INSIDIOUS OCULAR EFFECTS OF LASER RADIATION

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Most safety codes for lasers emitting in the wavelength band 400-1400 nm are based on threshold studies for a single event thermal lesion, where ocular damage is related to wavelength, retinal image size, pulse duration and energy density. Current codes of practice are derived from a 50% damage probability for different laser systems producing diffraction limited image sizes.

Noell in 1965 (1) discovered that the rat retina could be damaged by exposure to moderate light sources. Marshall (2) showed that pigeons exposed to moderate white light luminances suffered cone loss; he continued his work with fish (3) where he was able to selectively damage specific cones responding to one primary colour, by illuminating the aquarium with monochromatic light. Harwerth & Sperling (4) in their behavioural studies produced temporary and permanent colour blindness in monkeys following exposure to intense spectral sources. Ham (5) in his studies showed that retinal damage thresholds decreased for short wavelengths. Zwick (6) exposed 2 monkeys to very low luminances of argon laser irradiation on a hemisphere and was able to show that photopic visual function was substantially depressed and that recovery was minimal over a 12 month period.

Concern is now felt that current codes of practice may be inadequate to protect individuals exposed, for long periods, to subthreshold levels of laser irradiation, particularly so with lasers emitting at the blue end of the spectrum.

Many workers involved in activities such as research, holography, data processing and laser light shows are exposed over long periods to subthreshold laser irradiation. This has caused us to investigate visual function in one such group of workers who have been exposed to argon laser irradiation over a 2-year period in the development of a laser scan visual flight simulator.

MATERIALS AND METHODS

The laser scan, at present, employs two argon lasers of 5 watts nominal output working multimode. The laser camera illuminates a terrain model Fig I and is normally operated at 500 milliwatts. The information from the model modulates a laser projector which has operated for 90% of the time at 1 watt output and for remaining 10% of the time at 4 watts output. The display is presented on a hemisphere, the luminance of which has varied between 3.5-7.0 cd/m^2. The field of view to the observer is 180^o in the horizontal and 60^o in the vertical. The resolution of the display is 5,280 television lines and the colour is blue-green. Production systems will be in full colour, this will be achieved by separately modulating the blue and green lines of the argon laser and by adding red from a krypton laser.

Eight workers have been monitored and their exposure times for viewing the display and for being in the vicinity of the lasers are given in Table I.

As evidence from the literature suggests that cones are primarily at risk, the measures of visual performance have mainly concentrated on photopic function. The tests were:-

1. Clinical eye examination.
2. Liminal brightness increment for white and blue light at photopic and scotopic luminances.
3. Colour vision testing with Farnsworth-Munsell 100-Hue Test. Illumination of 10 Lux.
4. Perimetric field of view measurements for 2 mm white and blue stimuli.
5. Macula thresholds for white and blue light stimuli.
6. Central visual fields for white and blue light stimuli
7. Dark adaptation curves for white and blue light stimuli, following light adaptation.

The tests 5, 6 & 7 were made on a calibrated Friedmann Visual Field analyser. The unattenuated luminances of the white and blue light sources were 3.0 and 0.1 photopic nit seconds respectively. The blue filter used in these tests was an Ilford 623, a spectrophotometric trace of which is shown in Fig 2.

TABLE I. Estimated exposure times, of workers exposed to argon laser light.

SUBJECT	AGE	HOURS LOOKING AT HEMISPHERE DISPLAY	HOURS WORKING IN LASER ENVIRONMENT
A	47	0	0
B	44	2	100
C	40	3	1
D	32	3	0
E	45	1	1
F	25	300	120
G	40	150	10
H	32	20	100

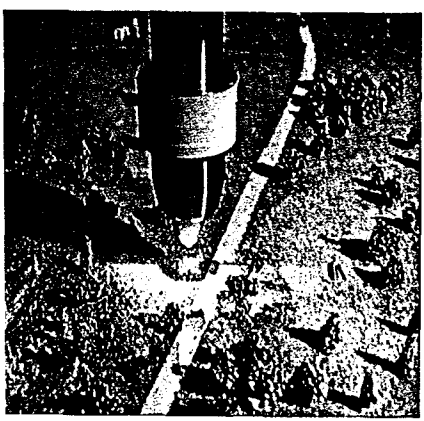

Fig I. View of laser camera and terrain model.

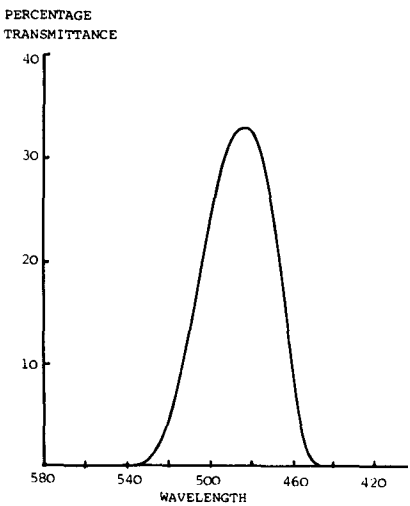

Fig 2. Spectrophotometric trace of Ilford 623 filter.

RESULTS

The clinical examination included an ocular history, tests of pupillary function, visual acuity estimates on a Snellen chart under white and blue illumination with a refraction where necessary, macula function tests using an Amsler grid, a fundoscopic examination and an examination of the anterior segment of the eye with a slit lamp. These tests did not reveal any pathology which could be attributed to work in a laser environment. The expected addition of a -0.50 sphere was necessary to restore visual acuity under blue illumination.

Colour vision testing with the Ishihara pseudo-isochromatic plates did not show any deficiencies. Colour vision testing with the Farnsworth-Munsell 100-Hue test under low illumination did reveal some error scores, particularly in the blue-green and purple hue regions.

TABLE 2. Farnsworth-Munsell 100-Hue test

SUB-JECT	HUE ERROR SCORES				TOTAL ERROR SCORES
	610-570 nm	570-500 nm	500-470 nm	470-630 nm	
	RED-YELLOW	YELLOW-GREEN	GREEN-PURPLE BLUE	PURPLE BLUE-PURPLE RED	
A	4	8	4	0	16
B	0	4	12	0	16
C	4	15	32	8	59
D	4	0	16	4	24
E	4	8	24	20	56
F	0	0	0	0	0
G	0	4	4	0	8
H	0	8	4	4	16

Perimetric assay did not show any loss of peripheral field for white or blue stimuli.

The log densities for the white and the blue macula thresholds are the maximum densities at which no error was made for ten consecutive stimuli. The log densities for the central fields are the maximum densities at which the central field was full for the white and the blue stimuli.

TABLE 3. Central fields and macula thresholds.

SUB-JECT	AGE	NORMAL LOG DENSITY FOR AGE (WHITE)	LOG DENSITY FOR FULL FIELD				MACULA THRESHOLDS. LOG DENSITIES.			
			WHITE		BLUE		WHITE		BLUE	
			Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
A	47	1.8	1.8	1.8	1.2	1.2	2.0	2.2	1.0	1.2
B	44	1.8	1.8	1.8	1.0	1.2	2.2	2.2	1.0	1.0
C	40	2.0	2.0	2.0	0.8	1.0	2.4	2.4	0.8	0.8
D	32	2.0	2.0	1.8	1.0	1.0	2.6	2.4	1.2	1.2
E	45	1.8	1.8	1.8	1.0	0.8	2.6	2.4	1.0	1.0
F	25	2.0	2.0	2.0	1.2	1.2	2.4	2.4	1.2	1.2
G	40	2.0	2.0	2.0	1.2	1.2	2.4	2.4	0.8	0.8
H	32	2.0	2.0	2.0	1.0	1.0	2.8	2.8	1.2	1.0

The results of the liminal brightness increment measures showed the expected increase in contrast threshold $(\frac{\Delta I_s}{I})$ at the scotopic luminances for both white and blue light.

TABLE 4. Liminal brightness increment

BACKGROUND LUMINANCE cd/m^2		$\Delta I+I$ cd/m^2 mean	I cd/m^2 mean	$\Delta I/I\%$ RANGE	MEAN
3.2×10^{-3}	BLUE	3.46	3.18	2.8-14.0	8.76
SCOTOPIC	WHITE	3.49	3.19	3.7-14.0	9.49
5.0×10^{-2}	BLUE	5.15	4.96	2.0-7.6	3.92
PHOTOPIC	WHITE	5.17	5.00	1.2-5.6	3.42

Dark adaptation curves after white light adaptation did not show any significant departures from normal for white and blue stimuli. The scotopic portion of the curve was not continued beyond 20 minutes.

DISCUSSION

This is a preliminary survey into the visual function of workers exposed to long term argon laser irradiation and as yet it has not been possible to demonstrate any visual decrement which could be, directly, attributed to work with lasers. Paradoxically the workers with the longest exposure times performed as well or better than those with minimal exposure. The decrements found were those which would be expected in any random group of varying age. The survey is limited, it involves eight workers of whom only half have been exposed for a significant period. It is intended to repeat the tests of visual performance at six monthly intervals as exposure times increase.

It will be understood that by the nature of the work exposure times are approximate, particularly with the variable exposure incurred when working in the laser environment. The exposure time for looking at the hemisphere display is more precise, as is the luminance. Should visual decrements develop it would be valuable to correlate these with display times over the six monthly intervals.

The dosimetry of laser exposure in man can never be as precise as that in experimental animals. It is considered, however, that the subtle changes in vision which may occur with long term low level laser irradiation may only be detected in man.

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