

References

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mance. At this writing, we are designing experiments to answer questions of this sort based on the introduction of broad-band noise such as is effected by our shape distortion. The previously cited results of Beckmann et al., Legge et al., Strohmeyer and Julesz, and Olzak and Thomas give good reason to pose the question in this way.

Finally, we should note that these preliminary studies are with printed text, not screens: 75 dpi display devices have inadequate resolution to make meaningfully small spacing or shape distortions. At normal reading sizes, screen characters are typically only 5–6 pixels. Thus, two screen pixels is already about 1/4 character width and the characters become unreadable too quickly. Related evidence for this is the unquantified method we used to produce poor shapes for the work of [9]. There we caused our Macintosh computer to produce 11-point type from its native Times Roman screen fonts by bitmap scaling 12-point fonts—a notoriously inappropriate technique which leads to many ill-placed pixels. Here, too, the distorted text was substantially more difficult to read than the similarly-spaced 12-point text.

Since inadequate resolution can sometimes be overcome by use of grayscale fonts, it is plausible that our methods might be applicable to them. We believe, however, that a better approach is to study the effect on readability of broad-band noise of controlled bandwidth and center frequency. Such an approach is more likely to be comparable to the results from Legge’s laboratory and to broad-band masking results in human vision.

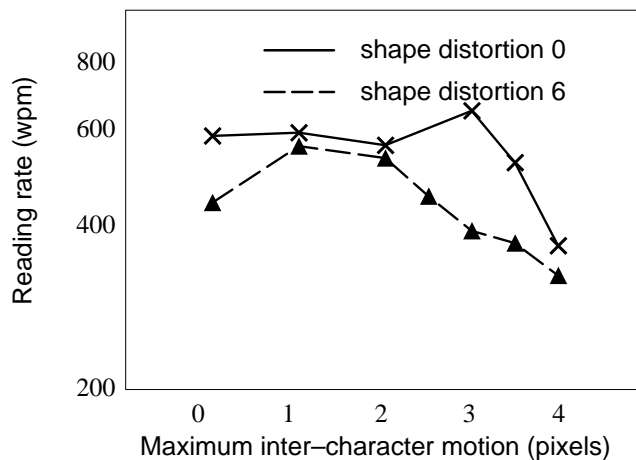


Figure 3: Reading rate vs. space distortion, subject kb.

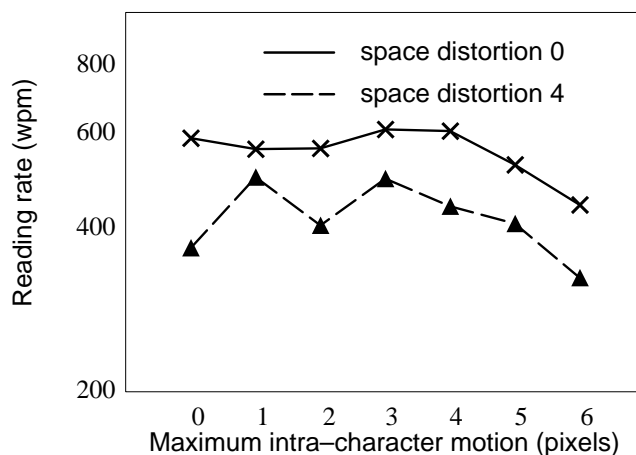


Figure 4: Reading rate vs. shape distortion, subject kb.

clearly characterized by extreme noise
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clearly characterized by extreme noise

Figure 1:

(a) maximum inter-character motion 0–4 pixels with normal shape.

(b) maximum intra-character motion 0, 2, 4 and 6 pixels with normal spacing.

as typographically inferior. It is not difficult to see that the regularity of stroke spacing will create a substantial peak to the power spectrum at the stroke frequency, whereas text set in fixed-width type will have this power more widely distributed. For illustrations of this, see the spectrograms in [14], pp. 46-47 and [8] p. 144.

The masking results cited above could qualitatively account for increased visibility of proportional-width type over fixed-width (or any ill-spaced) type, because ill-spaced type spreads the stroke frequency into broad-band noise.

All previous readability work of which we are aware has little quantification of either spacing or shape of letters. In this paper we report on our initial attempts to find such measures in ways which can be interpreted with human vision theory. However, in their present form they are difficult to cast in spatial frequency terms. This may make them unsuitable for comparison with results from Legge's laboratory or other vision-related hypotheses such as O'Regan's "grain size" explanations of reading rate constancies with viewing distance [11].

We sought numeric measures for the distortion of spacing and shape which could be independently manipulated. To distort the regularity of spacing we set characters with inter-character spacing randomly chosen from a uniform zero-mean distribution whose width is the parameter we manipulate. Thus, as many characters are too widely separated as too narrowly. If this width is n , motion is between $-n$ and n pixels. Our preliminary studies vary this parameter from 0 to 4, independently of changes in character shape (Figure 1a.)

To distort character shape, we build a new font in which each black pixel of each character is moved between $-n$ and n pixels with uniform probability. Thus, while only $1/(2n + 1)$ pixels remain unmoved, mean motion is zero and the general shape of the character remains recognizable for rather large n (up to about 1/4 of the character width)—but the details of character shape are randomly distorted (Figure 1b). The appeal of our spacing distortion is that it addresses the type designers' principle of uniformity of spacing (by distorting it). Previous studies of spacing distortions either narrow or

widen the letter spacing, but not both. Each of those manipulations potentially has a separate visual effect—which may explain reduced reading rates under severe distortion but give no insight into effects of design traditions. In the narrowing case, reading rate reduction has been ascribed to visual crowding [1]. In the widening case, a given set of characters is placed outside the visual span as defined by O'Regan [11, 12]. With enough such widening, this does result in decreased reading rates [5], but no studies in the literature control the intra-character stroke width (nor do we) to maintain uniform inter-stroke spacing in widely spaced type. Unfortunately, widening the intra-character stroke space actually changes the letter shape. Increasing inter-character spacing without changing the intra-character stroke space would generally result in power peaks at two distinct frequencies.

Since mean text width is unchanged by our manipulation, we contend that we are, on average, not subject to the visual effect of either the narrowing or the widening manipulations—we are purely testing the effect of uniformity. Our preliminary data indicate that spacing irregularity far beyond what would be accepted on aesthetic grounds has little impact on reading rate. (See especially the solid line in Figure 3)

Shape distortion may be a different matter. Our preliminary finding is that there is a reduction in reading rates when the characters become radically distorted, but that lesser distortion (again, even beyond what would be acceptable aesthetically) has little effect (Figure 4.) Visual inspection of the worst case characters in our data show them to be recognizable, but clearly characterized by extreme noise. (See Figure 2 for a sample with the maximum shape *and* spacing distortion in our study.)

clearly characterized by extreme noise

Figure 2: Maximal distortions: shape = 6 pixels, space = 4 pixels.

Although there is substantial debate in the reading literature about the precise relation of letter recognition to reading rates, it is natural to ask whether the distortion parameter we offer predicts character recognition perfor-

TOWARDS QUANTIFICATION OF THE EFFECTS OF TYPOGRAPHIC VARIATION ON READABILITY

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Abstract: Typographic wisdom holds that regular spacing and well-formed character shapes enhance readability. Are these components quantifiable in ways consistent with human vision theory? We construct texts using irregular spacings and distorted letterforms to verify and compare their effects. Our preliminary data indicate that shape distortion has more effect than spacing distortion.

Beginning with classic work of Tinker [16], there has been an effort to verify and quantify the rather strong traditions of typographers regarding what makes text the most readable. In recent years, reading and vision researchers have attempted to examine the relative roles of visual and cognitive components of reading [13, 12, 4] and to explicitly examine typographic factors rigorously [1, 9].

Typographers hold that fixed-width fonts are more difficult to read than proportional-width ones, but the opposite was argued by Arditì et al. [1]. However, in [9] we suggested that poor letter shape explained their data, rather than visual crowding, as they suggest. In experiments similar to theirs but with letter shape controlled, we concluded that there is little difference in reading rates between fixed- and proportional-width fonts at normal reading sizes, but that for well-formed characters at very small sizes proportional-width characters enjoy the advantages claimed by typographers. This finding, and some aspects (described below) of the spatial spectrum of text images has led us to search for quantifiable measures of letter shape and spacing in text readability investigations. This report describes our initial work in that direction.

There is important evidence from the laboratory of Gordon Legge [6, 7, 2] that purely visual factors have a quantifiable effect on reading rate. Legge and his colleagues have manipulated the spatial frequency content of text images and measured the effect on reading rate. This work represents a more controlled investigation than Tinker's and other studies which manipulate text size without quantified control of the spatial spectrum. At

normal reading sizes and for normal readers, Legge et al. [6] found that low-pass filtering of text had no effect on reading rates as long as the cutoff frequency was above about 2 cycles per character. Since this is the frequency at which the strokes of characters will become indistinguishable, this work suggests that overall letter shape, rather than precise location of character edges, has the major effect on readability of letters.

That conclusion is certainly in accord with type design principles, but in work described by Beckmann et al. at SID91 [2], that same laboratory reported a spatial frequency masking effect for text which suggests visual *relations* between the high and low spatial frequency content of text—relations which are not found in the visual system's response to simpler stimuli. In these experiments, they superimposed text filtered by a high-frequency band-pass filter on a different text filtered by a low-frequency band-pass filter. Each filter had about 1.5 octave width and the centers were about 2 octaves apart. They found that the high-band text masked the low-band text under normal viewing conditions. But varying the viewing distance—thereby effectively raising or lowering the center frequencies of the filters—can reverse which text is masked and which is visible.

In any case, vision researchers find that for many vision tasks, processing takes place in spatial frequency tuned channels that are sufficiently independent so that stimuli 2 octaves apart cannot mask one another. The conclusion of Beckmann et al. is that reading is not such a process. In addition, classic work of Strohmeyer and Julesz found some masking of cosine stimuli by broadband noise distant in center frequency from the stimulus [15]. More recent work of Olzak and Thomas [10] does suggest that channel models may not be fully appropriate to describe the response to complex stimuli.

One strongly held belief among type designers is that the inter-stroke distance, i.e., both between strokes within a character and between characters, in well-set text should be constant. This constraint is violated by fixed-width fonts, which is one reason they are regarded

Towards quantification of the effects of typographic variation on readability

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