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LETTER TO THE EDITORS

A CHART DEMONSTRATING VARIATIONS IN ACUITY WITH RETINAL POSITION

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Visual acuity is defined as the reciprocal of the visual angle, in minutes, subtended by a just resolvable stimulus. This critical dimension can be the gap in a Landolt C, the spatial period of a grating or the offset of a vernier, etc.

Acuity declines progressively from the fovea out to the periphery of the retina. It is down to half its maximum value at an eccentricity of only 30 min according to Jones and Higgins (1947), who used Landolt C's, or 105 min according to Ludvigh (1941), who used Snellen letters. Weymouth (1958) plotted the reciprocal of visual acuity, namely minimum angle of resolution, and found that several visual thresholds increased linearly with increasing retinal eccentricity, at least up to 30°. This was true of the data of Ludvigh (1941) on acuity for Snellen letters, Wertheim (1894) for gratings, Bourdon (1902) for vernier offsets, and Basler (1906, 1908) for movement detection thresholds. In step with these variations in acuity, the physiological grain becomes progressively coarser towards the periphery of the retina—receptor density, receptive field size and amount of visual cortex available. Hallett's review (1963) and Wilson's experiments (1970) showed that retinal summatory areas increase progressively with eccentricity. Hubel and Wiesel (1960) found that the mean diameter of receptive fields increases more or less linearly with eccentricity in the monkey retina. The same was true for the number of min arc of visual field handled by each mm of visual cortex (Daniel and Whitteridge 1961). Sixty-seven microns of cortex, containing about five cells, corresponded to one threshold unit anywhere in the retina. It appears to take a constant number of retinal receptive fields, and a constant amount of cortex, to do an equally fine discrimination, whether in the fovea or the periphery.

We measured recognition thresholds for letters (Paratipe Helvetica medium typeface) at retinal eccentricities lying between 4° and 55°. Two subjects were used, both of whom wore correcting eyeglasses. They viewed binocularly a white tangent screen of luminance 1·8 log ft-L from a distance of 57 cm. Individual letters were moved inwards on the horizontal meridian from the periphery towards the fovea until they were correctly identified. Trials on which the subject said he had involuntarily glanced towards the target letter were discarded.

Results are shown in Fig. 1. Recognition thresholds increased linearly with eccentricity up to 30°, with a letter 0·2° high being just identified at 5° from the fovea, and a letter 1° high at 25°. Thus for every degree of retinal eccentricity the minimum discriminable size increased by about 2·5 min. The best fitting regression line over this range was:

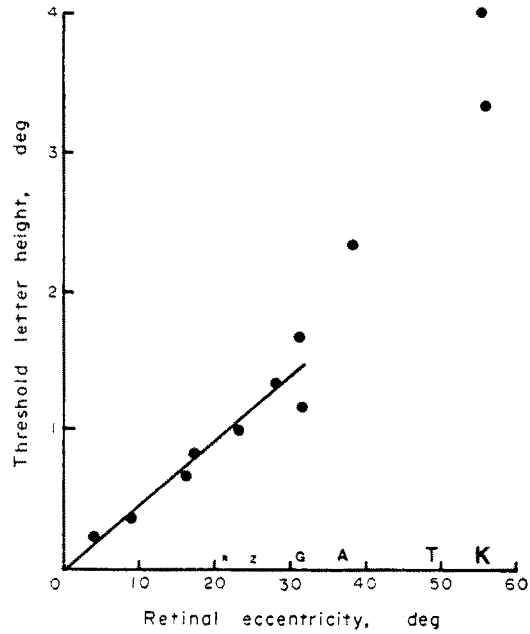

Fig. 1. Height of letters at which they could just be recognized increased linearly up to 30° retinal eccentricity, then increased somewhat more steeply. Regression line, fitted by least squares, is: $y = 0{\cdot}046x - 0{\cdot}031°$.

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(The small negative intercept is probably caused by experimental error.)

The results of Fig. 1, extrapolated to other retinal meridia, were used to construct the chart of Fig. 2, in which each letter is of threshold size when the centre is fixated. (In this multiple letter display, each letter tends to mask or obscure its neighbours (Taylor and Brown 1972; Monti 1973), so letters in the middle of a line may well be pushed below threshold).

In Figs. 3 and 4, each letter was arbitrarily made 10 times its threshold height, so each letter is about equally easy to read when the centre of the chart is fixated. For instance, a letter 5° from the fovea was made 2° high, and a letter 25° out would be 10° high.

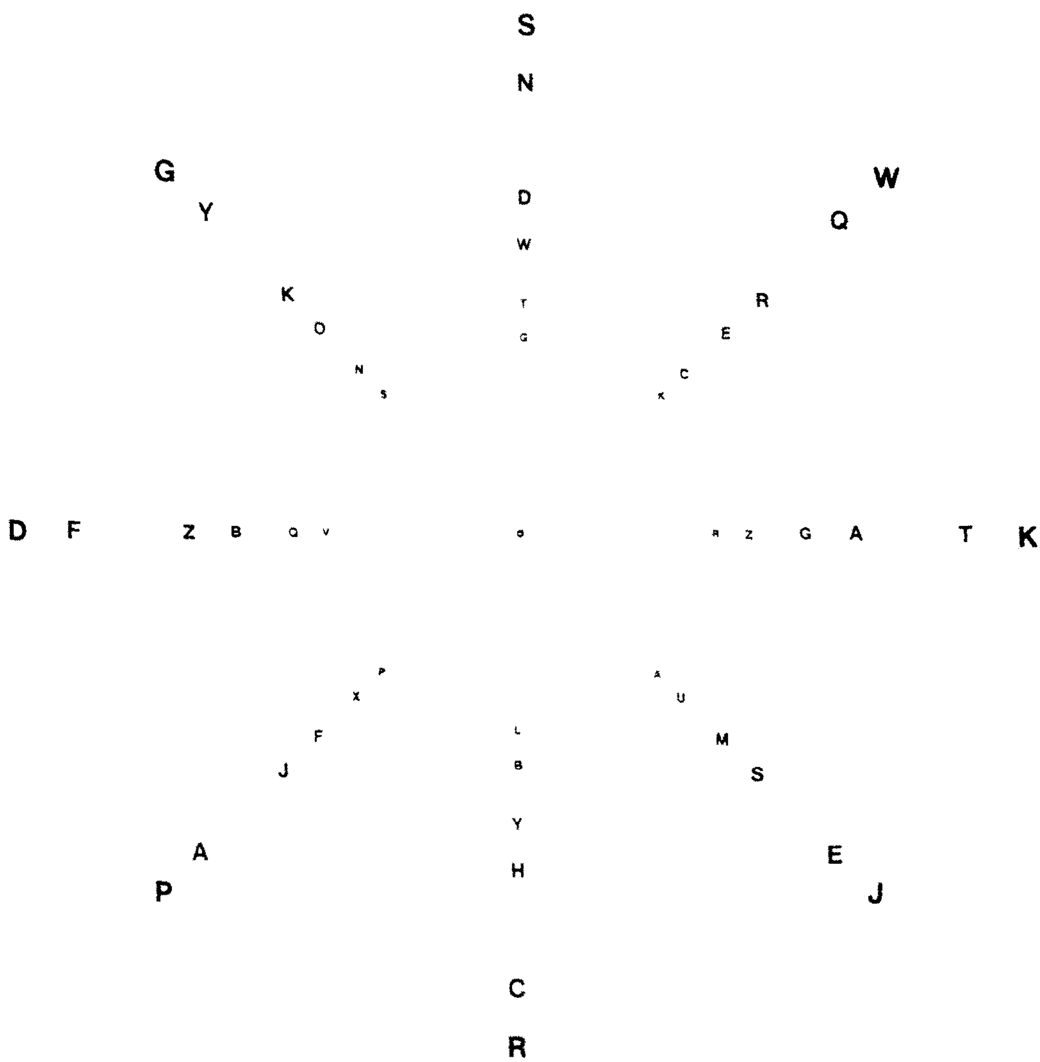

Fig. 2. All letters should lie at threshold when centre of this chart is fixated. Threshold letter size increases linearly with increasing distance from fixation point.

These charts have the unusual property of being equally readable at any viewing distance. From a viewing distance of 10 cm the letters in the outermost ring are approximately 10° high and 25° eccentric, while from five times as far away they are approximately 2° high and 5° eccentric. Any increase in viewing distance makes the retinal image of each letter smaller, but also moves it in towards the fovea where acuity is higher.

Since the design of the display is optimally matched to the resolution of the eye, it might have applications in conditions requiring maximum transfer of information during a single fixation, for instance in tachistoscopic displays of letters in a short-term memory task, where the subject has to perceive and recall as many letters as possible after a single brief exposure. In an attempt to increase the amount of information transmitted, Fig. 4 was prepared, with the same dimensions as Fig. 3 but containing 72 letters instead of 40. But the increased density leads to diminishing returns: the letters seem much harder to read in Fig. 3 than in Fig. 2, though they are of the same size in corresponding retinal regions. It is well known to clinicians that Snellen letters are harder to read if they are not sufficiently spaced out. Patients often complain that they can read the lines on an optician's chart if they are at the beginning or end of a line, but the ones in the middle get muddled up (Adler 1959). This may be related to Monti's finding (1973) that when a line of 1's and 0's was presented tachistoscopically, symbols in the middle of the line were harder to identify than those at the ends. As Monti points out, this is probably caused by lateral masking phenomena, not simply by sensitivity factors.

All the letters in Figs. 3 or 4 could easily be read off

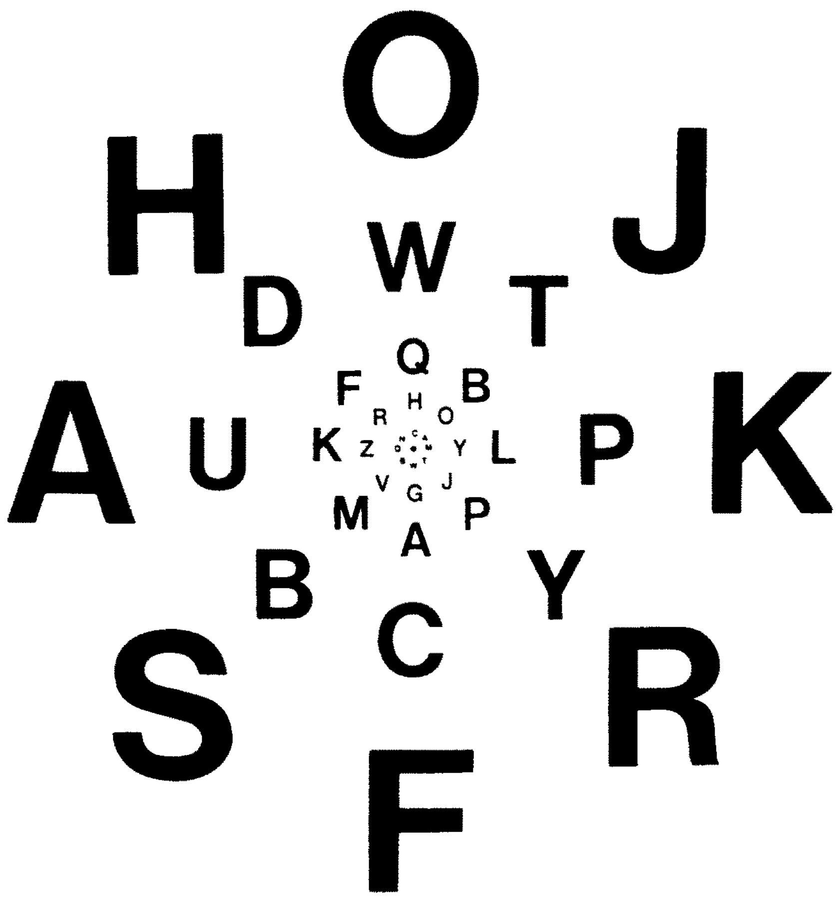

Fig. 3. All letters should be equally readable when centre of this chart is fixated, since each letter is ten times its threshold height.

an afterimage produced with a brilliant electronic flash and kept visible by rapid blinking. The eyes could not move about over the afterimage, which was stabilized on the retina, but the "inner eye" of one's attention could roam over different regions of the afterimage in order to read the letters there.

The charts give a pictorial impression of the progressive coarsening of the retinal grain from fovea to periphery. Other targets such as Landolt C's or verniers might also be used. Equally-visible movement across the retinal surface might be provided by a slowly rotating textured disc, fixated at its centre. Tangential velocity of each point on the disc would be proportional to its radius, as is the velocity threshold in different retinal regions (Basler 1906, 1908).

The retina can be compared to a city, with most of its receptor inhabitants densely packed into the foveal city centre, and with a sparser population spread out over more territory in the suburban periphery. The Manhattan skyline can be considered as a histogram of land prices, peaking in the downtown area where space is at a premium and people are squeezed in very tightly. Likewise, a graph of acuity across the retina is also a graph of information-gathering power, peaking

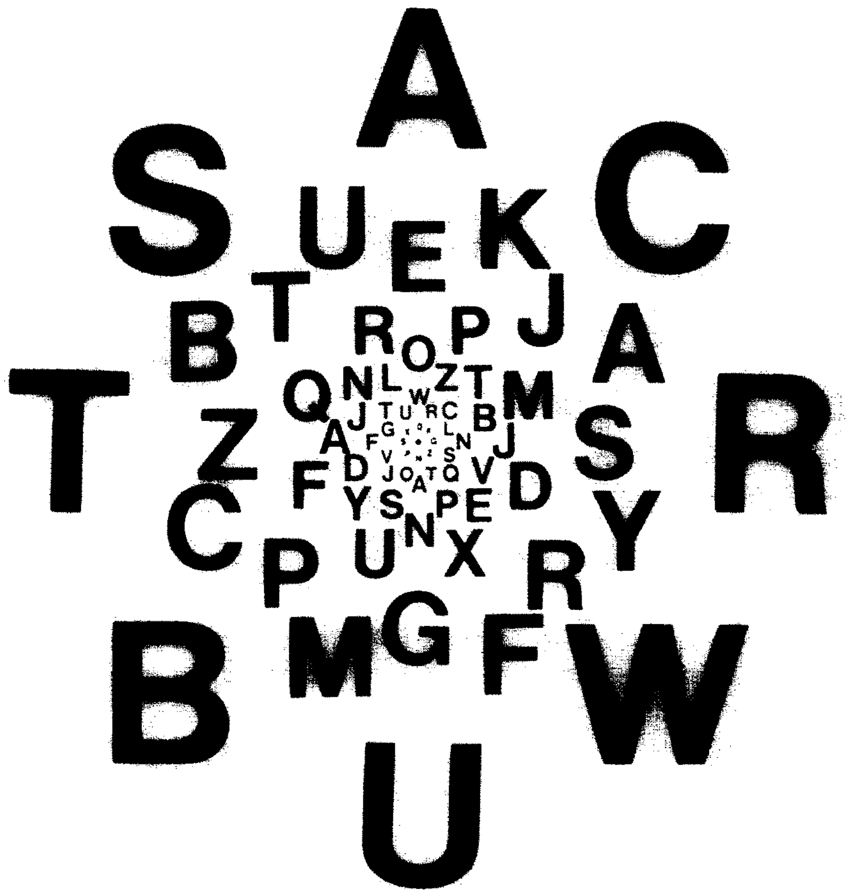

Fig. 4. Same dimensions as Fig. 3, but with more letters. Increasing the number of letters makes each letter harder to read, owing to supraretinal masking effects, not owing to acuity limitations. However, all letters can be correctly read off an afterimage.

in the fovea where the receptors are most densely packed. The acuity charts of Figs 2 and 3 are like stylized maps of a tiny city.

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