrease legibility (e.g., Bodoni “v” and Centaur “v”).

Table 25.
Relative legibility under different size adjustment: Letter v.

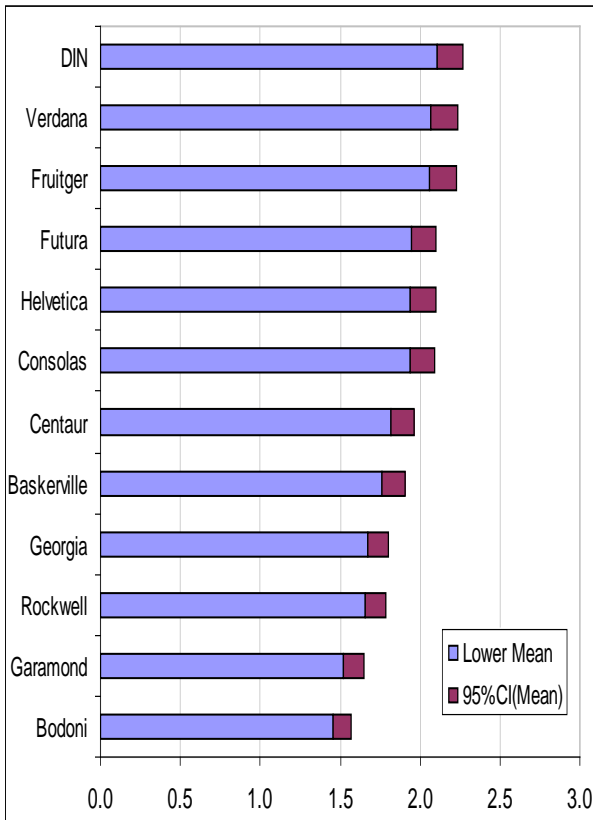
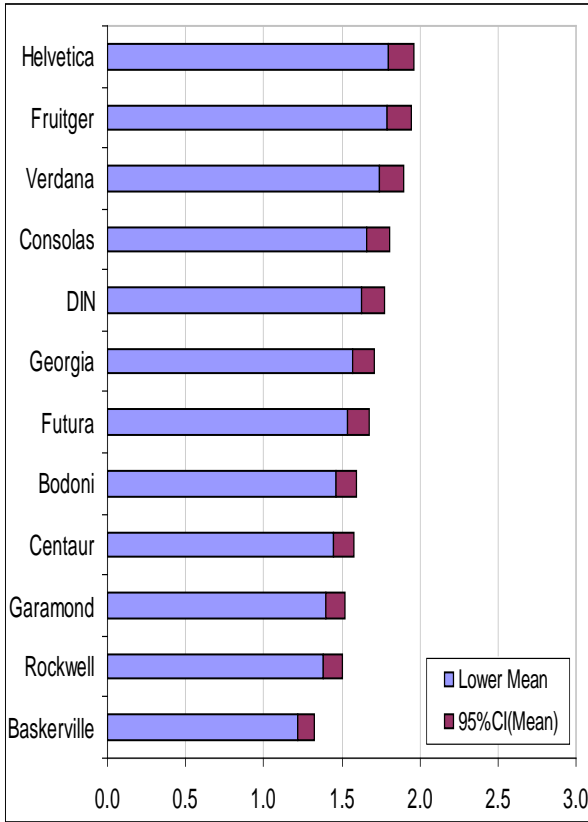
(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
v	Helvetica	1.253	v	Bodoni	2.542	v	Helvetica	1.103	v	Helvetica	1.103
v	Frutiger	1.231	v	Frutiger	2.332	v	Frutiger	0.876	v	Frutiger	0.876
v	Verdana	1.157	v	Verdana	2.270	v	Verdana	0.852	v	Verdana	0.852
v	Rockwell	1.132	v	Centaur	2.205	v	Rockwell	0.844	v	Consolas	0.844
v	Consolas	1.036	v	Consolas	2.164	v	Consolas	0.812	v	DIN	0.812
v	DIN	0.991	v	DIN	2.123	v	DIN	0.797	v	Georgia	0.797
v	Georgia	0.911	v	Georgia	2.047	v	Georgia	0.768	v	Futura	0.768
v	Futura	0.868	v	Futura	2.004	v	Futura	0.752	v	Bodoni	0.752
v	Bodoni	0.774	v	Helvetica	1.880	v	Garamond	0.684	v	Centaur	0.684
v	Garamond	0.696	v	Garamond	1.821	v	Baskerville	0.595	v	Garamond	0.595
v	Centaur	0.558	v	Rockwell	1.799	v	Bodoni	0.537	v	Rockwell	0.537
v	Baskerville	0.506	v	Baskerville	1.586	v	Centaur	0.532	v	Baskerville	0.532

(Hardcopy)

Standard	Height-	W/H-	Area-
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RL			Adjusted RL			Adjusted RL			Adjusted RL	
letter	Font	Mean	letter	Font	Mean	letter	Font	Mean	letter	Font
v	Verdana	1.906	v	Bodoni	2.598	v	Verdana	1.260	v	DIN
v	Frutiger	1.502	v	Rockwell	2.475	v	DIN	1.129	v	Verdana
v	Helvetica	1.475	v	Futura	2.400	v	Frutiger	1.105	v	Frutiger
v	Rockwell	1.411	v	Georgia	2.386	v	Helvetica	1.042	v	Futura
v	Futura	1.315	v	Frutiger	2.311	v	Consolas	1.039	v	Helvetica
v	Consolas	1.304	v	Helvetica	2.293	v	Futura	0.948	v	Consolas
v	Georgia	1.298	v	Verdana	2.256	v	Georgia	0.814	v	Centaur
v	DIN	1.220	v	Garamond	2.213	v	Rockwell	0.808	v	Baskerville
v	Bodoni	0.944	v	Centaur	2.211	v	Baskerville	0.774	v	Georgia
v	Baskerville	0.812	v	Consolas	2.173	v	Centaur	0.708	v	Rockwell
v	Garamond	0.750	v	Baskerville	2.163	v	Garamond	0.632	v	Garamond
v	Centaur	0.651	v	DIN	2.112	v	Bodoni	0.567	v	Bodoni



(Onscreen display)

(Hardcopy display)

Figure 24. Onscreen (left) vs. Hardcopy (right) for letter “v”

Letter w.

While character size and stroke width seem to be the main factor for determining Standard RL, equal stroke weight and wide opening seem to improve legibility. Overall, sans serif fonts seemed to be more legible than serif fonts, especially in the hardcopy condition.

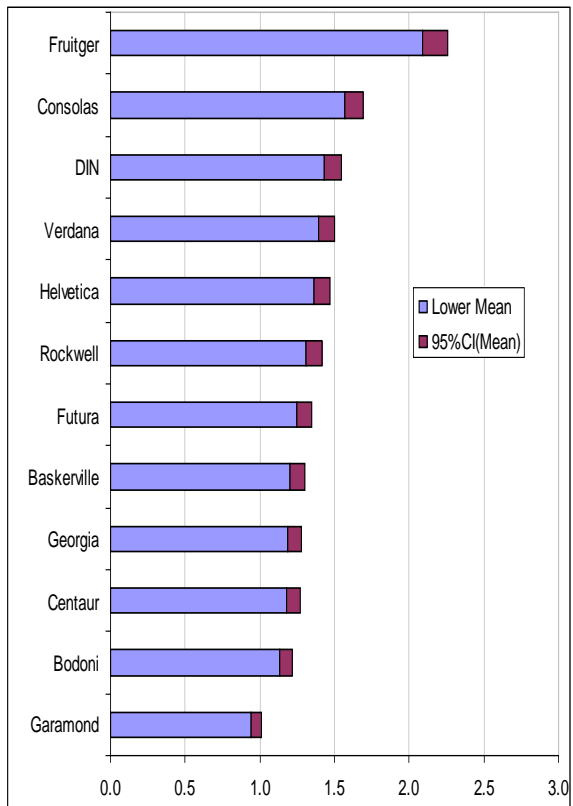
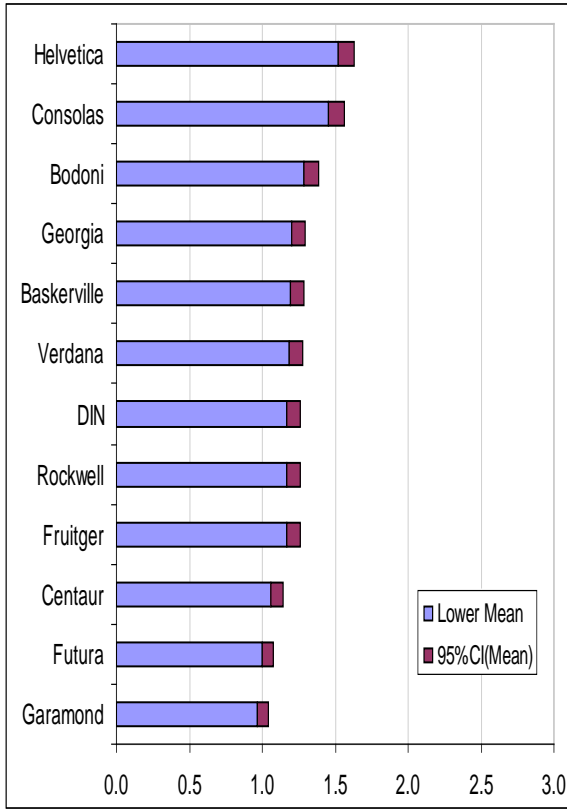
Table 16.
Relative legibility under different size adjustment: Letter w.

(Onscreen display)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
w	Rockwell	1.655	w	Bodoni	2.782	w	Helvetica	0.739	w	Helvetica	1.655
w	Helvetica	1.393	w	Baskerville	2.581	w	Rockwell	0.711	w	Consolas	1.393
w	Georgia	1.247	w	Helvetica	2.461	w	Frutiger	0.710	w	Bodoni	1.247
w	Verdana	1.199	w	Georgia	2.345	w	Consolas	0.706	w	Georgia	1.199
w	DIN	1.167	w	Verdana	2.305	w	Georgia	0.587	w	Baskerville	1.167
w	Futura	1.162	w	DIN	2.279	w	Verdana	0.577	w	Verdana	1.162
w	Frutiger	1.157	w	Futura	2.274	w	DIN	0.570	w	DIN	1.157
w	Bodoni	0.953	w	Rockwell	2.121	w	Futura	0.488	w	Rockwell	0.953
w	Baskerville	0.802	w	Centaur	1.968	w	Garamond	0.472	w	Frutiger	0.802
w	Garamond	0.754	w	Garamond	1.885	w	Bodoni	0.470	w	Centaur	0.754
w	Consolas	0.750	w	Consolas	1.881	w	Centaur	0.453	w	Futura	0.750
w	Centaur	0.612	w	Frutiger	1.816	w	Baskerville	0.436	w	Garamond	0.612

(Hardcopy)

Standard RL			Height-Adjusted RL			W/H-Adjusted RL			Area-Adjusted RL		
Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean	Letter	Font	Mean
w	Frutiger	1.957	w	Rockwell	2.803	w	Frutiger	1.122	w	Frutiger	1.957
w	Rockwell	1.881	w	Futura	2.667	w	Verdana	0.847	w	Consolas	1.881
w	Verdana	1.737	w	Frutiger	2.593	w	Consolas	0.840	w	DIN	1.737
w	Futura	1.677	w	Bodoni	2.568	w	DIN	0.767	w	Verdana	1.677
w	DIN	1.583	w	Georgia	2.542	w	Helvetica	0.731	w	Helvetica	1.583
w	Helvetica	1.535	w	Garamond	2.367	w	Rockwell	0.638	w	Rockwell	1.535
w	Georgia	1.502	w	DIN	2.365	w	Futura	0.607	w	Futura	1.502
w	Consolas	1.004	w	Helvetica	2.333	w	Georgia	0.578	w	Baskerville	1.004
w	Bodoni	0.919	w	Baskerville	2.257	w	Baskerville	0.528	w	Georgia	0.919
w	Baskerville	0.895	w	Centaur	2.203	w	Centaur	0.460	w	Centaur	0.895
w	Garamond	0.876	w	Verdana	2.167	w	Bodoni	0.441	w	Bodoni	0.876
w	Centaur	0.646	w	Consolas	1.941	w	Garamond	0.389	w	Garamond	0.646



(Onscreen display)

(Hardcopy display)

Figure 25. Onscreen (left) vs. Hardcopy (right) for letter “w”

Overall comparison across font types

Table 27.
Summary of 2-way ANOVA of presentation and font on relative legibility, with or without size adjustment.

		Subject (Presentation)	Presentation	Font	Presentation* Font
Standard RL	F Value	60.07	136.06	167.39	3.53
	Pr > F	<.0001	<.0001	<.0001	<.0001
Height-Adj RL	F Value	55.7	167.03	15.14	18.37
	Pr > F	<.0001	<.0001	<.0001	<.0001
W/H-Adj RL	F Value	37.59	24.85	285.7	33.08
	Pr > F	<.0001	<.0001	<.0001	<.0001
Area-Adj RL	F Value	38.71	41.85	61.62	13.39
	Pr > F	<.0001	<.0001	<.0001	<.0001

Table 27 summarizes the results of legibility comparisons by fonts and presentation conditions (onscreen vs. hardcopy) on different size-adjusted relative legibility, separately. The analysis was done by collapsing all letters together and comparing the mean legibility between fonts and presentation conditions. As shown in the table, presentation and font both affected relative legibility, with or without size adjustment. However, as seen in Figure 26, in the Standard RL measure, the RL distribution across fonts seem to be very similar between Onscreen and Hardcopy conditions. The difference between Onscreen and Hardcopy conditions in the Area-adjusted RL (and in Height-Adjusted RL and W/H-Adjusted RL, not shown here) may be due to the difference in the character size measures. Still, the focus is on the RL distribution across fonts within a presentation condition, before and after size adjustment.

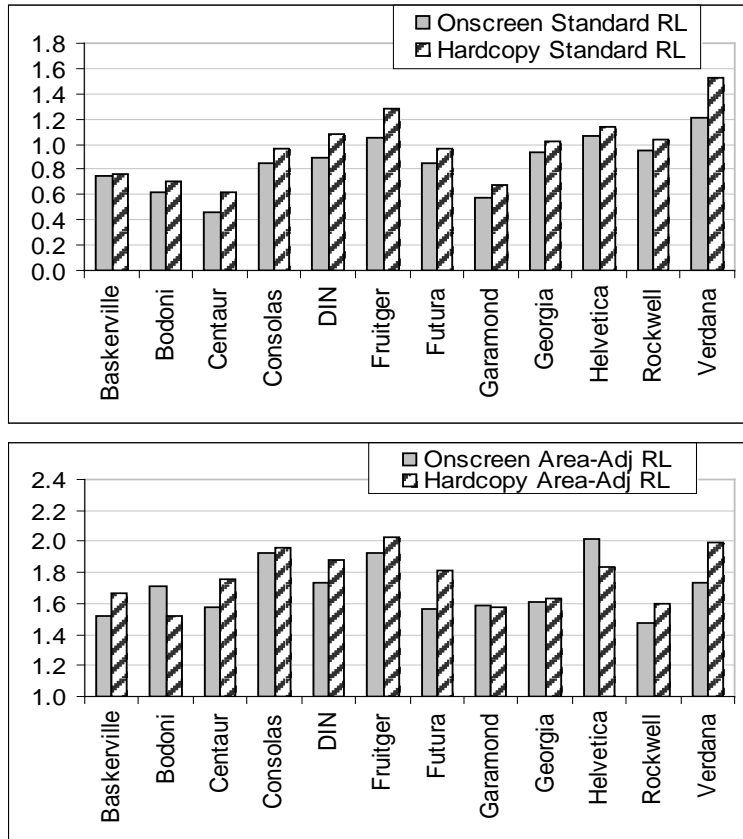


Figure 26. Overall comparison of Standard RL and Area-Adjusted RL across fonts and presentation mode (Onscreen: solid gray bars, Hardcopy: black striped bars)

Table 28 listed the font by the descending order within each type of relative legibility measure. While the effect of font type was significant on legibility, it seems for different reasons in different measures. The order in Standard RL is clearly affected by character size; the larger the actual size, the more legible the character. After area adjustment, however, it seems that sans serif fonts and the only monospace font, Consolas, performed much better than serif fonts in both the onscreen and hardcopy conditions. Although the selected serif fonts tend to be smaller than the sans serif fonts, the size is not the determining factor since the size difference has been compensated by the formula. Instead, the critical factors seem to be in the font designing itself, such as the size of the opening, the stroke weights,

and the appearance of some decorative details. Overall, essential forms with wide space between segments seem to improve legibility.

Table 28. Overall comparison across fonts (collapse all letters).

(Onscreen)

Standard RL					Height-Adjusted RL				
Font	Category	W x H	Area	Mean	Font	Category	W x H	Area	Mean
Verdana	Sans serif	2.2 x 2.15	4.73	1.213	Verdana	Sans serif	2.2 x 2.15	4.73	2.167
Helvetica	Sans serif	1.8 x 2.25	4.05	1.069	Georgia	Serif	2.13 x 2	4.25	2.067
Fruitger	Sans serif	1.95 x 2.3	4.49	1.058	Bodoni	Serif	1.73 x 1.7	2.93	2.057
Rockwell	Serif	2.35 x 2.5	5.88	0.950	Baskerville	Serif	2.05 x 1.9	3.90	1.987
Georgia	Serif	2.13 x 2	4.25	0.932	Futura	Sans serif	2.13 x 2	4.25	1.985
DIN	Sans serif	1.95 x 2.15	4.19	0.898	Consolas	Monospace	1.65 x 2	3.30	1.984
Futura	Sans serif	2.13 x 2	4.25	0.850	Helvetica	Sans serif	1.8 x 2.25	4.05	1.962
Consolas	Monospace	1.65 x 2	3.30	0.848	Garamond	Serif	1.8 x 1.75	3.15	1.926
Baskerville	Serif	2.05 x 1.9	3.90	0.746	Fruitger	Sans serif	1.95 x 2.3	4.49	1.910
Bodoni	Serif	1.73 x 1.7	2.93	0.620	Centaur	Serif	1.63 x 1.6	2.60	1.905
Garamond	Serif	1.8 x 1.75	3.15	0.569	DIN	Sans serif	1.95 x 2.15	4.19	1.902
Centaur	Serif	1.63 x 1.6	2.60	0.459	Rockwell	Serif	2.35 x 2.5	5.88	1.667
Width/Height-Adjusted RL					Area-Adjusted RL				
Font	Category	W x H	Area	Mean	Font	Category	W x H	Area	Mean
Helvetica	Sans serif	1.8 x 2.25	4.05	1.059	Helvetica	Sans serif	1.8 x 2.25	4.05	2.018
Fruitger	Sans serif	1.95 x 2.3	4.49	1.035	Fruitger	Sans serif	1.95 x 2.3	4.49	1.930
Consolas	Monospace	1.65 x 2	3.30	0.901	Consolas	Monospace	1.65 x 2	3.30	1.921
Verdana	Sans serif	2.2 x 2.15	4.73	0.869	Verdana	Sans serif	2.2 x 2.15	4.73	1.732
DIN	Sans serif	1.95 x 2.15	4.19	0.869	DIN	Sans serif	1.95 x 2.15	4.19	1.732
Rockwell	Serif	2.35 x 2.5	5.88	0.866	Bodoni	Serif	1.73 x 1.7	2.93	1.707
Georgia	Serif	2.13 x 2	4.25	0.756	Georgia	Serif	2.13 x 2	4.25	1.612
Futura	Sans serif	2.13 x 2	4.25	0.736	Garamond	Serif	1.8 x 1.75	3.15	1.586
Baskerville	Serif	2.05 x 1.9	3.90	0.675	Centaur	Serif	1.63 x 1.6	2.60	1.572
Bodoni	Serif	1.73 x 1.7	2.93	0.674	Futura	Sans serif	2.13 x 2	4.25	1.569
Garamond	Serif	1.8 x 1.75	3.15	0.645	Baskerville	Serif	2.05 x 1.9	3.90	1.523
Centaur	Serif	1.63 x 1.6	2.60	0.588	Rockwell	Serif	2.35 x 2.5	5.88	1.477

(Hardcopy)

Standard RL					Height-Adjusted RL				
Font	Category	W x H	Area	Mean	Font	Category	W x H	Area	Mean
Verdana	Sans serif	2.11 x 2.5	5.28	1.525	Bodoni	Serif	1.92 x 1.6	3.07	2.287
Fruitger	Sans serif	1.91 x 2.2	4.20	1.277	Centaur	Serif	1.66 x 1.6	2.66	2.172
Helvetica	Sans serif	2.03 x 2.2	4.47	1.135	Rockwell	Serif	2.23 x 2	4.46	2.159
DIN	Sans serif	1.95 x 2.2	4.29	1.086	Fruitger	Sans serif	1.91 x 2.2	4.20	2.154
Rockwell	Serif	2.23 x 2	4.46	1.031	Georgia	Serif	2.18 x 2	4.36	2.147
Georgia	Serif	2.18 x 2	4.36	1.018	Garamond	Serif	1.93 x 1.7	3.28	2.116
Futura	Sans serif	1.94 x 2	3.88	0.964	Baskerville	Serif	1.88 x 1.8	3.38	2.102
Consolas	Monospace	1.73 x 2.2	3.81	0.964	Futura	Sans serif	1.94 x 2	3.88	2.097
Baskerville	Serif	1.88 x 1.8	3.38	0.760	Verdana	Sans serif	2.11 x 2.5	5.28	2.047
Bodoni	Serif	1.92 x 1.6	3.07	0.704	Helvetica	Sans serif	2.03 x 2.2	4.47	2.047
Garamond	Serif	1.93 x 1.7	3.28	0.677	DIN	Sans serif	1.95 x 2.2	4.29	2.007
Centaur	Serif	1.66 x 1.6	2.66	0.625	Consolas	Monospace	1.73 x 2.2	3.81	1.906
Width/Height-Adjusted RL					Area-Adjusted RL				
Font	Category	W x H	Area	Mean	Font	Category	W x H	Area	Mean

Verdana	Sans serif	2.11 x 2.5	5.28	1.172	Fruitger	Sans serif	1.91 x 2.2	4.20	2.023
Fruitger	Sans serif	1.91 x 2.2	4.20	1.044	Verdana	Sans serif	2.11 x 2.5	5.28	1.997
Consolas	Monospace	1.73 x 2.2	3.81	1.009	Consolas	Monospace	1.73 x 2.2	3.81	1.954
DIN	Sans serif	1.95 x 2.2	4.29	0.972	DIN	Sans serif	1.95 x 2.2	4.29	1.883
Helvetica	Sans serif	2.03 x 2.2	4.47	0.950	Helvetica	Sans serif	2.03 x 2.2	4.47	1.840
Futura	Sans serif	1.94 x 2	3.88	0.853	Futura	Sans serif	1.94 x 2	3.88	1.817
Georgia	Serif	2.18 x 2	4.36	0.766	Centaur	Serif	1.66 x 1.6	2.66	1.753
Rockwell	Serif	2.23 x 2	4.46	0.750	Baskerville	Serif	1.88 x 1.8	3.38	1.671
Baskerville	Serif	1.88 x 1.8	3.38	0.706	Georgia	Serif	2.18 x 2	4.36	1.632
Centaur	Serif	1.66 x 1.6	2.66	0.658	Rockwell	Serif	2.23 x 2	4.46	1.597
Garamond	Serif	1.93 x 1.7	3.28	0.629	Garamond	Serif	1.93 x 1.7	3.28	1.576
Bodoni	Serif	1.92 x 1.6	3.07	0.571	Bodoni	Serif	1.92 x 1.6	3.07	1.521

Overall comparison across letters

Table 29.

Summary of 2-way ANOVA of presentation and letter on relative legibility, with or without size adjustment.

		Subject(Presentation)	Presentation	Letter	Presentation*Letter
Standard RL	F Value	60.35	136.7	204.89	8.28
	Pr > F	<.0001	<.0001	<.0001	<.0001
Height-Adj RL	F Value	69.56	208.57	231.21	16.19
	Pr > F	<.0001	<.0001	<.0001	<.0001
W/H-Adj RL	F Value	34.29	22.67	272.51	13.3
	Pr > F	<.0001	<.0001	<.0001	<.0001
Area-Adj RL	F Value	55.15	59.62	443.29	22.6
	Pr > F	<.0001	<.0001	<.0001	<.0001

Table 29 summarizes the results of legibility comparisons by letters and presentation conditions (onscreen vs. hardcopy) on different size-adjusted relative legibility, separately. As in the previous analysis, this was done by collapsing all fonts and comparing the mean legibility between letters and presentation conditions. Both presentation and letter affected relative legibility, with or without size adjustment. While there are some difference between onscreen and hardcopy conditions, the pattern is generally the same within the same RL measure. Basically, letter m and letter w are more legible in Standard RL; after area adjustment, however, the difference between letters decreases and letter r becomes the most legible, probably

due to the size compensation and the letter form is much simpler and easier to recognize than other letters.

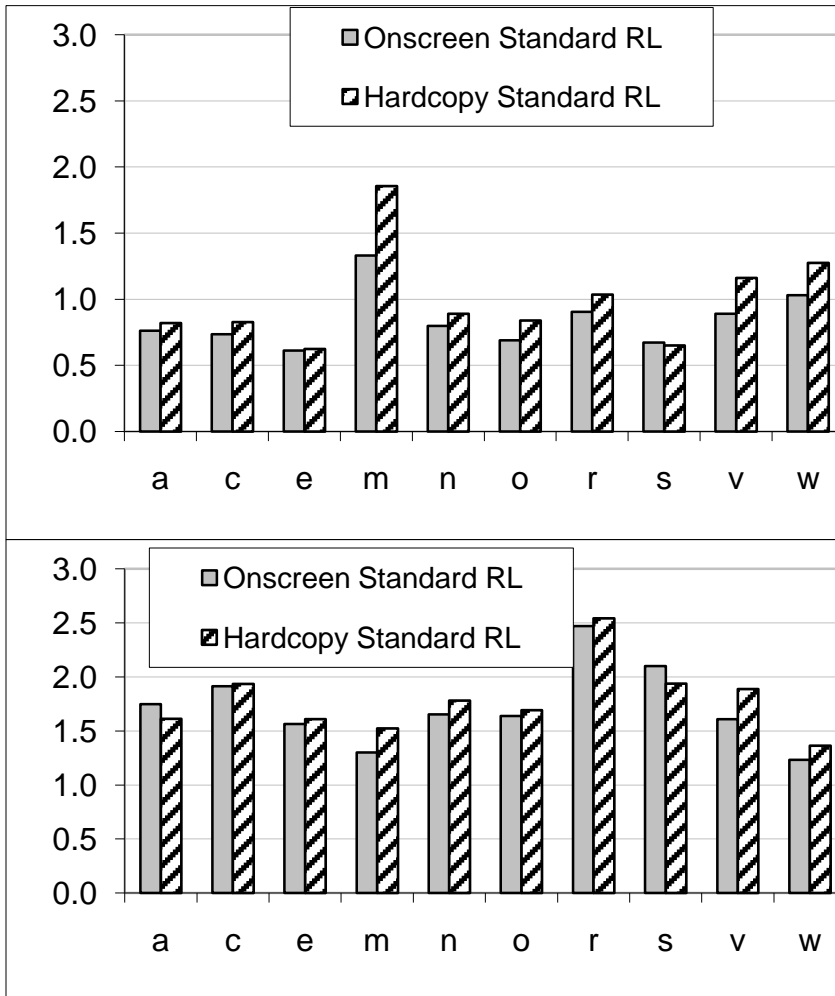


Figure 27. Overall comparison of Standard RL and Area-Adjusted RL across letters and presentation mode (Onscreen: solid gray bars, Hardcopy: black striped bars)

Conclusion

Size matters

The results clearly show the importance of the actual character size to the legibility of a character. The larger the character itself (e.g., m and w) and the larger the font design in general (such as Verdana, Helvetica, Fruitger, Rockwell and DIN), the higher the unadjusted Standard Relative Legibility. Within a same letter, the x-height obvious plays an important role. Larger x-height often indicates larger character size as a whole, hence increases the Standard legibility. This is especially important for letters with more strokes or in more complicated form, as small character size means more crowded design and some segments or strokes will have to be sacrificed. As shown in the r-squares values contributed by all the size-related factors (Table 14) for each letter, while character size is not the only factor determining the Standard RL, it is the most influential one.

Clear, less crowded form is better

When all characters were Height-, Width/Height-Ratio- or Area-adjusted, there were still significant differences between fonts, indicating that while size is a major factor, the manner in which the limited space is utilized is also important.

While each letter seems to have different determining factors in their design, overall, a simple, clear, and open design tend to be more legible, even after size adjustment. For this reason, sans serif fonts tend to be more legible than serif fonts. Within limited space, the serifs seem to interfere with legibility: they not only occupy some space of the main strokes but also make segments more crowded and results in later interference effect. This drawback is shown in both onscreen and hardcopy conditions.

Other details - individual letters

Our findings suggest that some small details of individual letter design affect character legibility.

For example, for letter a, fonts with distinctive lower bowl under a clear cap (e.g., Verdana, Frutiger) and a straight vertical stem (e.g. Consolas, Frutiger, DIN) were more legible than fonts with one single bowl (e.g., Futura) or curvy stroke (e.g. Rockwell, Georgia, Helvetica).

For the relatively simple letter c, a wider opening and vertical elongation both seem to improve legibility, perhaps enabling better differentiation from o and e. Again, a constant stroke width seemed to improve legibility, however the unique shape of Centaur had the best area-adjusted legibility.

Similar rules as for letters a and c seem to apply to letter e. Wider openings and a slightly higher cross-bar favored legibility. Garamond and Baskerville also have enhanced thickness of vertical stroke width on the left side of the letter which may have helped legibility. The only slanted cross-bar (Centaur) was associated with poor legibility.

For o, another round-shape letter, a clear frame of the circle seems important. It should be neither too thin (e.g. Centaur) nor too thick (e.g. Rockwell), and slight vertical elongation also seems to promote better legibility.

For rectangular shaped letters, (m, n and w), a constant bold stroke width without serifs seemed best. Wider end openings also seem to enhance legibility, although the Bodoni "m" and "w" seem exceptions to this. Another finding is the low legibility of the Consolas m. Confined to the same space given to all characters in this mono-spaced font, this m has the smallest width which forces all segments to be compressed into a small region and decreases the legibility.

The letter v is triangular shaped. After size-adjustment, several of the serif fonts performed well (Bodoni, Baskerville, Georgia). It appears that the small serifs

at the top of the v assist legibility of this letter, making it an exception regarding serifs.

Letter s has a unique shape. Serif fonts with good contrast between the stem and the two ends (e.g. Garamond, Baskerville and Bodoni) and fonts without serif but with clear separation of the stem and the two ends seemed to be more legible. An exception is Verdana "S", which meets the above criteria but has low area-adjusted legibility. This leads to the concern of the area adjustment.

The letter r has a relatively simple appearance, and in general, occupies the smallest space. Due to the simplicity of the character, it is more legible than most letters (Figure 27). Even without size-adjustment it is quite legible, but it is certainly the most legible after area-adjustment. Consistent with other letters, clear stems of the two parts with visible contrast between the main vertical stroke and the attached line at the top improve legibility (e.g., Frutiger and Verdana). Over-emphasis of the top line seems to lower legibility (e.g., Consolas and Verdana). Rockwell appears to suffer because the top stem seems to go in both directions.

These findings point out the effects of some design details on character legibility. To summarize, larger characters are more legible. However, making characters larger concurrently decreases space between lines and decreases character spacing or increases the horizontal extent of words. Each of these consequences can have negative effects on text readability and need to be balanced against the legibility-improving effects of size. In general, bolder and constant stroke widths are more legible. Certain characters have unique identifying characteristics that must be properly emphasized for optimal legibility. For example the top stroke on r, the cross bar on a and e, and the opening on c and e. For the current study, serifs generally seemed to harm legibility, in both electronic and hardcopy displays. However, there are a few situations in which serifs seemed to help, such as on v and

possibly s, r and w. These observations are based upon the 12 point characters that were studied. The results may be different for a different font size or different letters.

This study has shown that both size and detail are clearly important to the design of individual letters in order to accomplish high legibility. The height-, w/H-ratio- and area-adjusted legibility findings show that detail is very important. Although detail is clearly important, it is almost certainly more important than the findings indicate. This is because in the size-adjusted legibility measures, the larger letters still had an advantage. Even though the legibility measures were adjusted for size, the larger characters still had more pixels/character space with which to create details within the frame of the character.

Word legibility is ultimately more important to the reading task than letter legibility. The results of this study provide useful information about individual letter design characteristics that affect legibility. The effects on word recognition, however, can be much more complex. It has already been demonstrated that, through lateral inhibition, the letters within a word interfere with one another thereby making threshold recognition of words less than letters. Lateral inhibition has also been called "contour interaction". The contours of letters interfere with one another. It is possible that some letter features or contours may enhance the legibility of an individual character (as measured in this study); however those same features may increase interference with neighboring letters resulting in a net loss of word legibility. Another factor to consider is the relative importance of particular letters in word recognition. It is generally accepted that letters with ascenders and descenders have enhanced relative legibility compared to those without and that those particular letters are more important at establishing word identity. However, what is the real relative importance of each of the characters in a word? Letter design characteristics

such as size and detail can potentially be used to alter letter legibility within a word in order to balance each letter's legibility with its importance to word recognition.

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