

Legibility of Outline and Solid Fonts with Wide and Narrow Spacing

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Abstract

Using a visual acuity criterion for legibility, outline fonts are about 82% less legible than their solid counterparts. Crowding effects are similar for the two types of fonts. Both sets of results can be adequately explained by contrast sensitivity of visual channels serving 1-4 c/character.

Keywords

Legibility, visual acuity, reading, typography.

Introduction

Several studies in recent years have



Figure 1. The letter O from the font used in the present study, in both solid and outline form. Power spectra (normalized and thus not comparable in absolute power), of slices taken through the middle of each image are shown in the grey panel above, with all energy below 1 c/character removed.

demonstrated strong effects of typography on text legibility [1-6]. The approach taken in this laboratory has been to assess the effects of typographic variables by comparing legibility of fonts that vary *only* in the dimension of interest (e.g. stroke width, spacing). While in the past we have used reading speed as a legibility criterion [3,7], our recent work has defined legibility as the smallest letter size that can be effectively read. In the present study we examine the legibility of outline fonts relative to their solid counterparts, under conditions of wide and close spacing.

Outline fonts are of interest because they have relatively little energy in the low

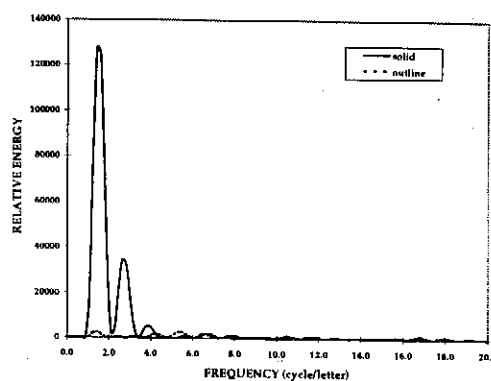


Figure 2. Contrast energy of the solid and outline O's compared (transform performed in 256^2 pixel image to avoid edge artifacts). Energy below 1 c/character has been removed for clarity and scale. Energy in the 1-2 c/character band is roughly 65 times greater in the solid than the outline versions.

object spatial frequency bands, which are known to be sufficient for character recognition and reading. **Figure 1** illustrates, with the letter O used in our study, the shift in the distribution of contrast energy from lower to higher spatial frequencies after removing the solid interior of letter strokes. **Figure 2** compares the relative contrast energy in these O's in all bands above 1 c/character. The outline font is vastly reduced in overall contrast energy, and especially for frequencies less than about 4 c/character. Overall energy above 4 c/character is comparable in the two letters. Outline fonts resemble both high-frequency letters such as those suggested by Howland et al. [8] for clinical acuity measurement, and high-pass filtered letters [9], both of which, like outline fonts, contain relatively low energy in the low object frequencies. Unlike these, however, outline fonts are occasionally used in actual typography.

In addition to evaluating the relative legibility of outline fonts to solid fonts, we were also interested in the issue of whether outline fonts would be less susceptible to crowding effects than solid fonts. In particular we were interested in whether we might find evidence for a lateral masking explanation of letter crowding (see **Figure 3**).



Figure 3. Lateral masking and crowding. If recognition of solid and outline letters are mediated by low and high object spatial frequencies respectively, neighboring letters should impinge less upon the smaller receptive fields serving high object spatial frequency processing of outline fonts.

Method

Letters (the set of which contained the Sloan optotypes) were generated using METAFONT [10], and displayed in lines of 5 letters on a 1280 x 1024 resolution monitor using methods described elsewhere [11]. Background and foreground luminances were 43 and 2 cd/m² respectively. The letter forms used are shown in **Figure 4**. The outline font was identical to the solid font except that all the pixels except those of a single pixel border, were removed. With most acuity measurements, letter size may be varied by redrawing the image in different sizes on the display screen. In our experiment, however, where image characteristics have to be preserved (especially the thickness of the outline border of the font relative to font size), angular size was varied by changing viewing distance. This was accomplished by folding the observer's view through zero, one or two first surface mirrors, and rendering the image on the screen with appropriate left-right sense. The two inter-letter spacings we chose were one character height (45 pixels) and 1/45 character height (one pixel), which previous work had indicated would produce a strong crowding effect, at least with solid letters [2].

We used the method of constant stimuli, with all viewing distances (letter sizes) and font conditions randomized, after informal bracketing of thresholds. Observers identified verbally the letters in the 5-letter strings; the experimenter typed these responses into the computer.

Results and Discussion

Figure 5 shows raw data from three highly practiced subjects, while **Table 1** details the

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
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Figure 4. Letter forms similar to those used in the experiment (upper solid, lower outline). Actual letters used were 45 x 45 pixels. Black border of outline letters in actual font was one pixel wide, or 1/45 letter height.

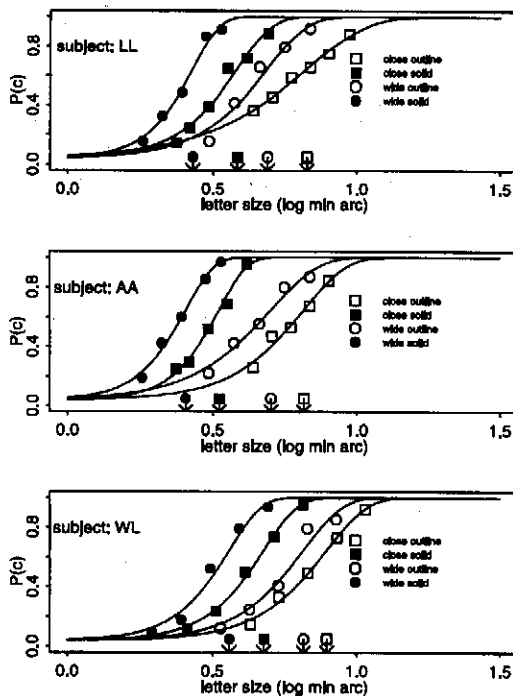


Figure 5. Psychometric functions relating probability of a correct letter identification to log letter size for two observers. Each point represents 130 letter identifications. The curves are maximum likelihood fits of Weibull functions ($P(c)=1-(1-\gamma)\exp[-(a/\alpha)^\beta]$, where a is letter size, α is the 64.6% correct threshold, and β is a slope parameter [12-13]. The arrows on the x-axis indicate the location of α for each condition.

thresholds averaged across subject. For all subjects, acuity for outline fonts is about 0.25-0.3 log units worse than for solid fonts. The geometric average ratio of outline to solid font size threshold, which corresponds to the size of the effect in units of linear size, was 1.82. That is, our outline fonts had to be about 82% larger than solid fonts for equivalent legibility. (Note that this is not an entirely general result in that legibility is likely to depend critically on the width of the outline font border.) Given the

	Outline	Solid
Wide	0.735992	0.466076
Narrow	0.846302	0.595301

Table 1. Log letter size thresholds for the four conditions averaged over the three observers.

drastic difference in contrast energy between the two fonts (see **Figure 2**), especially in the low object frequencies that we know to carry useful information distinguishing characters, the difference in acuities between the two fonts seems extremely modest.

The effect of spacing was about 0.11-0.14 log units for both the solid and outline fonts, a value consistent with earlier findings [2]. Here, the effect size in linear units is 1.32. At first glance the finding that crowding effects are the same for solid and outline fonts would argue against spatial-frequency dependent lateral masking theories of crowding. This issue will be revisited below.

How well do the image characteristics of the letters explain the 82% difference in legibility between outline and solid fonts? We computed power spectra of our letter set and integrated the energy within the 1-4 c/character band. This low object spatial frequency band is fairly certainly the one mediating letter recognition at the acuity limit for *solid* fonts, since a) we know from filtered letter work [14-15], that this band is sufficient for mediating letter recognition, b) lower spatial frequencies contain little information distinguishing the letters, and c) higher spatial frequencies are filtered out at the acuity limit by the eye's optics and sampling. Is this also true for our outline fonts?

Within this low object spatial frequency band, the average ratio of power of solid fonts to outline fonts is 28.3. This corresponds to a contrast ratio of 5.3. Assuming letter recognition in the acuity task takes place within this object band, outline fonts need 5.3 times more contrast within the band, for equivalent legibility.

We also measured contrast sensitivity of our three subjects over the range of 6-60 c/deg using 1 Hz square wave (temporal) modulated sine wave gratings in a 1.4 deg circular window, at a luminance equated to that of the acuity display. This was done in order to estimate the slope of the CSF in the region of the acuity limit. Results are shown in **Figure 6**.

Since the data are not linear, we fit only the highest four spatial frequencies with a straight line, on log-log coordinates. These coordinates were chosen because we were

interested in the magnitude of the contrast gain (a ratio) that would result from a logarithmic change in spatial frequency. The slope of this line, using the data of all three observers, is 3.24.

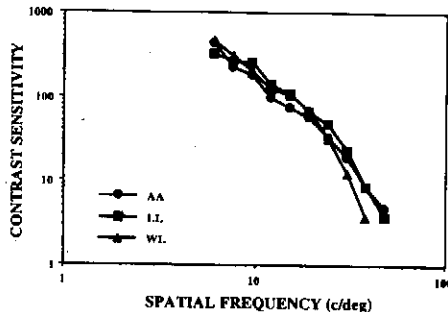


Figure 6. Contrast sensitivity for the three subjects. Each data point is the average of 10 adjustments.

Using this figure, we reason as follows: The 82% decrease in acuity for outline fonts relative to solid fonts corresponds to a log change of -2.6 on the spatial frequency axis, which in turn results in a log contrast gain of 0.84 and linear contrast gain of 6.95. Recall that within the 1-4 c/character band presumably mediating the acuity task, the contrast boost required by the diminished contrast energy of the outline font was 5.3. Our contrast sensitivity data indicate that by making the letters larger on the retina, we have boosted effective contrast sensitivity by a factor of almost 7, easily explaining the legibility difference between the two fonts.

It is also interesting to note that if letter recognition at the acuity limit is mediated within the 1-4 c/character object frequency band for both fonts, crowding effects would no longer be predicted to be greater for solid than outline fonts. Thus our results may still be consistent with lateral masking theories. Thus all the data of our experiment are most parsimoniously explained by the contrast sensitivity function.

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