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ON THE REDUCTION OF EYE-STRAIN WHEN READING

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Abstract—Successive lines of printed text form a pattern of stripes that may induce eye-strain and headache. Volunteers suffering eye-strain or headache from reading were asked to use a variety of aids, some of which merely guided the eye and some of which also attenuated the pattern of stripes above and below the passage of text being read. In two studies about one-third of the volunteers benefited from the latter aids to the extent that they wished to continue using them despite the inconvenience involved. These volunteers tended to report more visual illusions when they looked at a pattern of striped lines.

INTRODUCTION

Certain patterns of striped lines (e.g. Fig. 1) are judged unpleasant, giving rise to complaints of eye-strain and headaches. These patterns also provoke illusions of colour, shape and motion. The illusions appear to provide an index of a person's susceptibility to headache: persons with frequent headache report seeing more illusions in these striped patterns, and persons with consistently unilateral headache tend to report illusions predominantly in one lateral visual field (Wilkins *et al.*, in press). Successive lines of printed text comprise a pattern of stripes and in this paper it will be argued that these stripes may provoke some of the eye-strain and headaches that are attributed to reading.

When asked to read different printed texts at a comfortable distance volunteers position them so that the spatial frequency of the stripes formed by the print is roughly the same regardless of the spacing of stripes on the page (Wilkins *et al.*, in preparation). The spatial frequency chosen varies from person to person having a mean of 1.5 c/deg. Fig. 2 shows the function relating the adverse effects of striped patterns to their spatial frequency and it will be noted that text lies on the steep low-frequency portion of the curve.

We reasoned that if reading does indeed provoke eye-strain and headache because of the striped properties of the text it might be possible to treat these symptoms by reducing the number of stripes. We therefore developed reading aids that covered the lines of text above and below those being read. The devices are illustrated in Fig. 3(a) and (b). They consisted of two parallel rectangular pieces of plastic joined together at one end. In one case the device was made from a single sheet of plastic and the gap measured 2 × 13.5 cm. The second aid was made of three sheets of plastic so that the size of the gap could be varied in height from 0 to 5 cm. Both devices were designed to be positioned over the page so that the text being read appeared in the gap. As the text was read the device had therefore to be moved down the page progressively, but not necessarily line by line.

These reading aids resemble devices patented in 1924 by H. R. Morgan and in 1935 by D. W. Brown (U.K. patent specifications 219881 and 421907 respectively). Both were masks designed to reveal only one line of print. A similar device invented by R. H. Bradshaw and known as the Hawes Reading Screen was until recently marketed by Alfred Hawes and Son (79 Leadenhall Street, London EC3A 3DL, U.K.). It was made of aluminium covered with a matt black surface and had a central aperture of variable width. The device was larger than those shown in Fig. 3(a) and (b), being designed to cover an entire page. It was sold for use by elderly patients with incipient senile cataract and macular changes who needed high levels of ambient illumination in order to read, but who were consequently affected by specular glare

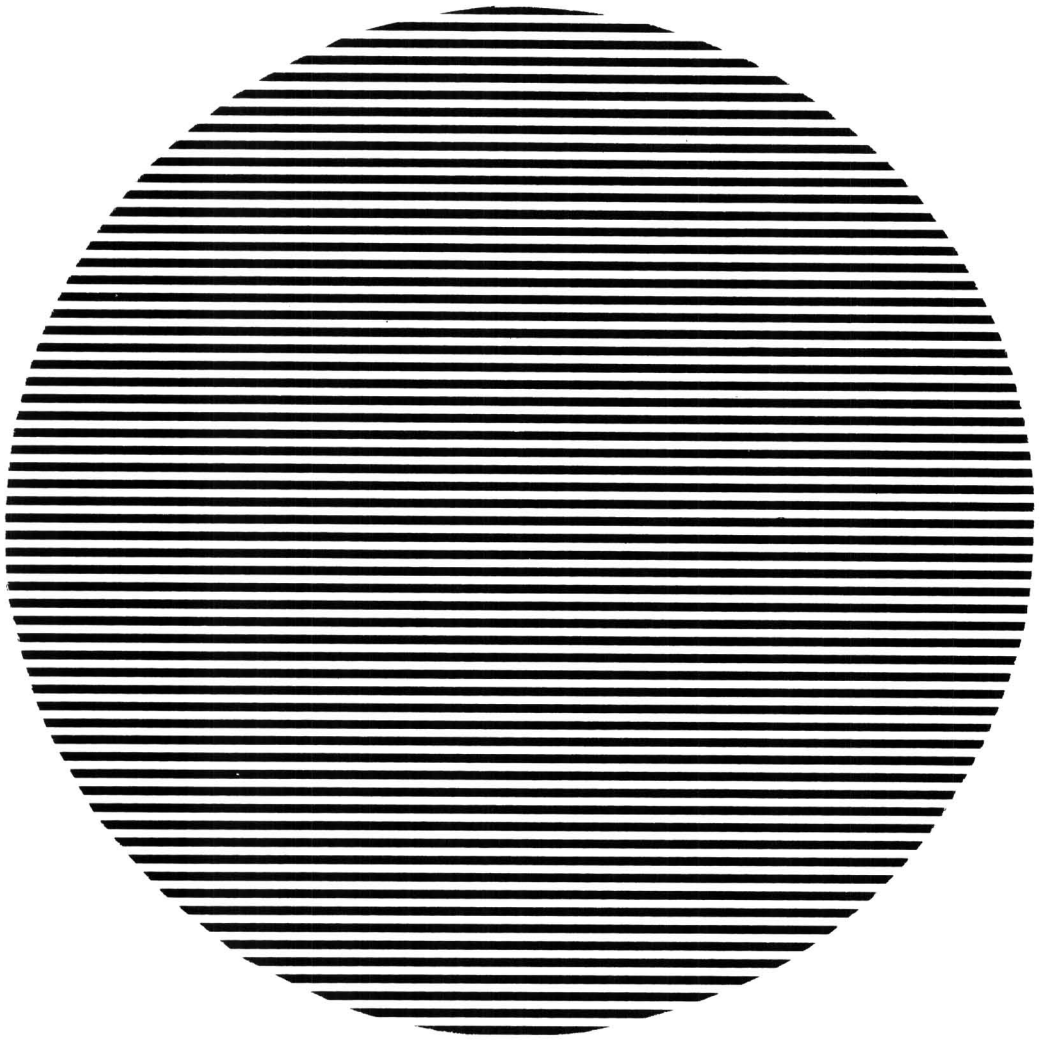

Fig. 1. An example of a pattern of stripes that induces "patterned glare" and provokes complaints of eye-strain, dizziness and headache.

from the page. A similar device known as the Prentice Typoscope (Prentice, 1897) [see Mehr (1969)] is still in current use. In one commercially available form it consists of a piece of card, white on one side and matt black on the other, measuring 152 × 75 mm with a central aperture 102 × 13 mm. (Note that an aperture of this size is frequently insufficient to include a complete line of text.) Although Prentice originally described his aid as a means of reducing the effects of extraneous light in patients with cataract or amblyopes wearing high corrections, it is also used to help patients who have difficulty locating words in text.

The rationale of the present aids was to reduce the adverse effect of striped text, rather than to reduce the specular reflections from the page, or even to assist in the location of words. They did not therefore have to cover the entire page because the effects of patterns of stripes are greater in central vision than in the periphery (Wilkins *et al.*, 1980). Neither was it essential to occlude the stripes completely: it was necessary only to reduce their contrast. The plastic reduced the contrast of the lines it covered by virtue of a matt surface. The text beneath the plastic was therefore sufficiently visible to enable the reader to find his way

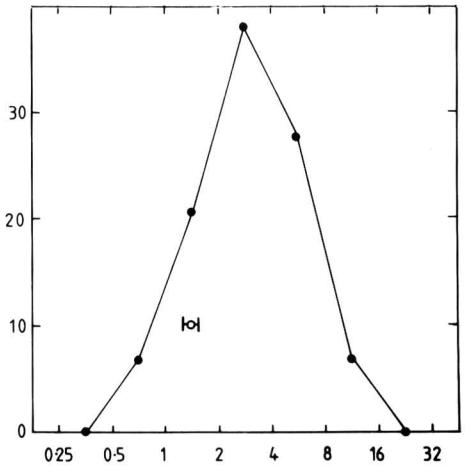

Fig. 2. Percentage of subjects reporting adverse effects when viewing striped patterns, expressed as a function of the number of cycles of the pattern subtending 1° at the eye. When a group of 33 volunteers held samples of text at a preferred reading distance the spatial frequency of the pattern of successive lines of print had a mean and SD as shown. [Data from Wilkins *et al.* (in press)].

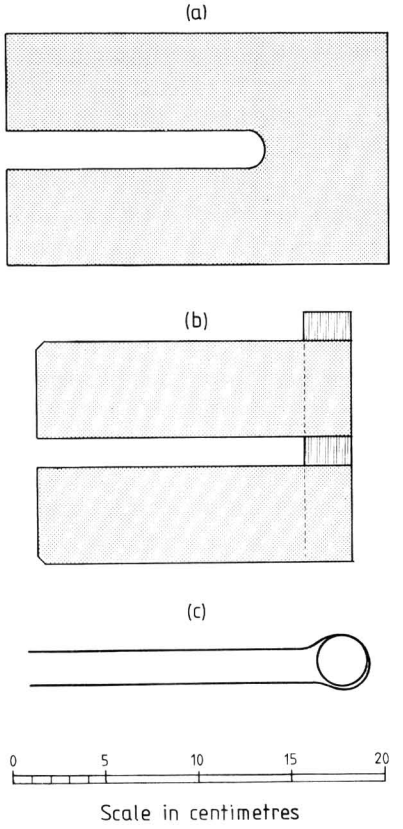

Fig. 3. Scaled diagram of three reading aids.

around the page and to refer back if necessary, but not of a contrast likely to induce eye-strain and headache.

The devices described earlier can be thought of as spatial filters. They reduce the power in the mid range spatial frequencies introduced by the repetitive pattern of successive lines of text.

Two investigations of the clinical effectiveness of the devices shown in Fig. 3(a) and (b) have been undertaken, using a variety of placebo controls. The volunteers were recruited by an advertisement worded as follows: "Does reading give you eye-strain or headache? The Medical Research Council is evaluating a simple reading aid that may prevent headaches and eye-strain. If you would like to try it out contact . . ." The volunteers recruited in this way were invited to use a variety of aids and to compare their effectiveness.

EXPERIMENT 1

Procedure

In the first study the advertisement referred to earlier was posted in libraries and opticians' waiting rooms in the Cambridge area and 21 volunteers were recruited (seven men, 14 women, aged 20 – 60). They were sent two aids by mail, both made of plastic sheet 1.5 mm thick, cut as shown in Fig. 3(a). One aid was made from darkened plastic (ICI Pacton Neutral 9034 polish/polish finish) and one from clear plastic (ICI Darvic polish/polish finish). Both sheets were sprayed with a lacquer that gave the surfaces a matt non-reflective surface (Kodak colour print lacquer matt; catalogue No. 3171469). This matting agent gave the surfaces a cloudy appearance and reduced the clarity of any print beneath.

The aids were accompanied by a set of instructions that, with the help of suitable illustrations, suggested three methods of use, the first two of which were placebo. It was suggested that: (1) the upper margin of the aid could be held below the line being read and used as a guide; (2) the text could be read through the plastic of the aid; and (3) the text could be read through the central slot. Volunteers were requested to use the aids for 1 week comparing

each of the suggested methods. They then completed a questionnaire which asked: (1) whether they found the aids helpful; (2) which of the two aids they preferred to use; (3) which method they preferred; and (4) whether or not they would continue to use the aid. The questionnaire also solicited suggestions for improving the design of the aids.

The volunteers were asked to attend for an ophthalmic examination and 17 of the 21 did so. The examination included a brief history, measurements of near and far acuity, retinoscopy, ophthalmoscopy, subjective refraction, tests of fixation disparity, suppression and stereopsis. Colour vision was assessed using the Ishihara colour plates, and the visual fields were examined by confrontation. Patients completed a questionnaire about their headaches and eye-strain, and were asked on two separate occasions to report the illusions they saw in a pattern of striped lines, using the following checklist: colour, fading of the pattern, blurring, bending of the lines, shimmering, flickering, dots streaming up and down, shadowy lines that were not really there, other. The pattern was similar to that in Fig. 1. It was viewed for about 10 s at a distance of 40 cm, subtending 28° with a spatial frequency of 3 cycles deg^{-1}. The mean luminance was 300 cd m^{-2}, and the Michelson contrast 0.7. The pattern is potentially epileptogenic (Wilkins *et al.*, 1980) and so persons with a previous history of epilepsy were told not to take part. None opted out, but the test was curtailed on one occasion owing to the induction of a headache.

Results

The results are summarized in Table 1. Eleven of the 21 participants said that they found the reading aid helpful, although only seven thought that they would continue to use it. Fourteen out of 17 subjects preferred to read through the slot rather than by either of the "placebo" methods ($P < 0.05$, two-tailed sign test). There was no overall preference for either aid. The dark aid induced greater simultaneous contrast than the light, and so the absence of any significant preference for the darker aid suggests that contrast effects of this kind do not provide an explanation for the value of the aid.

Table 1. Summary of the results of the two studies

		No. of subjects		Mean No. of different illusions seen	
Benefit?	Use?	Study 1	Study 2	Study 1	Study 2
Yes	Yes	7	11	2.9	3.2
Yes	No/?	4	7	2.3	2.0
No/?	No/?	6	10	1.0	2.2
—	—	4	8	—	—
		—	—		
		21	36		

The ophthalmic examination failed to reveal any difference between the volunteers for whom the aid was a success and those for whom it was not. The only difference between these groups was a slight tendency toward a *superior* visual acuity in the former, but it was not significant.

The protocols of the ophthalmic examinations were given to an ophthalmic optician with no prior knowledge of the patients to rate as to whether the patient's present prescription (if any) was adequate. There was no significant association between his ratings and the success or failure of the reading aid.

There was no significant difference between those who did and did not find the reading aid helpful in terms of the sex or age of the subject, the frequency of headache reported, or the incidence of photophobia or visual aura. There was, however, a tendency for the people who saw more visual illusions in the striped pattern to report that they planned to continue using the aid [see Table 1 ($Z = 1.789$, $P = 0.035$, one tail) (Meddis, 1980)].

Eleven months after the examination the seven patients who said they would continue to use the aid were contacted again and asked whether they were still using the aid. Five said they were, two of whom spontaneously reported a reduction in the incidence of headaches.

EXPERIMENT 2

A second study was undertaken: (1) to increase the sample size and establish whether the

illusions were associated with the effectiveness of the aid; and (2) to compare a revised design of the aid with alternative placebos. Four of the volunteers in the first study suggested that the optimal size of the slot might vary with the type of text being read. Accordingly the two rectangular sections of the aid above and below the slit were joined at one end so that the size of the slit could be adjusted [Fig. 3(b)].

Procedure

The aid shown in Fig. 3(b) was initially constructed by riveting the rectangular sections to a slotted strip, and subsequently by adhering them to a magnetic slide. A placebo aid was made from brass wire 1.5 mm in cross-section bent to the shape illustrated in Fig. 3(c) and painted matt black. The separation of the arms could be adjusted by bending the wire.

The advertisement used in the previous study was sent to the 43 libraries of the University of London with a request that it be posted. Over a 6-month period 36 volunteers replied (15 men and 21 women, aged 19 – 55) and all were sent a revised questionnaire. The questionnaire included questions about headaches and eye-strain, and a self-administered version of the illusions test described earlier, which included a caution advising persons with epilepsy or frequent migraine to avoid looking at the pattern. When the questionnaire was returned the volunteer was sent the two aids together with a second questionnaire soliciting comments. He was asked to use the aid for a week before completing the second questionnaire. This questionnaire asked the volunteers firstly whether or not they would continue to use one or both of the aids, giving reasons. They were then asked whether they noticed any benefits from using the aids, setting aside the inconvenience that this involved. To confirm their responses to the first question they were asked whether the benefits, if any, were worth the inconvenience of using the aid. They then gave an opinion as to whether the best separation of the arms depended on the text they were reading, and if so how. They were asked whether they found it useful to be able to adjust the separation of the rectangular arms or whether a suitable aid could be made with fixed arms. Finally they were invited to estimate the best separation for an aid with fixed arms and a suitable range of separations for an adjustable aid.

Results

Thirty-six volunteers completed the headache and eye-strain questionnaire and were sent the reading aids. Eight subsequently failed to return the questionnaire evaluating the aids (despite a stamped addressed envelope and subsequent reminder). Of the remaining 28 volunteers, 18 said they found the plastic aid helpful and of these 11 said that the benefits were worth the inconvenience, and that they would continue to use it (see Table 1). One opted for the placebo and two gave inconsistent replies which cast doubt upon their validity. Evidently the 11 subjects who chose the plastic aid did so because it helped, rather than for reasons of suggestibility. The reasons that they gave included the reduction of glare (five subjects) or eye-strain (five subjects), the prevention of backtracking (three subjects) and improvement in concentration or prevention of distraction (five subjects).

Considering only the 11 volunteers who said they would continue to use the aid, 10 reported finding the adjustment of the arms useful, and eight said that the optimal adjustment varied with the size of text. The suggestions for a suitable range of adjustment varied considerably, with a minimum between 0 and 13 mm and a maximum between 10 and 35 mm. The suggested separation for an aid with fixed arms varied from 6 to 35 mm. In view of this range, and the dependence of the optimal separation on the text being read, an aid with fixed arms is unlikely to be as widely acceptable as one with adjustable arms, regardless of the separation used.

At the end of the revised headache and eye-strain questionnaire the following eight symptoms of eye-strain were listed: irritation or soreness of the eyes, pain in response to light, faint colours surrounding objects, spots or shapes in front of the eyes, narrowing of vision (one or both sides), redness of the eyes, temporary blurring of vision (despite glasses if

worn), dryness of the eyes. Respondents were asked to estimate the frequency with which they experienced each symptom, using a 10-point scale which began "never, less than once a year, about once a year, more than once a year but less than once a month . . ." and ended "more than once a day". Each response was given a score from 1 to 10 according to its position on this scale, and these scores were summed for each subject. There was a significant difference between the subjects who planned to continue using the aid and those who did not, in terms of the mean reported incidence of the eight symptoms. These symptoms are listed earlier in order of the difference between the two groups. One interpretation of this finding is that it was the subjects who were affected by symptoms of eye-strain who found the aid helpful and were prepared to put up with the inconvenience involved in using it.

For the 24 subjects whose data were available there was a significant positive correlation between their experience of eye-strain (as measured by the incidence of symptoms) and the number of visual illusions they reported when looking at the grating described earlier [Spearman's rank correlation (r_s) = 0.56, $P < 0.01$].

Taking the data from the two studies as replications in an analysis of variance by ranks (Meddis, 1980), the number of illusions reported by subjects who said they would continue to use the aid was significantly higher than for the other subjects [$Z = 1.88$, $P = 0.028$, one tail (Meddis, 1980)].

DISCUSSION

The results of both studies are consistent in showing that about one-third of volunteers derive benefit from the reading aid to the extent that they wish to continue using it, despite the obvious inconvenience involved in doing so. This finding is unlikely to be due to suggestion, because of the relatively small effect of the various placebos.

There is support for the hypothesis advanced in the Introduction that the beneficial effects of the aid are due to the attenuation of the pattern of stripes rather than the reduction of glare from reflections. "Glare" is a sensation that may be due not only to reflected light but also to pattern; the stripes shown in Fig. 1 may be said to produce a "patterned glare". Experience of visual discomfort of this kind varies considerably from one individual to another and may be measured by presenting a pattern similar to that in Fig. 1 and asking the individuals to describe what they see (Wilkins *et al.*, in press). Somewhat surprisingly, people who find the reading aid helpful tend to be those who experience more visual illusions in patterns of this kind. Because of the relevance of this finding for explanations of the mechanisms underlying the reading aid a further study was undertaken with asymptomatic volunteers.

A group of 43 women aged 34 – 60 from the Applied Psychology Unit subject panel were asked to compare text with and without the reading aid and asked about the visual effects that the aid produced. Twenty-seven reported beneficial visual effects such as an apparent increase in the size of text, separation of the lines, or contrast of the letters. Twelve noticed no such effects and four gave equivocal replies. A version of the illusions test had previously been administered (involving a succession of five horizontal square-wave gratings similar to those used earlier, circular in outline and increasing logarithmically in diameter from 1.8 to 28°). There was a small but significant difference in the total number of illusions reported by subjects who considered the aid to have beneficial visual effects as compared with those who did not [mean 5.4 vs 4.2, $Z = 1.98$, $P < 0.05$ (Meddis, 1980)]. This result supports the findings of the two earlier studies.

Taken together, the results of the studies reported in this paper strongly suggest that some of the visual discomfort experienced when reading is attributable to "patterned glare" and that this "glare" may be due to successive lines of text. Such a viewpoint would explain why it is evidently necessary to cover the stripes above as well as those below the text being read. It is consistent with the finding that small changes in the separation of successive lines of text affect

judgments of its "clarity" (Wilkins *et al.*, in press).

Findlay and Wilkins (in preparation) have shown that patterns of stripes surrounding a fixation target can increase the SD of the position of the eye. The SD varies considerably from one person to another, and people with unstable fixation tend to see more illusions. Perhaps in attenuating the pattern of stripes the reading aid enables people with relatively poor occulomotor control to find words more readily.

If the reading aid has its effect mainly because it reduces the luminance and contrast of the pattern of stripes that surrounds the text being read, it should be effective mainly when the reading material forms a large continuous pattern of closely-spaced lines. Text such as newsprint in which the linear component is broken up by columns or frequent paragraphing should be less likely to induce "patterned glare" and the reading aid may not be necessary or effective. These predictions are in accordance with the informal observations of our volunteers and provide the motivation for current research.

The aid with adjustable arms is now being marketed by Engineering and Design Plastics, 84 High Street, Cherry Hinton, Cambridge CB1 4HZ, U.K.

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