Visual after-effects associated with the use of high-resolution visual display units

D L SMERDON AND H E WILLSHAW

From Birmingham and Midland Eye Hospital, Church Street, Birmingham

SUMMARY A long-lasting visual after-effect associated with the use of a high-resolution green visual display unit (VDU) is described in eight normal volunteers. Its duration to a standard VDU exposure is measured. It is related to the McCollough effect and is thought to be either a fatiguing of green colour-coded edge-detectors or an associative phenomenon. A reduction or loss of the usual foveal peak of the critical flicker frequency (CFF) to red is also described.

We report a long-lasting visual after-effect associated with the use of a high-resolution green computer screen. In recent years there has been concern over possible hazards from exposure to television screens and more recently microcomputer monitors and visual display units (from now on collectively referred to as VDUs).¹⁻³ In the past, subjective visual problems with VDUs have been attributed to poor hardware design, occult refractive error, and extra-ocular muscle imbalance or poor working environment. Although steps have been taken to minimise these problems, one look at a microcomputer peripherals catalogue will show that they have not disappeared.⁴

There have been no scientific reports of detectable visual ill effects from VDU exposure, and it has been said that screening for such ill effects is therefore unnecessary.^{1,5} The effect which we report, although not easy to quantify, is very easy to produce. We have tested eight normal volunteers for this effect. Our aims were: (1) to develop a test-card which would allow subjective detection of the after-effect; (2) to see what proportion of subjects could detect the after-effect; (3) to measure the duration of the after-effect to a standard VDU exposure; (4) to determine if there were any other effects of the green-screen VDU on colour vision.

Materials and methods

Eight normal volunteers were tested, four males and four females, with an age range of 19 to 31 and a mean age of 25. Of the eight subjects tested only one had

Correspondence to David Smerdon, FRCS, North Riding Infirmary, Newport Road, Middlesbrough, Cleveland, TS1 5JE.

any knowledge of the possible after-effects. No concurrent medication was allowed.

A test card was constructed (Fig. 1). This was made from a sheet of black card cut to the same size as the VDU screen. White instant lettering in various sizes (24, 18, 14, 10, and 6 point) was used for the white-on-black text, and a small section of standard type-written text used for the black-on-white. Instant print white lines were used for the gratings (1.5 point) and the fan (2 point). The board was given a coat of matt finish protective sealant. It was examined at 0.75 m under ambient lighting.

The standard exposure to the VDU screen was taken to be reading a word processing file (1164 words on six screen pages) on a 12 inch (30 cm) green high-resolution VDU at a distance of 0.75 m under ambient lighting. Each page was exposed for one minute (extra time was spent rereading), giving a total of six minutes' exposure. The brightness control was set to the minimum usable level (where formatting instructions and other half-intensity characters become barely visible) and its position marked. The screen luminance was 2.2 cd m⁻² as measured with a Gossen Mastersix Lightmeter (contact readings; angle $\Theta=0$). No adjustment to the system was allowed between testing, and in view of this the screen luminance was assumed to remain constant.

The screen pixel resolution was 800×400. The mode used was 80 columns×24 rows. Each 'letter-cell' (one column by one row) was an area 10×16 pixels. An 8×13 pixel central block was available for text construction. The blank border of the letter cell provided for horizontal and vertical letter spacing. Text was made up as in Fig. 2.

Each subject was asked to comment on the test

Fig. 1 The test card.

card before and after VDU exposure, and then hourly thereafter until any visual after-effect had gone. Immediately after VDU exposure, but before the second test card examination, each subject was shown a plain white card. Any immediate after-

image was allowed to fade completely before the second test card examination. The subjects were asked to examine and comment on the test card. A white card was then held over half the card as in Fig. 3, and the subjects again asked for their comments. Direct questions about colour were not allowed. If an after-effect was seen, direct questions were allowed about which parts of the test card were most affected.

The total duration of the effect was recorded.

Our colour vision tests were the Farnsworth-Munsell 100 hue-test and the Tübinger critical flicker frequency (CFF) profile. The latter test was performed at three retinal locations (foveal and 10° to either side) to a 0.1° (approximately 6 mm) green (550 nm) then red (656 nm) target. Background luminance of 10 asb (approximately 3 cd m^{-2}) and prefilter target luminance of 1000 asb (approximately 30 cd m^{-2}) were used. The end point for each reading was taken to be the first detection of flicker when the flicker frequency was reduced from just inside perceived fusion. Plotted graphically, the usual result is a foveal peak for each colour and target size. Both these tests were performed before and within one hour of the test exposure.

Fig. 2 VDU pixel construction

Fig. 3 The test card in use with white card as comparison.

Results

None of the subjects reported any visual problems with the test card prior to VDU exposure. After VDU exposure seven out of eight subjects reported no immediate after-image on the white card. The eighth subject did report an immediate after-image of a purple horizontal bar towards the lower border of the card. This faded completely within one minute.

Five subjects reported an immediate apparent change in the test card. The white lines and lettering appeared coloured. The other three subjects did not appreciate any change until the sheet of white paper was examined for comparison, when the perceived colour change became apparent. Direct questioning about colour change was not required.

The colour seen varied from pink through purple and mauve to 'blueish', but remained constant for

each subject. The test card responses are summarised in Table 1. All subjects saw the white-on-black print and lines as somewhere between pink and blue. Five thought the smallest print was most coloured. Seven observed a shift towards the larger print when the test card was moved further away.

All subjects found the gratings to be coloured. Three reported that the gratings were of equal colour, three that the horizontal and two that the vertical lines were more coloured. The fan produced a similar response, but, in addition seven reported that the oblique lines were least coloured. The white box with the typewriting was seen unchanged by one subject, whereas the others saw the white box surrounded internally by a coloured fringe extending in by 1 or 2 mm. Six of these subjects saw the letters in the white box as if they had been typed on a coloured band.

On repeated testing the effect was found to decrease steadily. The first part of the test card which reverted to normal was the apparent coloured band under the type. The oblique lines on the fan followed, then the fringe round the white box. The gratings faded next, leaving the white-on-black print as the last part of the card to revert to normal.

The duration of the effect lasted from 2 to 11 hours, with an average of 5.5 hours. 100-hue testing revealed no gross change (Table 2).

Table 2 Results of Farnsworth-Munsell 100-hue testing

Subject	Scores	
	Before	After
1	50	28
2	44	12
3	12	24
4	86	38
5	12	8
6	36	53
7	35	20
8	72	83

Table 1 Test card responses immediately after test exposure

Subject	Hue	White text				White box		Gratings		Fan		Duration hours
		1	3	5	CS	Print	Border	V	H	V	H	
1 (F)	Pk	++	++	+++	Y	++	+++	++	+++	++	+++	+
2 (F)	B	+++	++	++	N	+	++	++	++	++	++	+
3 (F)	Pk	++	++	++	Y	+	++	++	+++	++	+++	+
4 (F)	M	++	++	+++	N	+	++	++	++	++	++	+
5 (M)	Pl	+++	+++	+++	N	++	+++	+++	++	+++	++	+
6 (M)	Pl	+++	++	++	Y	0	++	++	+++	++	++	+
7 (M)	Pl	++	++	+++	Y	++	+++	+++	++	++	++	+
8 (M)	Pl	++	++	+++	N	0	0	++	+++	++	+++	++

CS=colour shift towards larger letters when test card moved away. Scores indicate qualitative relative intensity of effect.

V=vertical. H=horizontal. O=oblique.

Pk=pink. B=blue. M=mauve. Pl=purple.

Table 3 Averaged results of critical flicker frequency

Target colour	Degrees from fixation		
	10 nasal	0	10 temporal
Green before	34.0	43.5	34.5
after	43.6	49.9	42.4
Red before	25.2	29.0	24.7
after	33.4	32.8	31.5

Measurement of the critical flicker frequency (CFF) profile to red and green showed a preservation of contour of the CFF profile to green, but a consistent reduction, or loss, of the foveal peak of the CFF profile to red (Table 3). This is plotted graphically in Fig. 4. The averages of the frequencies at the three retinal locations have been plotted for red and green targets before and after VDU exposure.

Discussion

We report two effects. The first was a subjective change in hue of white print and lines on a black background and to a less extent black print on a white background.

This was not a standard coloured after-image,

which is gone within minutes and requires only a white background to observe.⁶ One of our subjects saw a standard after-image after her test exposure. She saw a purple bar inferiorly on the white card. This was produced by the horizontal green bar at the foot of the VDU screen (the status line in the Superwriter word processing program). It was gone within one minute. A standard after-image is produced by fatiguing specific colour sensitive cones. The remaining cones respond normally, producing a relative overaction, hence the coloured after-image.

A related phenomenon occurred on viewing the test card. There were, however, important differences. This effect lasted an average of five hours after only six minutes' exposure and was not seen on plain white paper. The effect required white print on a black background or other white-black interface for its detection. This would suggest that an edge-detecting mechanism was involved.

It would seem that the green-sensitive edge detectors were fatigued. Detectors sensitive to red and blue edges were unaffected and therefore relatively overacted and produced blue-red colours at white-black interfaces. This mechanism took considerably longer to return to normal than cone fatigue and would suggest as different site of processing.

Fig. 4 Critical flicker frequency profiles to red and green targets before and after VDU exposure.

Fig. 5 The McCollough effect test pattern.

Fatigue of colour-coded edge-detectors had been described before⁷ and is known as the McCollough effect, which is produced as follows. A horizontal and then a vertical square-wave grating is viewed alternately for several seconds. The horizontal has a blue and the vertical an orange background. After 10 minutes of this adaptation a subsequently observed test pattern (Fig. 5) looks orange on the right and blue-green on the left. The colours exchange places when the figure is rotated through 90° and is therefore orientation specific. In other words, the effect is an orientation-contingent chromatic after-effect (OCCA). Many studies have since been done on OCCAs which have increased our knowledge about them, but great debate still exists on where and how they are produced.⁷⁻¹⁴

We used computer generated text instead of a grating as a stimulus and believe we have fatigued *all* the green sensitive edge detectors, not just those of a particular orientation. However, given the predominance of vertical and horizontal lines in the make-up of individual letters, it is not surprising that we found the oblique lines on the fan to be least coloured. The test-card included lines much longer than any single line found in the computer text, and yet these were as coloured as the text itself. This would suggest that this mechanism of colour coded edge detection is not line-length specific.

Recent studies into OCCAs have suggested that they may represent a conditioned response.⁹⁻¹³ This view was supported by the finding that, after test exposure, occluding the eyes prevented deterioration of the effect for surprising amounts of time — over 10 days in one study.⁹ It was thought that presenting the test pattern weakened the conditioned response (rather like Pavlov ringing his bell without giving food) and produced decay of the effect. The effect decayed faster the more it was tested.¹¹ One might expect that if the subject was not tested the effect would persist indefinitely. This was found to be true

only if the eyes were occluded, because incidental exposure to the white-black interfaces which exist in our everyday surroundings initiate decay of the effect.¹¹ Other workers have doubted the conditioning theory.¹⁵

One of the characteristics of OCCAs is their long duration when compared with standard after-images. The OCCA-like effect produced by the VDU has a similar longevity. In recent studies the higher the luminance of the stimulus pattern, the greater the saturation of the initial after-effect. Similarly, the longer the test pattern exposure, the longer lasting the OCCA.¹⁶ The experienced observer can detect this effect 24 hours after an exposure of one hour (personal observation). It is possible that this after-effect is responsible for some of the subjective complaints of VDU operators, who may have this effect for prolonged periods of time. It may go unnoticed by the VDU operator for prolonged periods, as it produces only a subtle change in the observers surroundings. This may lead to visual symptoms (personal observations). With this in mind a VDU which does not produce this effect would seem preferable. The effect is not unique to the VDU, in that a colour transparency of the VDU screen with similar luminance, produces a very similar response.

We confirmed previous findings that colour vision is not affected by green-screen VDUs in that there was no significant change in the Farnsworth-Munsell 100-hue test. However, we did find a tendency towards reduction or loss of the foveal peak of the CFF profile to red. CFF is a reflection of the refractory period of the retinal neurones under study; the longer the refractory period, the lower the CFF. The expected result when the colour CFF is tested at fixation and 10° to either side is a foveal peak (except with blue light, when such a peak is difficult to detect owing to the relative scarcity of foveal blue cones). We expected there to be no change or, if the test was

performed soon enough after the VDU exposure, a reduction in the foveal peak of the green CFF profile consistent with the expected changes in a standard after-image. The reason for the reduction in the foveal peak of the red CFF profile is unknown and merits further study.

We thank Mr Ivan Bradley, senior medical photographer at the Birmingham and Midland Eye Hospital, and the staff of the Department of Medical Photography, East Birmingham Hospital for the illustrations.

References

- 1 Lee WR. Working with visual display units. *Br Med J* 1985; **291**: 989–91.
- 2 Health and safety executive. London. *Visual display units*. London: HMSO, 1983.
- 3 Bruton DM. Medical aspects of cathode ray tube display systems. *Trans Soc Occupational Med* 1972; **22**: 56–7.
- 4 Anonymous. *Inmac computer users ideas book*. November 1985: 20, 43, 46, 47, 110.
- 5 Harrison MR. Visual display units. *Aust J Ophthalmol* 1983; **11**: 1, 39–41.
- 6 Daw NW. Colour vision. In: Moses RA, ed. *Adler's physiology of the eye – clinical application*. St Louis: Mosby, 1981: 545–61.
- 7 McCollough C. Color adaptation of edge-detectors in the human visual system. *Science* 1965; **149**: 1115–6.
- 8 Murch GM. Retinal area specificity in the McCollough effect. *Am J Psychol* 1974; **87**: 189–95.
- 9 Jones PD, Holdin DH. Extremely long-term persistence of the McCollough effect. *J Exp Psychol (Hum Percept)* 1975; **1**: 323–7.
- 10 Montalvo FS. A neural network model of the McCollough effect. *Biol Cybern* 1976; **25**: 49–56.
- 11 Holding DH, Jones PD. Delayed one-trial extinction of the McCollough effect. *Q J Exp Psychol* 1976; **28**: 683–7.
- 12 Shute CC. Influence of centrally active drugs on the McCollough effect. *J Physiol (Lond)* 1978; **278**: 47P.
- 13 Murch GM. The role of test pattern background hue in the McCollough effect. *Vision Res* 1979; **19**: 939–42.
- 14 Lund NJ, MacKay DM. Sleep and the McCollough effect. *Vision Res* 1983; **23**: 903–6.
- 15 Skowbo D, Forster T. Further evidence against the classical conditioning model of McCollough effects. *Percept Psychophys* 1983; **34**: 552–4.
- 16 White KD. Luminance as a parameter in establishment and testing of the McCollough effect. *Vision Res* 1976; **16**: 297–302.

Accepted for publication 20 August 1987.