REPRINT SYSTEM LC 269

ERGONOMICS, 1987, VOL. 30, NO. 12, 1705–1720 APU 2146.87

The clarity and comfort of printed text

A. J. WILKINS and M. I. NIMMO-SMITH

MRC Applied Psychology Unit, 15 Chaucer Road, Cambridge CB2 2EF, UK

MRC APPLIED PSYCHOLOGY UNIT
15 CHAUCER ROAD
CAMBRIDGE

Keywords: Clarity of text; Eye-strain; Visual discomfort; migraine; Epileptic photosensitivity; Fount.

The successive lines of printed text form a pattern of 'stripes'. The spatial characteristics of this pattern have been measured and found to be similar to those of patterns that induce discomfort, anomalous visual effects and even seizures. It is argued that reading provokes 'eye-strain' and seizures because of the striped properties of text, and that it is for this reason that headaches and seizures are reduced by covering the lines of text above and below those being read. In studies in which subjects are asked to judge the clarity of text it is shown that judgements of clarity are affected by the spatial characteristics of the pattern, in particular, the spacing between the lines. The average area of the page occupied by a letter (i.e. the product of the separation between the lines and the mean horizontal spacing between the centres of letters) accounts for less variance than does the separation between the lines of text. Within the constraints of conventional typography, the clarity of text could perhaps be improved without increasing costs by reducing slightly the typical spacing between the letters in order to increase the spacing between the lines.

1. Introduction

If you look at the pattern of stripes in figure 1 you may see a variety of anomalous visual effects: illusions of colour, shape and motion. Some people see only a few effects, others see many illusions after only one or two seconds' observation. You may find the pattern unpleasant to look at: it may even induce feelings of dizziness and nausea. If you suffer from migraine or photosensitive epilepsy it is advisable to avoid looking at the pattern because there is the possibility that it might bring on an attack (Wilkins *et al.* 1984).

About 4% of patients with epilepsy are liable to suffer from visually induced seizures. Their susceptibility to such seizures can be studied without inducing attacks by means of the electroencephalogram (EEG), which exhibits spike and slow waveforms when the patients look at visual stimuli that are likely to evoke an attack. The patterns that elicit such waveforms are very specific and strikingly similar to the patterns that induce illusions. Both illusions and epileptiform activity are most likely to occur in response to a pattern such as that in figure 1 which is composed of many stripes with strong contrast and equal width and spacing, each stripe subtending about 10 min of arc at the eye (Wilkins *et al.* 1984).

A grating such as that shown in figure 1 is defined by: (*a*) its overall size; (*b*) its period (i.e. the distance between the centres of adjacent bars) or, alternatively, its spatial frequency (i.e. the number of periods per unit distance); (*c*) its duty cycle (the proportion of a period that is bright and (*d*) its contrast (often expressed as the Michelson contrast, which is defined as the difference in luminance between the light and dark bars, divided by the sum of their luminances).

The probability of illusions and seizures is shown as a function of these variables in figure 2 (after Wilkins *et al.* 1984).

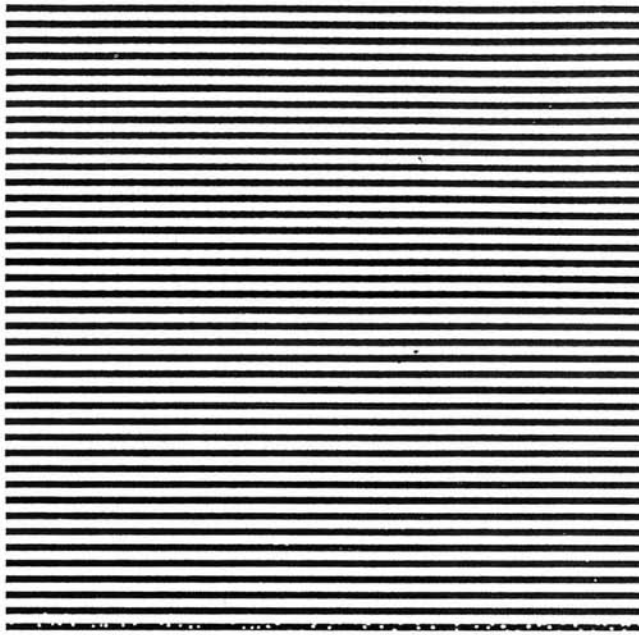

Figure 1. A pattern of stripes that can be unpleasant to look at and can induce illusions of colour, shape and motion. WARNING: Avoid looking at the pattern if you are susceptible to migraine or epilepsy.

Text forms a grating-like pattern where the size of the page (minus the margins) determines the size of the grating, and the interline spacing (see figure 3) corresponds to the period of the grating. If the ascenders and descenders of letters are ignored, the duty cycle is determined by the height of the central body of the letters (x-height in figure 3) divided by the interline spacing. The contrast of the grating depends on the contrast of the ink on the paper and the width and spacing of the letter strokes.

The work presented here is discussed in five different sections. The first two show that the characteristics of the 'stripes' of printed text are within the range appropriate for the induction of illusions and seizures. The third section reviews studies indicating that the observation and reading of printed text can induce illusions and seizures and that these effects can be reduced by attenuating the brightness and contrast of the lines of text above and below those being read. On the assumpiton that the induction of illusions will adversely affect the visual clarity of text, the fourth part of this paper investigates clarity in relation to the striped characteristics of text and shows that clarity may be improved without increasing the cost of print. The fifth section discusses the experimental findings in relation to current trends in printing practice.

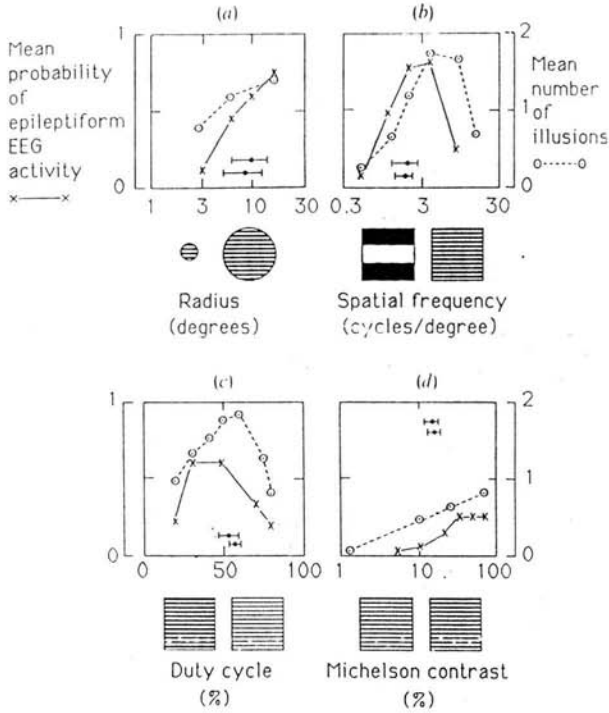

Figure 2. The mean number of illusions seen in a pattern of stripes and the probability with which the pattern will induce epileptiform EEG abnormalites in patients with photosensitive epilepsy, expressed as functions of the spatial parameters of the pattern (after Wilkins *et al.* 1984). (*a*) Effects of field size (angular subtense of the radius of the pattern at the eye). (*b*) Effects of spatial frequency of a square-wave grating (number of spatial cycles of the pattern in one degree subtended at the eye). (*c*) Effects of duty cycle (proportion of spatial cycle occupied by bright bars). (*d*) Effects of Michelson contrast (difference in the luminance of the bright and dark sections of the pattern expressed as a proportion of their sum). The solid points and horizontal bars indicate the mean ± 1 s.d. of the value of the parameter for text, when text is considered as stripes. The upper and lower bars refer to 'less clear' and 'clear' text, respectively. The data in (*a*) are derived from study 4, those in *b* and *c* from study 5, and those in *d* from study 3. In *a*, central fixation of the page is assumed, and half the width of the page is taken as the radius of the pattern. Icons beneath each *x*-axis demonstrate variations in the parameter. The patterns in these icons are shown with horizontal stripes, although some of the data were collected with patterns having different orientations. In general, pattern orientation had little effect. The curves were obtained by manipulating each parameter independently. The values of the other parameters were chosen arbitrarily, but as the data were acquired it transpired that the values chosen were close to those for which illusions and epileptiform EEG activity were maximally likely. Note that the parameter ranges for text are close to the peak of the functions for spatial frequency and duty cycle.

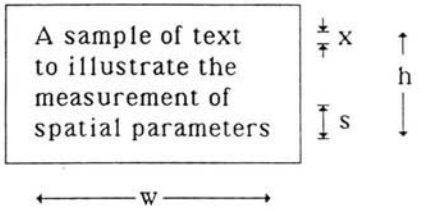

Figure 3. A schematic diagram to show how the x-height (x), line separation (s), page height (h) and page width (w) were measured. In studies 4 and 5 the angular height of the page was calculated as

$$2\tan^{-1}(h/2d)$$

and the angular width similarly. The fundamental spatial frequency of the text was calculated as

$$1/\tan^{-1}(s/d)$$

The duty cycle was estimated as $(s-x)/s.100\%$. As the viewing distance decreased the angular width of the page increased, the spatial frequency of the text decreased and the duty cycle remained unchanged.

2. Contrast of lines of text

One of the obvious ways in which text and gratings may be distinguished concerns the fact that lines of text are broken up into the strokes that comprise the letters. As a result, the average contrast of the lines is lower than that in figure 1. The probability of illusions and seizures as a function of the contrast of a pattern of stripes is shown in figure 2*d*. The probability is a linear function of the log of the contrast, and low contrasts (above about 10%) can be sufficient to induce illusions. The first three studies address the question as to whether the contrast of the 'stripes' from text is sufficient to induce illusions and seizures, and whether the ascenders and descenders of letters can justifiably be ignored in considering the duty cycle of the grating.

2.1. *Study 1*

In order to measure the mean reflectance of linear sections of the page the following apparatus was constructed. Light from a quartz-halogen lamp was directed along one path of a randomized bifurcated optic fibre bundle to an aperture measuring 1·0 mm by 76·5 mm. The aperture was positioned 0·8 mm above the page of a book with the long axis of the aperture parallel to the lines of text. The light reflected normally from the page was collected by other adjacent fibres in the bundle which directed the light to a photodiode that was filtered optically to approximate the spectral response of the eye. When the aperture was moved across the lines of text in a direction orthogonal to the lines, the output of the photodiode gave an estimate of the mean reflectance of linear sections of the page.

Figure 4 shows for a small sample of text (see inset) how the mean reflectance of a linear horizontal section of the page changed with vertical position. As can be seen, the ascenders and descenders contributed little to the variations in reflectance: the reflectance showed a rapid change between an upper limit of about 90% and a lower limit of about 65%.

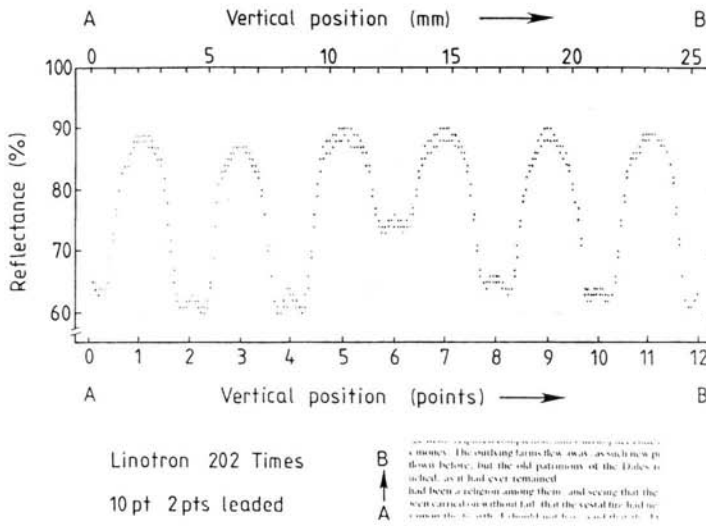

Figure 4. The mean reflectance (*y*-axis) of the text shown in the inset, averaged horizontally, and shown (*x*-axis) as a function of vertical position (A–B). The recording was made by a randomized bifurcated optic fibre which transmitted light to and collected the reflected light from a section of the text measuring 1·0 mm high by 76·5 mm wide.

As mentioned above, the Michelson contrast of a grating is defined as the difference between the light and dark sections of the pattern expressed as a ratio of the sum of their luminances. If text is considered as a 'grating' the ratio remains constant irrespective of the illumination reaching the page and is determined by the reflective properties of the paper and the ink, and spatial properties of the text such as the density of the lettering and the width of the letter strokes. For the text shown, the Michelson contrast was close to 22%. The text was printed on matt paper which was a good Lambertian reflector, but the reflectance was measured normal to the paper and so a small specular component of reflection was included in the readings. The measurements of contrast were therefore underestimates. As can be seen from figure 2(*d*), a grating with a contrast of 22% and otherwise appropriate spatial characteristics has sufficient contrast to induce illusions and seizures.

The next study was designed to determine the contrast of 'stripes' from a wide range of founts.

2.2. *Study 2*

Passages of text were taken from samples published by Western Printing Services Ltd. They were printed on matt paper in black ink of stable contrast. In the first set of samples the following typefaces were set on a Mergenthaler Linotype variable input phototypesetter: Baskerville, Bembo, Century Schoolbook, Garamond, Helvetica, Melior, Optima, Palatino, Plantin, Sabon and Times. Nine samples were available for

each fount: 9, 10 and 11 point set with 1, $1\frac{1}{2}$ and 2 point leading (i.e. space between the lines [one point = 0·0138 in]). The space between the lines is greater than the leading because it includes an upper and lower margin around the letters, both those with ascenders and those with descenders. This margin separates the lines of text when the text is 'set solid', i.e. without leading). Samples in the second group were set on a Linotron 202. For this group, the following typefaces were available in addition to those listed above: Aldus, Aster, Bauer Bodini, Electra, Goudy Old Style, Imprint, Meridien Old Style, Rockwell Light, Trump Medieval and Univers Medium. There were only three samples for each fount: 9 point with 2 point leading, 10 point with 2 point leading and 11 point with 1 point leading. The mean contrast for the lines of text was measured for each sample in the above sets. An analysis of variance with fount, letter size and leading as factors was performed for the first set of samples. All three factors affected measurements of contrast significantly (fount: $F(10,297) = 46{\cdot}4$, $p < 0{\cdot}0001$; size: $F(2,297) = 30{\cdot}2$, $p < 0{\cdot}0001$; leading: $F(2,297) = 7{\cdot}9$, $p < 0{\cdot}0005$) but only one of the factors, namely fount, accounted for an appreciable proportion of the variance (fount: 49%; size: 6%; leading 2%).

A similar analysis of variance was performed for the second set of samples, but with only fount and size (9 or 10 point) as factors. Once again both factors were significant but only fount accounted for a substantial amount of the variance (fount: $F(19,120) = 17{\cdot}8$, $p < 0{\cdot}0001$, 64% variance explained; size: $F(1,120) = 5{\cdot}1$, $p < 0{\cdot}03$, 1% variance explained). In both the above analyses the interactions between the factors accounted for less than 13% of the variance.

Figure 5 shows the founts against a scale of contrast: as might be expected the heavier faces have a higher contrast. Note that although the contrast of the lines is influenced mainly by fount, the contrasts range from a minimum of 12·9% to a maximum of 22·2%. The range is therefore very slight given the effects of contrast on the induction of illusions and seizures shown in figure 2(*d*).

The next section considers the remaining characteristics of the 'stripes' of printed text, namely the angular subtense, spatial frequency and duty cycle.

2.3. *Study 3*

Fourteen volunteers from the subject panel of the Applied Psychology Unit (6 men and 8 women aged 31–74) were asked to choose, from their personal collection, two books, one having 'clear' and the other having 'less clear' text. The mean contrast value for the 14 samples of 'clear' text was 18·4%, s.d. 2·8%, range 13–26% and for the 'less clear' text the mean was 17·6%, s.d. 3·0%, range 12–23%. The difference was not significant. The Pearson product moment correlation between the contrast of the lines and the contrast of the ink on the page (measured by similar photometric methods) was 0·53. Thus only 28% of the variance in line contrast was explained by the contrast of the ink on the page. The results suggest that, for a typical range of books, a typical range of contrasts of ink on paper and a typical range of founts, the fount has a greater contribution towards the line contrast than does the contrast of the ink on the paper. These factors influence line contrast over a relatively narrow range when compared to the range of the function shown in figure 2(*d*) which relates line contrast to the induction of illusions and seizures. From this figure it can be seen that the range of contrasts of the 'stripes' of printed text are within the range that will induce illusions and seizures, and that the ink and the fount are likely to have little influence on any aversive effects of the 'stripes'.

The next section considers the remaining characteristics of the 'stripes' or printed text, namely the angular subtense, spatial frequency and duty cycle.

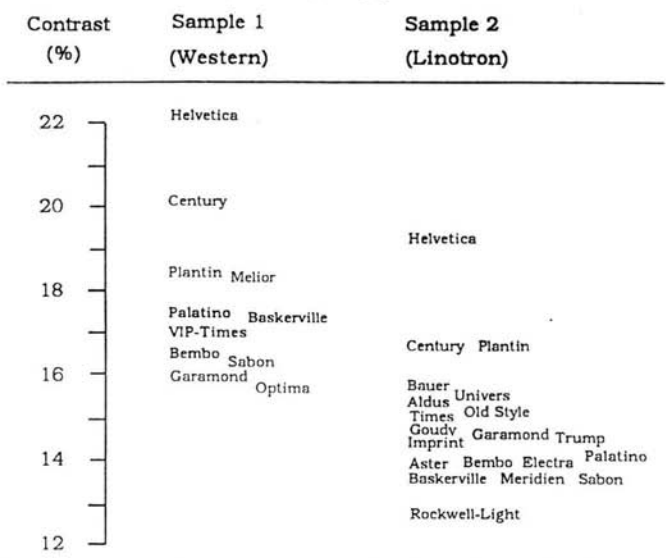

Figure 5. Mean contrast of lines of text shown as a function of the fount in which the text was printed. Two different samples are shown. Note that the vertical position of the founts on the second sample is lower, presumably due to differences in the contrast of the ink or the thickness of the letter strokes. The relative contrast of the various founts is nevertheless consistent between samples.

3. Factors other than line contrast

Figure 2 shows the manner in which the probability of illusions and seizures is affected by the angular subtense of a pattern of stripes (figure 2(*a*)) and by the spatial frequency in cycles per degree visual angle (figure 2(*b*)). Both of these variables depend on the distance at which the grating is viewed. The following study was designed to obtain typical values for printed text. The duty cycle of the 'stripes' (which does not vary with viewing distance) was also measured.

3.1. *Study 4*

3.1.1. *Subjects*: The subjects were undergraduates from the Arts Faculty of the University of Cambridge, reading History and English; 18 men and 8 women, aged 18–25. Eight reported that they invariably wore glasses when they read in order to correct short sight.

3.1.2. *Procedure*: The subjects were each asked to select two books, one which had 'clear printing that was easy to read', and one which was 'less easy to read' because the printing was 'less clear'. It was emphasized that the content or comprehensibility of the books was immaterial. Subjects were asked to position each book in turn at a comfortable reading distance and then to measure the distance from their eyes to the printed page.

A typical page from each book was photocopied and the following measurements made: (*a*) the height and width of the printed page, excluding margins; (*b*) the interline spacing; (*c*) the height of the central body of the letters (*x*-height).

3.1.3. *Results*: The majority of subjects chose textbooks and none selected books for children or the partially sighted. Table 1 shows the mean values and standard deviations for the variables. The angular height and width of the page and the spatial frequency of the component lines have been calculated on the basis of each subject's comfortable reading distance. It is evident that the distance at which subjects hold books with 'less clear' text is on average about 20% closer to the eye than the distance at which books with 'clear' text are held. As a result of this difference, the parameters of field size and spatial frequency show effects of the judged clarity of the text. As is shown later, other parameters such as duty cycle also show effects of judged clarity, and these are not attributable to viewing distance. For the moment the point to note is that the values of the various parameters are within the range responsible for illusions and seizures.

Table 1. Mean values for the comfortable reading distance and the spatial parameters of text for 'clear' and 'less clear' text. Standard deviations are given in parentheses after the mean. The results of studies 4 and 5 are tabulated separately. Further detail is given in table 3.

Variable		Mean value		
		'Clear' text	'Less clear' text	Difference (%)
Reading distance (mm)	Study 4	345(98)	272(105)	−21
	Study 5	402(92)	339(101)	−16
Height of page (mm)	Study 4	165(17)	164(19)	−6
Height of page (degrees)	Study 4	27·1(8·0)	33·3(9·5)	+19
Width of page (mm)	Study 4	102(15)	97(18)	−5
Width of page (degrees)	Study 4	17·8(6·6)	21·7(7·2)	+22
Interline spacing (mm)	Study 4	4·38(0·48)	3·78(0·65)	−14
	Study 5	4·37(0·84)	3·41(0·61)	−22
Spatial frequency (cycles/degree)	Study 4	1·39(0·41)	1·44(1·70)	+3
	Study 5	1·63(0·40)	1·81(0·70)	+11
Duty cycle (%)	Study 4	62·3(3·4)	60·5(4·2)	−3
	Study 5	58·6(4·9)	54·6(5·8)	−7

The above findings were obtained with undergraduates as subjects and printed material consisting mostly of textbooks. In order to ascertain the general applicability of the findings a different population of subjects took part in the next study.

3.2. *Study 5*

3.2.1 *Subjects*: Volunteers on the subject panel of the Applied Psychology Unit took part. They comprised 20 men and 14 women aged 19–63 (mean 44).

3.2.2. *Procedure:* The procedure was similar to that of the previous experiment except that the subjects were specifically instructed to avoid books for children or the partially-sighted. Only the reading distance, *x*-height and line separation were recorded.

3.2.3. *Results*: The results are summarized in table 1 and, as can be seen, the values of the parameters are similar to those previously obtained, lying within the range over which striped patterns induce illusions and seizures.

The abscissae of figure 2 show the mean values of field size, spatial frequency and duty cycle for the 'clear' and 'less clear' text obtained in studies 4 and 5. As can be seen the values are close to those optimal for the induction of illusions and seizures.

4. The 'stripes' of text induce illusions and seizures

The evidence that certain patterns of stripes can induce undesirable visual and neurological effects has been reviewed in sections 2 and 3 and it has been shown that the successive lines of printed text comprise a pattern with parameters within the range appropriate for these undesirable effects. It will now be demonstrated that text can indeed induce illusions of the type seen in striped patterns.

4.1. *Study 6*

A pilot study asked subjects to fixate a word in the centre of three lines of text or a full page of text for 5 s or for 30 s and to report 'curious or anomalous visual effects', if any. Three of 16 subjects reported movement, but only in response to a full page of text when it was observed for 30 s. The movement resembled the shimmer seen in patterns of stripes. Accordingly, the following experiment gave subjects a list of the illusions commonly reported in patterns of stripes (after Wilkins *et al.* 1984) and asked whether any such illusions were seen.

4.1.1. *Subjects*: 15 men and 5 women (aged 30–76) on the subject panel of the Applied Psychology Unit took part. They wore their reading lenses, if any, and they were not examined optometrically.

4.1.2. *Materials*: Two text samples from those published by Western Printing Services Ltd were photocopied. The texts were identical passages from 'The Small House at Allington' set on a Mergenthaler Linotype variable input phototypesetter in Century Schoolbook. One was set in 9 point with 1 point leading and the other was set in 11 point with 1 point leading. The duty cycles of the 'stripes' in the two samples were 46% and 62%, respectively.

4.1.3. *Procedure*: The subjects were shown the 9-point text and the 11-point text in turn under ceiling mounted fluorescent lighting such that the mean luminance of the page was about 50 cd/m^2. They were asked to position the page on their lap so that the viewing distance was about 0·4 m. They then fixated a letter in the centre of the block of text for 30 s and subsequently reported any visual effects they had seen using the following checklist: 'red, green, blue, yellow, blurring, bending of stripes, shimmering, flickering, fading, shadowy shapes, other (please specify)'.

4.1.4. *Results*: Nine of the 20 subjects reported seeing visual effects in the 9-point text and 13 reported seeing such effects in the 11-point text. The most commonly reported effect was that of blurring, but every other category of effect was also reported. The reported effects might have resulted in part from poor refraction, or from the influence of the checklist. For these reasons the group results are of less interest than the unsolicited response of one subject, reproduced in figure 6. This subject was among

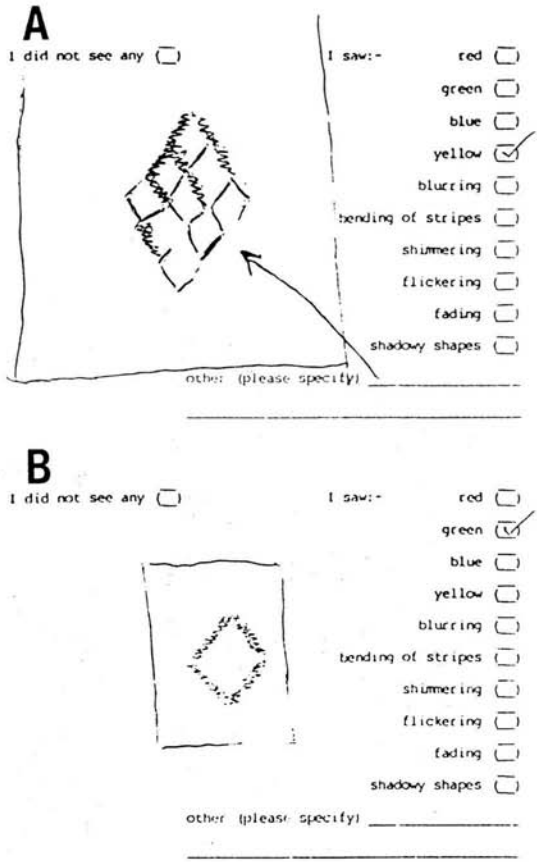

Figure 6. The illusions reported by a subject after fixating a letter in the centre of a page of text. (*a*) Nine-point text with 1 point leading; (*b*) 11-point text with 1 point leading.

three to report 'shadowy shapes' and he spontaneously reproduced the shapes graphically. He depicted a rhomboid lattice typical of that seen in patterns of stripes, the size of the rhomboids changing with the spacing of the lines, just as occurs with variations in the spatial frequency of a grating. The lattice is not easily explained in terms of ocular factors and has been attributed to cortical inhibition (Georgeson 1985). The lattice has since been reported by another subject with whom the authors have had informal conversations. She suffered from migraine and was susceptible to the 'bothersome' lattice if she read when tired.

4.2. *Other studies*

Three other studies support the idea that the striped properties of printed text can have adverse effects. These have been reported in detail elsewhere and so a brief description will suffice here. All three studies concern the effects of a reading mask that darkens and

blurs the lines of text above and below those being read, leaving three lines clearly visible. The first study comprised two experiments with volunteers who suffered eye-strain or headache from reading (Wilkins and Nimmo-Smith 1984). The subjects were asked to compare the reading mask with a variety of other placebo controls. One third of the sample said that the mask produced effects that were sufficiently beneficial to be worth the inconvenience of using it. This was not the case with devices that guided the eye without occluding the text. The number of illusions seen in a pattern of stripes was higher among the subjects who reported beneficial effects than among the others. In the second study, normal volunteers on the subject panel of the Applied Psychology Unit were asked to report whether the reading mask produced any beneficial visual effects. Those subjects who reported such effects (improvements in the clarity of the text, apparent increase in the spacing of the lines or the size of the lettering) tended to report more illusions in a pattern of striped lines than those for whom the mask was ineffectual (Wilkins and Nimmo-Smith 1984).

In the third study two patients with primary generalized epilepsy took part (Wilkins and Lindsay 1985). In both patients routine intermittent photic stimulation induced a photoconvulsive response in the EEG. Epileptiform EEG abnormalities were also induced when the patients looked at patterns of striped lines similar to that in figure 1. Periods lasting about 1 min, during which the patient was at rest, were randomly intermixed with periods during which the patients read a book in the usual way and with periods during which the book was read using the reading mask. The incidence of epileptiform abnormalities when the patients were at rest, and when they were reading with and without the reading mask are shown in table 2. The incidence of epiliptiform abnormalities was significantly increased when the patients read, and was significantly reduced by the use of the reading mask.

Table 2. Incidence of epileptiform EEG activity (discharges/min) while at rest and when reading with and without a mask. Data from two pattern-sensitive epiliptic patients. (After Wilkins and Lindsey 1985).

	Patient MN	Patient IJ
At rest	0·70	0·00
Reading without mask	1·48	2·67
Reading with mask	0·73	0·58

5. The clarity of printed text in relation to its cost

The findings reported in sections 2–4 suggest that the successive lines of print form a pattern of 'stripes' that might have deleterious effects on the clarity of printed material. If this is the case, it ought to be possible to improve the clarity by changing the characteristics of the striped pattern. According to the data in figure 2 the clarity would be improved by increasing the spacing between the lines because this both increases the duty cycle and reduces the spatial frequency. Such changes will inevitably increase the cost of text unless the interletter spacing is reduced when the interline spacing is increased, so as to keep the letter density constant. This section of this paper addresses the question as to whether, *within the range of line spacing and letter density conventionally used*, it is possible to improve clarity without an increase in cost.

5.1. *Study 7*

The following measurements of the samples of text from studies 1 and 2 were added to those already taken.

(*a*) The mean width of letters (as estimated in study 4 from the number of characters in two lines, and in study 5 from the width of the letter sequence 'and').

(*b*) The number of paragraphs per page (mean of ten pages: study 4).

The data were then reanalysed and the analyses are summarized in table 3.

Table 3 shows the percentage difference between the values of each variable for 'clear' and 'less clear' text, together with the percentage variance explained by this

Table 3. Mean values of comfortable reading distance and spatial parameters of text expressed separately for 'clear' and 'less clear' text. The standard deviations are shown in parentheses. The variance in judgements of clarity explained by each variable is also shown.

Variable measured or derived		Mean value: 'Clear' text	Mean value: 'Less clear' text	Difference (%)	Variance explained (%)
Reading distance (mm)	Study 4	346(98)	272(105)	−21	29·2*
	Study 5	402(92)	339(101)	−16	30·3*
Interline spacing (mm)	Study 4	4·38(0·48)	3·78(0·65)	−14	33·7*
	Study 5	4·37(0·84)	3·41(0·61)	−22	37·7*
Spatial frequency (cycles/degree)	Study 4	1·39(0·41)	1·44(1·70)	+11	6·6ns
	Study 5	1·63(0·40)	1·81(0·70)	+12	5·7‡
x-height (mm)	Study 4	1·64(0·14)	1·47(0·20)	−10	26·9*
	Study 5	1·78(0·22)	1·52(0·20)	−15	32·5*
x-height (degrees)	Study 4	0·30(0·13)	0·35(0·12)	+21	14·1‡
	Study 5	0·27(0·08)	0·29(0·12)	+7	3·3ns
Duty cycle (%)	Study 4	62·3(3·4)	60·5(4·2)	−3	7·5†
	Study 5	58·6(4·9)	54·6(5·8)	−7	18·6*
Mean letter width (mm)	Study 4	1·64(0·30)	1·45(0·22)	−12	16·8*
	Study 5	1·86(0·26)	1·59(0·19)	−15	30·9*
Mean letter width (degrees)	Study 4	0·30(0·14)	0·34(0·12)	+13	9·4‡
	Study 5	0·28(0·08)	0·30(0·12)	+7	3·4ns
Letter cell area (mm^2)	Study 4	7·26(1·78)	5·59(1·43)	−23	6·6‡
	Study 5	8·29(3·12)	5·51(1·43)	−33	30·3*
Height of page (mm)	Study 4	165(17)	164(19)	−6	0·2ns
Height of page (degrees)	Study 4	27·1(8·0)	33·3(9·5)	+19	31·2*
Width of page (mm)	Study 4	102(15)	97(18)	−5	2·7ns
Width of page (degrees)	Study 4	17·8(6·6)	21·7(7·2)	+22	19·9‡
Mean no. paras/page	Study 4	4·2(2·4)	6·7(13·1)	+59	27ns

* $p < 0.001$.
† $p < 0.01$.
‡ $p < 0.05$.
ns, not significant.

difference when the data were subjected to a series of analyses of variance with each variable in turn as the main effect. Many of the variables are associated with each other and so the percentage variance explained does not sum to 100.

As noted earlier, the distance at which subjects hold books with 'less clear' text is about 20% closer the eye than that at which they hold books with 'clear' text. In present printing conventions, interline spacing and letter height are correlated and it is therefore possible that subjects position the books so as to achieve a certain angular letter size rather than a certain spatial frequency of the lines of text.

The product of the line separation and the mean width of the letters is referred to in table 3 as the letter cell area. It is a measure on which the cost of printing heavily depends, but its contribution to the variance is not consistent across the two samples and it explains relatively little of the variance, less than that explained by the interline spacing, for example. These findings suggest that the clarity of printed material could be increased at no extra cost by slightly increasing the spacing between the lines while decreasing slightly the width of the letters or the horizontal spacing between them.

To judge whether this would indeed result in an improvement, the contribution to the variance from the area of the letter cell was statistically controlled. For the data from study 5 the remaining variance explained by the spacing of the lines was 12·8%, and those explained by the *x*-height and the letter width were 5·5% and 2·2%, respectively, The analysis therefore suggests that for a representative sample of books there would be an improvement in clarity if the interline spacing was increased (slightly) while the density of the lettering remained the same.

An increase in letter density might result in an increase in the contrast of the *lines* of text. It is unlikely that such an increase would affect the incidence of anomalous visual effects, given the function shown in figure 2 (*d*) and the results of studies 4 and 5. On the other hand it is conceivable that an increase in the contrast of the lines might adversely affect preference for some other reason. Study 8 investigated whether this would be the case.

5.2. *Study 8*

5.2.1. *Subjects*: Twenty-one members of the subject panel of the Applied Psychology Unit (14 men and 5 women aged 22–76) took part.

5.2.2. *Materials*: Ten passages of identical text from 'The Small House at Allington' were selected from those published by Western Printing Services. The text was phototypeset in Mergenthaler Linotype in the following founts: Baskerville, Bembo, Century Schoolbook, Helvetica, Melior, Optima, Palatino, Plantin, Sabon and Times. All the passages had an identical interline spacing of 3·8 mm and *x*-heights in the range 1·6–1·7 mm. The 'duty cycle' therefore varied from 42% to 45%. All the founts were set in 10 point with 1 point leading, except Helvetica, which, because of its atypically large *x*-height, was set in 9 point with 2 point leading. The line contrasts of the ten samples averaged 18·1% (s.d. 2·5%) and ranged from 15·3% to 22·5%.

5.2.3. *Procedure*: The subjects were asked to rank the ten samples of text in their order of preference for reading them.

5.2.4. *Results*: Kendall's coefficient of concordance for the rankings was 0·21, $p < 0{\cdot}05$. The correlation between the ranked preference and the line contrast was +0·75 ($p < 0{\cdot}01$), indicating that the subjects preferred texts with high *line* contrast. The

contrast of the ink on the page varied little from one text to the next and was not significantly associated with subjects' preferences.

Within the range of founts used, the subjects evidently preferred those that provided the highest line contrast (as opposed to contrast of the ink of the page). This finding indicates that, not suprisingly, preference is influenced by factors other than those that induce illusions. Note that in this experiment factors that influence the induction of illusions, such as spatial frequency and duty cycle, were effectively controlled, and that over the range of values used, variations in line contrast should not have affected the induction of illusions appreciably.

6. General discussion

The successive lines of printed text comprise a pattern of 'stripes'. The spatial parameters of this pattern are within the range appropriate for the induction of discomfort, anomalous visual effects and seizures. In susceptible people, text is capable of inducing such adverse effects, and these effects can be reduced by covering the lines above and below those being read.

It has been known for a considerable time that the separation of the lines of text affects its legibility (e.g. Tinker 1963, Poulton 1972), particularly when the lettering is small (e.g. Reynolds 1979). The separation of the lines affects the spatial frequency and duty cycle of the pattern of 'stripes', and on both counts the greater the separation the lower the probability of any adverse effects. Perhaps for this reason, judgements of the clarity of text obtained in the above studies are critically dependent on the spacing of the lines, more so than the overall density of lettering on the page. As a result, the clarity of text can potentially be increased at no extra cost by increasing the separation between the lines slightly and decreasing slightly the mean horizontal spacing between the centres of letters, within the limits of conventional typography. There are several ways in which such a decrease in horizontal spacing might be achieved. Most would increase the contrast of the lines of text, but the findings of study 8 suggest that this increase would not necessarily be disliked.

Another way in which the adverse effects of the striped pattern can be alleviated is to break blocks of text by frequent paragraphing, and by printing more than one column on the page. The advantages for clarity have been discovered pragmatically and perhaps inadvertently by the designers of newspapers. In newspapers the linear components of the text are broken up by printing in narrow columns, with frequent paragraphing and frequent alterations of letter size. In addition the right justification with narrow columns increases the variation in the mean density of the lines, further disrupting the linear properties, and providing landmarks for the eye.

The development of soft fount has provided the possibility of adjusting letter size, shape and spacing in a context-sensitive manner (Knuth 1982), that is, in relation to the shape of neighbouring letters. The perceived size of letters is known to depend on interletter spacing (Skottun and Freeman 1983), but despite the problems this entails, Kindersley (1976) has proposed a system for a letter spacing that is sensitive to the context of the adjacent letters, with a view to increasing the letter density while maintaining legibility. One consequence of the use of this system is a reduction of the heterogeneity of text, (e.g. 'rivers') and a homogeneity that emphasizes the sucessive lines. In the light of the present findings, it would be of interest to determine whether the homogeneity of the linear properties of text exaggerates their adverse effects.

It remains to put the above ideas directly to the test by examining publishers' house styles. A small increase in line spacing over and above that conventionally used should render the text clearer, even if it is accompanied by a small decrease in interletter spacing or letter width.

Acknowledgments

The authors are grateful to Ben Craven, Roger Watt and to three referees for comments on an earlier version of the paper, to Michael Morgan for help with the measurement of line contrast and to Kathleen Watts and Lucy Taylor for data collection. The work was funded by the Medical Research Council and the Health and Safety Executive.

References

GEORGESON, M. A., 1985, Inferring cortical organisation from subjective visual patterns. In D. ROSE and V. G. DOBSON (eds.) *Models of the Visual Cortex* (Wiley, London).

KINDERSLEY, D., 1976, *Optical Letter Spacing for New Printing Systems* (Wynkyn de Worde Society, London).

KNUTH, D. E., 1982, The concept of a meta-fount. *Visible Language*, **16**, 3–27.

POULTON, E. C., 1972, Size, style and vertical spacing in the legibility of small typefaces. *Journal of Applied Psychology*, **56**, 156–161.

REYNOLDS, L., 1979, Progress in documentation. Legibility studies: their relevance to present-day documentation methods. *Journal of Documentation*, **35**, 307–340.

SKOTTUN, B. C., and FREEMAN, R. D., 1983, Perceived size of letters depends on inter-letter spacing: a new visual illusion. *Vision Research*, **23**, 111–112.

TINKER, M. A., 1963, *Legibility of Print* (Iowa State University Press, Ames Iowa).

WILKINS, A. J., and LINDSAY, J., 1985, Common forms of reflex epilepsy: physiological mechanisms and techniques for treatment. In T. A. PEDLEY and B. S. MELDRUM (eds.) *Recent Advances in Epilepsy II* (Church Livingstone, Edinburgh).

WILKINS, A. J., and NIMMO-SMITH, I., 1984, On the reduction of eye-strain when reading. *Opthalmic and Physiological Optics*, **4**, 53–59.

WILKINS, A. J., NIMMO-SMITH, I., TAIT, A., MCMANUS, I. C., DELLA SALA, S., TILLEY, A., ARNOLD, K., BARRIE, M. A., and SCOTT, S. G. C., 1984, A neurological basis for visual discomfort. *Brain*, **107**, 989–1017.

Manuscript received 16 October 1986.
Revised version received 10 June 1987.
Revised version accepted 10 August 1987.

Les lignes successives d'un texte imprimé forment un motif de "raies". Les caractéristiques spatiales de ce motif ont été mesurées et on a trouvé qu'elles étaient similaires à celles d'un motif qui induit une gêne, des effets visuels anormaux ou même des crises. On soutient que la lecture peut entraîner une astreinte oculaire et des crises à cause des raies que forment les lignes du texte et qu'il est possible de réduire les maux de tête et les crises en cachant les lignes qui sont au-dessus et en-dessous de celle dont la lecture est en cours. Dans les études où l'on demande au sujet d'évaluer la clarté du texte, on montre que ce jugement est affecté par les propriétés spatiales du motif, en particulier par l'espacement entre les lignes. La surface moyenne d'une page occupée par une lettre (c.à.d. le résultat de la séparation entre les lignes et l'espacement horizontal entre les centres des lettres) intervient moins dans la variance que n'intervient la séparation entre les lignes du texte. Compte tenu des contraintes de la typographie classique, il semble possible d'améliorer la clarté d'un texte sans accroître le coût en réduisant légèrement l'espacement entre les lettres afin d'augmenter l'espacement entre les lignes.

Die aufeinander folgenden Linien eines gedruckten Textes stellen optisch ein Streifenmuster dar. Die räumlichen Verhältnisse dieser Muster wurden gemessen, wobei herausgefunden wurde, daß diese mit Mustern vergleichbar sind, die beim Auge unangenehme und unnatürliche Seheffekte hervorrufen.

Es wird behauptet, daß durch die gestreiften Eigenschaften eines Textes das Auge angestrengt wird, und man durch das Abdecken der Zeilen ober- und unterhalb des Textes das Auftreten von Kopfschmerzen reduzieren kann.

In Studien, die sich hauptsächlich mit der Beurteilung der angenehmen Lesbarkeit beschäftigen, ergab sich, daß diese besonders durch das räumliche Linienmuster, speziell dem Platz zwischen den Zeilen beeinflußt wird. Der durchschnittliche Raum einer Seite, der curch einen Buchstaben beansprucht wird (z.B. das Produkt der Zeilenabstände und der horizontale Raum zwischen den Mittelpunkten zweier Buchstaben) ist weniger verantwortlich für eine unangenehme Lesbarkeit des Textes als der Abstand zwischen den einzelnen Zeilen. Trotz der vorgegenbenen Zwänge der konventionellen Typografie kann die Klarheit eines Textes, ohne Entstehung von Mehrkosten durch eine leichte Reduzierung des Platzes zwischen den Buchstaben untereinander und dem dadurch ermöglichten größeren Zeilenabstand verbessert werden.

印刷文の連続する行によってストライプ・パターンを形成する。このパターンの空間特性を測定し，それが不快感，異常な視覚効果および発作さえも誘起するパターンの空間特性に類似していることが分かった。本文のストライプ性のために読書によって「眼精疲労」と発作が生じると論じられ，読んでいる行の上下の行を隠すと頭痛と発作が軽減されるのはこの理由による。被験者が本文の明瞭さを判断するように要求された研究では，明瞭さの判断がパターンの空間特性，特に行間隔に影響されることが分かっている。頁当たりの文字が占める平均面積（すなわち，行間隔と文字中心間の平均水平間隔の積）は行間隔よりも小さい分散要因である。従来の活版術の制約内では，文字間隔をわずかに減らして行間隔を増やすと，費用増なしに本文の明瞭さを改善できるものと思われる。