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Letter Strokewidth, Spacing, and Legibility

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Introduction

The development of computerized typography has revolutionized our ability to create type designs, in facilitating both the rapid design of new fonts and the alteration of their characteristics almost infinitely[10, 13]. Although type designs vary for a variety of reasons, their primary purpose is to serve as the elements of text-coded communication. *Legibility* is a general term that refers to the effectiveness of typography in communicating the text code. It can be defined and measured in several ways, including direct judgment, reading speed[11, 3, 9], and visual acuity[16].

What characteristics of type design affect legibility of letters and words? Although there have been a number of studies comparing legibility of different specific fonts and type styles (reviewed in [16]), there are few studies that have identified general characteristics of letters and words that contribute to their legibility.

We have designed a text font that is suitable for assessing the relative legibility of several different characteristics of letters and words. Certain characteristics of this font, which is generated using the font design language METAFONT [10], can be varied parametrically, yielding a family of fonts that are identical except for intended and systematic variations. In this study, we examine the effects of letter strokewidth and letter spacing on legibility. We have adopted the acuity metric of legibility; that is, we consider legibility to be inversely related to the minimum size at which text can be read.

Method

Figure 1 illustrates the font family used in this study. The well-known Sloan optotypes are letters within one particular variant of the font (Figure 1(a)), in which strokewidth is equal to 0.2 letter height; other letters in the font were intended to conform to the same design principles as are inherent in the Sloan set.

Stimuli, which were strings of 5 letters, were displayed on a Mitsubishi color monitor driven by an X-windows (X11) server residing on a Silicon Graphics IRIS 4D/25 graphic workstation. The final pixel resolution of the display was 1280 horizontal by 1024 vertical. Luminances of the letter forms and their backgrounds was 0.148 and 79.42 cd/m^2 respectively. Client software that actually ran the experiments, via a local network, resided on a Sun SparcStation 2. Only a single line of letters was displayed and tested at a time. Letters were sampled (with replacement) uniformly from the entire alphabet, and no attempt was made to eliminate strings that formed words or phonetically coherent units.

In order to reduce the size of the letters at the eye, the display was viewed at a distance of 95 cm through the objective lenses of a reversed pair of Minolta 10X25 wide angle Pocket Binoculars, which had a measured transmittance of 65%. At the resulting optical distance of 950 cm, the range of character sizes we employed allowed us to test acuities in the range 20/32 to 20/6.3 (0.2 to -0.5 LogMAR). Subjects were constrained by a chinrest, and viewed the display through the binoculars, which were mounted directly in front of their eyes

Our optotypes were intended to vary in size by .05 log unit between lines, as compared with the 0.1 log unit step size used by the charts emulated, to improve the precision of acuity measurements. Digitization error caused sizes to depart slightly from their intended values, of course, but for all letters the size along the (vertical) dimension of lowest resolution differed from its intended value by no more than 1.5%, and by only 0.75% on average. The letter sizes we used ranged from 2.2 cm to 0.43 cm.

Five observers, aged 23-43, including two of the authors, were tested. Two of these were emmetropic, and two slightly myopic. The myopic subjects wore their correction. A 1-up 1-down staircase procedure was used, in which character size decreased when the subject read all 5 letters in a line correctly, or increased if at least one letter was read incorrectly. To initiate fast convergence of the staircase, a step size of 0.1 log unit between lines was used initially, until the subject read one or more characters in a line incorrectly, at which point step size was reduced to .05 log unit (12.2% size difference between lines) for the remainder of the run. Subjects identified letters verbally to the experimenter, who typed responses into the computer, and the procedure ran until there were 24 reversals of the staircase.

Results and Discussion

Figure 2 plots log minimum angle of resolution (MAR) against letter strokewidth, for each of the five subjects and for the average of the five (panel) and for each of three letter spacings (parameter). For the widest spaced letters, legibility is an inverted U-shaped function of strokewidth, with very thin and very thick letters being more difficult to identify. However, a range encompassing at least an octave (0.1–0.2 letter height) of strokewidths has essentially the same legibility. It is reasonable to suppose that the thickest stroked letters become less legible because gaps and other distinguishing features are more difficult to resolve (see Figure 1).

For closer spacings, legibility does not suffer so much when letters are extremely thick-stroked, as they do for wider spacing. With close spacing, small gaps probably do not serve as such effective distinguishing marks since they exist between as well as within letters. Additionally, with close spacing the letters are more difficult to localize than they are when separated by more space.

Figure 3 shows the same data replotted to emphasize effects of spacing on legibility. In general the effects of close spacing are similar for all strokewidths except the thickest, where wide spacing fails to offer an advantage.

Acuity for letters or optotypes presented in close proximity to other letters [1, 3, 7, 14, 15] or other contours [7, 12] is widely known to be significantly worse than it is for isolated letter or optotype forms. Such deficits, known as "crowding" phenomena, have been found to be worse in amblyopia and in disorders

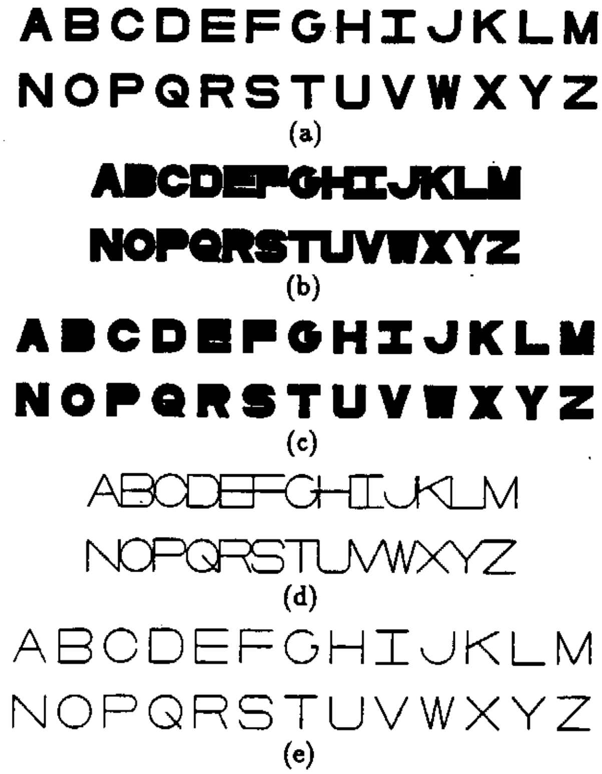

Figure 1: A sampling of fonts used in the study. (a) The basic font from which the others are derived, with strokewidth equal to 0.2 letter height. In this instance, spacing is equal to 0.4 letter height. (b) strokewidth = 0.3 letter height, spacing = 0.025 letter height. (c) strokewidth = 0.3 letter height, spacing = 0.4 letter height. (d) strokewidth = 0.025 letter height, spacing = 0.025 letter height. (e) strokewidth = 0.025 letter height, spacing = 0.4 letter height.

of the central visual field[5, 7, 12, 15]. At ARVO in 1993 [4] and at the International Low Vision Conference in 1993 [2], we proposed that crowding phenomena were simply an instance of lateral masking of the target letter by the neighboring contour. We hypothesized that since spatial masking occurs predominantly within spatial frequency bands, crowding phenomena should depend on the spectral composition of the target and neighboring forms. Since the Fourier spectra of thick-stroked letters have more energy at lower object spatial frequencies than do thin-stroked letters, they can exert a masking influence over a larger neighboring region. Our finding that crowding effects are no greater for thick-stroked than thin-stroked letters suggests either that a) contrary to our earlier beliefs, crowding is not an instance of spatial-frequency dependent lateral masking, or b) in-

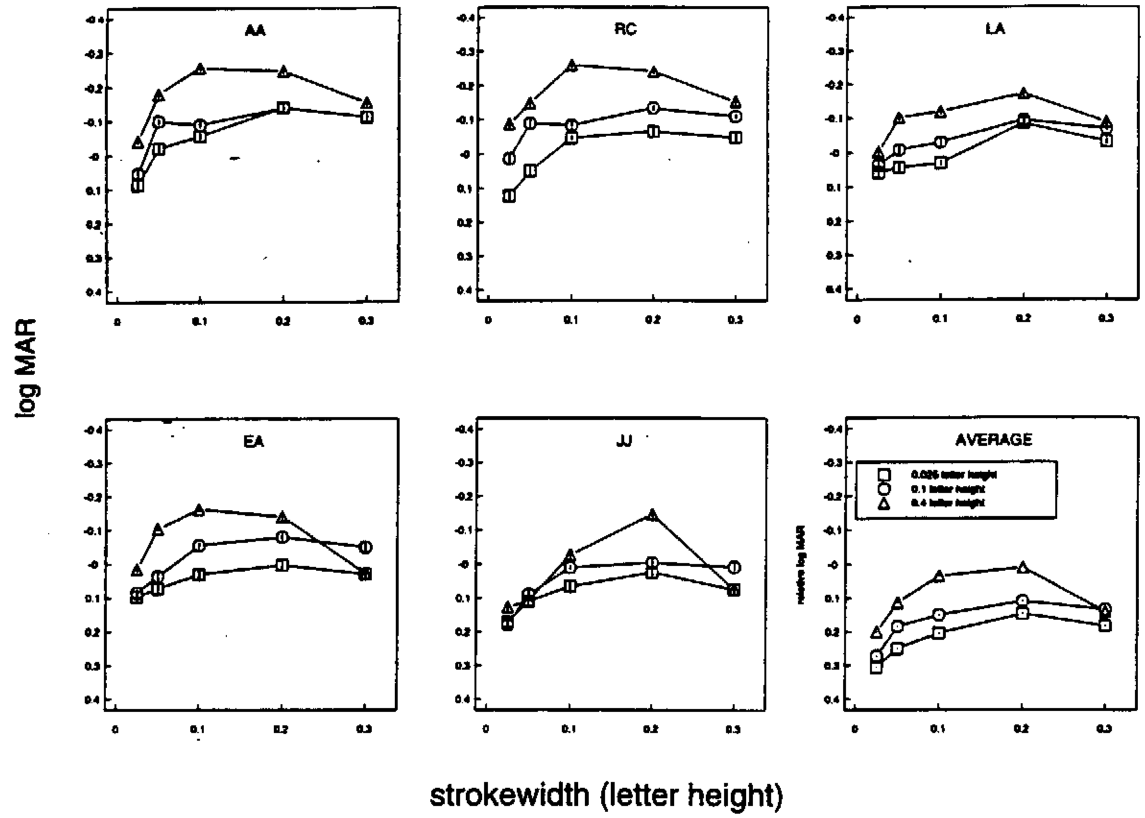

Figure 2: Legibility measured as log MAR, as a function of letter strokewidth for 5 subjects and 3 spacings (shown in the inset in the lower right panel). Average data are shown as departures from maximum legibility. Standard error bars are shown only for individual subjects' data.

formation critical to letter identification at the acuity limit exists within a fixed spatial frequency band.

References

[1] Anstis, S. M. (1974). A chart demonstrating variations in acuity with retinal position. *Vision Research*, 14:589–92.

[2] Arditi, A. (1994). On the relationship of letter acuity to reading acuity. In A. C. Kooijman, P. L. Looijestijn, J. A. Welling and G. J. van der Wildt (Eds.) *Low vision: Research and new developments in rehabilitation*. IOS Press. Amsterdam, The Netherlands, 38–45.

[3] Arditi, A., Knoblauch, K., and Grunwald, I. (1990). Reading with fixed and variable character pitch. *Journal of the Optical Society of America A*, 7:2011-2015.

[4] Arditi, A. and Cagenello, R. (1993). Why reading acuity is worse than and is poorly predicted by letter acuity. *Supplement to Investigative Ophthalmology and Visual Science*, 34(4), 1417.

[5] Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature*, 226:177–8.

[6] Burian, H. M. (1969). Pathophysiologic basis of amblyopia and its treatment. *American Journal of Ophthalmology*, 67:1–12.

[7] Flom, M. C., Weymouth, F. W., and Kahneman, D. (1963). Visual resolution and contour interaction. *Journal of the Optical Society of America*, 53:1026–32.

[8] Jacobs, R. J. (1979). Visual resolution and contour interaction in the fovea and periphery. *Vision Research*, 19:1187–95.

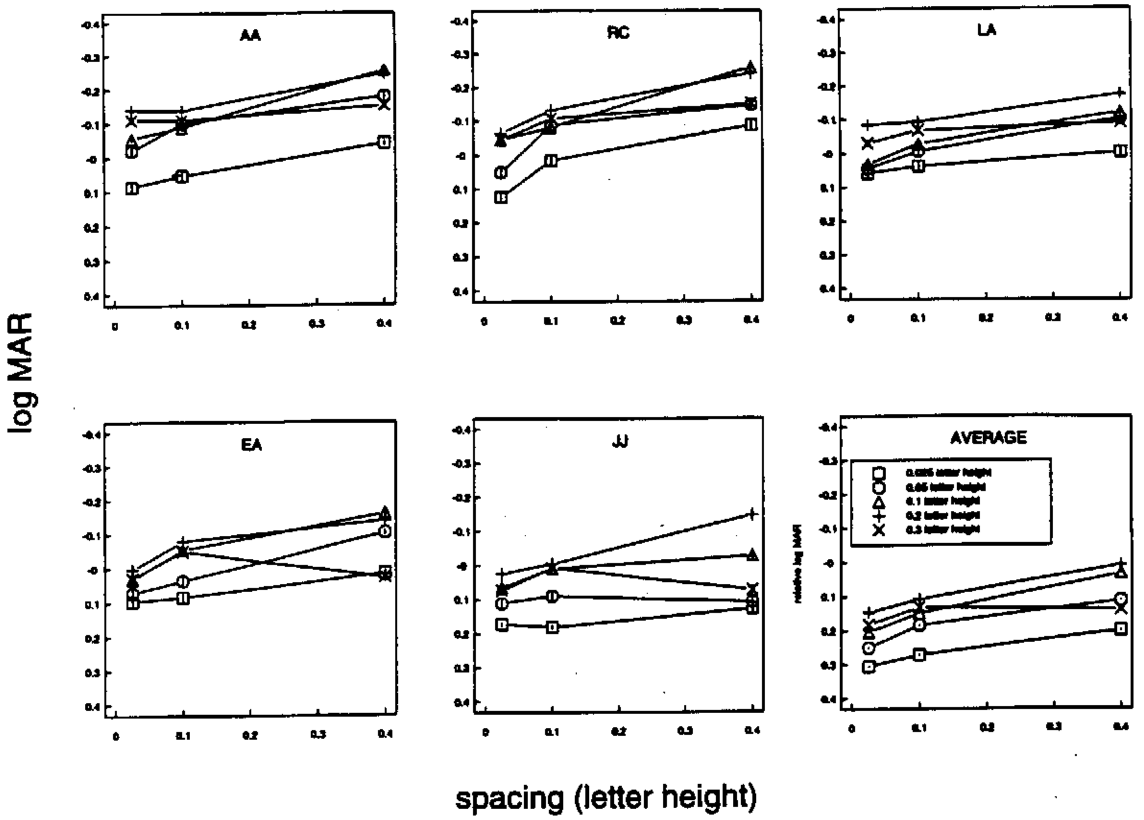

Figure 3: The same data as Figure 2, replotted as a function of spacing to show crowding effects.

[9] Knoblauch, K., Arditi, A. and Szlyk, J. (1991). Effects of chromatic and luminance contrast on reading. *Journal of the Optical Society of America A*, 8:428–439.

[10] Knuth, D. E. (1986). *The METAFONTbook*. American Mathematical Society, Addison-Wesley.

[11] Legge, G. E., Pelli, D. G., Rubin, G. S., and Schleske, M. M. (1985). Psychophysics of reading. I. normal vision. *Vision Research*, 25:239–252.

[12] Loomis, J. M. (1978). Lateral masking in foveal and eccentric vision. *Vision Research*, 18:335–8.

[13] Rubenstein, R. (1988). Digital typography: An introduction to type and composition for computer system design. Reading, Massachusetts, Addison-Wesley Publishing Company.

[14] Skottun, B. C. and Freeman, R. D. (1983). Perceived size of letters depends on inter-letter spacing: a new visual illusion. *Vision Research*, 23:111–12.

[15] Stuart, J. A. and Burian, H. M. (1962). A study of separation difficulty: Its relationship to visual acuity in normal and amblyopic eyes. *American Journal of Ophthalmology*, 53:471–477.

[16] Tinker, M. A. (1963). *Legibility of print*. Iowa State University Press, Ames, Iowa.