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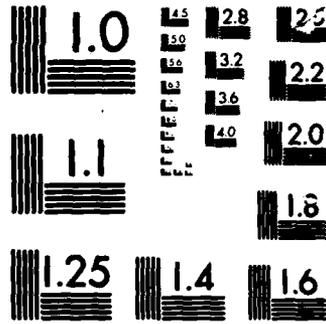
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OCULAR HAZARDS ASSOCIATED WITH LASER EXPOSURE

HARRY ZWICK, PhD
and
JOAN ALLEN, BS

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Ocular Hazards Associated with Laser Exposure--Zwick and Allen

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Human Subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 50-25 on the use of volunteers in research.

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ABSTRACT

In our experiments we have investigated the effects of low-level laser exposure on spatial vision measured in animal subjects. In monkeys trained to report minimal visual resolution as well as contrast thresholds for varying size targets (contrast sensitivity) we found that small spot (50 micron) exposure can significantly alter these measures of spatial vision. Such effects have both medical and tactical implications. Because such levels of exposure may produce prolonged change in spatial visual function even at levels below the maximum permissible exposure (MPE) level, the military medical community is faced with a dilemma that repeated exposure could result in considerable tissue destruction in non-regenerating neural retinal tissue long before any significant change in visual function is measurable. Long-term measurements of animal spatial vision has revealed subtle but significant evidence of visual function loss that is associated with low-level laser exposure to the fovea. Such effects may cause sufficient alterations to spatial vision to produce momentary distractions in complex military performance, such as target tracking. These potential hazards to human vision and visual performance have motivated development of human visual protective materials to counter low-level, multi-spectral laser exposure, as well as the development of new troop training strategies that should provide countermeasures through improved training scenarios. Recovery

1.0 INTRODUCTION

In recent years, the potential combat threat from directed energy sources has caused increasing concern. Laser range finders, laser designators, and potential laser weapons all pose unique hazards to the human eye. Because of the highly collimated nature of laser light, the earliest medical concerns regarding such sources involved the possible production of very small lesions in the retina. Because military visual tasks require an intact central fovea (the retinal area responsible for fine spatial resolution and color vision) and because laser lesions might destroy these visual functions, damage to the central fovea has received considerable attention. Furthermore, since these laser devices have ultrashort pulse characteristics combined with a broad range of output wavelengths in the visible and near-infrared spectrum, they pose a unique hazard to the human visual system. Laser light characteristics, such as narrow spectral bandwidth and beam coherence, represent aspects of laser sources that have received limited attention, although they may be potentiating factors in low-level retinal damage processes.

We will review the significant research in the area of acute laser exposure, limitations of this data base, and the implications such data have for military performance and medical diagnosis of laser combat ocular injury.

2.0 ANIMAL INVESTIGATIONS

In order to evaluate alteration in visual function from acute laser exposure, extensive use has been made of animal behavioral techniques. Such investigations have made a significant contribution to our present knowledge of visual deficits induced by acute laser exposure. They form a bridge between observations obtained from human accident cases and the exact dosimetry and manipulation available under laboratory conditions. Furthermore, such investigations have supported development of an increasing understanding of retinal damage mechanisms associated with light exposure.

A summary of non-human primate acute foveal exposure effects on spatial vision is presented in Table 1. These investigations involve the gross effects on visual acuity from large foveal lesions as well as more subtle effects from lower level exposure conditions. Each investigation has been ranked with regard to its effect using a human retinal injury evaluation criteria developed by Wolfe (1).

The earliest animal investigations utilized single pulse Q-switched laser sources in anesthetized animals to irradiate the fovea accurately (2-6). Visual acuity, the ability of the visual system to

TABLE
 CHANGES IN RHESUS SPATIAL VISION AND VISUAL PERFORMANCE INDUCED BY INTENSE LASER EXPOSURE

Authors	Foveal Exposure Level	Foveal Spot Size (u)	Foveal Damage	Recovery Time	Visual Decrement Wolfe Grade(1)*
Yarkozow et al (1966)	Ruby	> 500	Total	None obtained	IB-IIIB+
694, 20 nsec	Photo-coagulator		1000 micron	in post period	
Waiskrantz, Cowey (1967)	Xenon	> 500	0.5 to 3	None given	IB-IIIB
Xenon, long pulse	Photo-coagulator		lesion fovea	24 hr	
			optic disc		
			diameters		
Graham et al (1969)	2.34 J/cm ²	950	Partial	None over 36	IB-IIIB
694 nm			300	days post	
200 nsec			microns		
Farrer*	1.0 mJ	<100	Lesioned	Not available	IIIB
1.06			area partial		
20 nsec			1000		

Table (continued)
 CHANGES IN RHETUS SPATIAL VISION AND VISUAL PERFORMANCE INDUCED BY INTENSE LASER EXPOSURE

Authors	Foveal Exposure Level	Foveal Spot Size (u)	Foveal Damage	Recovery Time	Visual Decrement Wolfe Grade(1)*
Zwick et al (1974)	1.1 mJ	1000	Central	Scotopic 2 wk	IIB
634 nm			300	photopic 6 mo	
20 nsec				to 3 yr	
Meridan et al (1981)	Argon laser	1000	300 foveal	Not given	IIB
514 nm	Photo-coagulator		center		
ZW (laser head)	2W (laser head)				
50 msec					
Robbins et al (1973, 1980)	1-10 mW	50-350	Not observed	Temporary in	0-1 Transient
633, 647, 514 nm	(corneal power)		time of exposure	20 min	
100 msec					
	11 mW				IIB Permanent



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Table (continued)
 CHANGES IN RHESUS SPATIAL VISION AND VISUAL PERFORMANCE INDUCED BY INTENSE LASER EXPOSURE

Authors	Foveal Exposure Level	Foveal Spot Size (μ)	Foveal Damage	Recovery Time	Visual Decrement Wolfe Grade(1)*
Zwick et al (1983)	0.5 J-3.5 J	20-50	Punctate	Full recovery	Pre IB Transient
532 nm	TIE		lesions	12-16 min	
20 nsec					
Callin et al (1981)	0.55 J-3.5J	20-50	...	1-3 sec	0 (No effects to transient effects reported)
513 nm	TIE				
white					
(480, 508, 595 nm)					

Table (concluded)

*Wolfe's Grades of Injury and Visual Acuity Following Laser Retinal Injury. Wolfe subgraded each of the grades. The ophthalmoscopic findings for each grade/range of visual acuity in the early phase of injury for subgrades A (extrafoveal lesion) and B (foveal lesion) are defined as follows:

I = retinal edema; A, 20/15; B, 20/30 to 20/200;

II = retinal necrosis; A, 20/14 to 20/40; B, 20/40 to 20/400;

III = subretinal and/or intraretinal hemorrhage; A, 20/15 to 20/50; B, 20/100 to 20/400;

IV = vitreous hemorrhage and/or full-thickness retinal hole; A, 20/15 to finger counting or worse; B, 20/100 to finger counting or worse.

+Measurements not made beyond 24 hr; full recovery time unknown.

#Personal communication, 1982, DN Farrer, PhD, USAFSAM.

...No evidence that foveal exposures were made.

resolve minimal size targets, generally required several months for stabilization of the effects of acute light exposure on spatial visual function. In some studies, measurement of chromatic visual function, spectral sensitivity for foveal and parafoveal retinal areas, was employed (2,7). These investigations demonstrated that the effects of foveal damage measured with spectral backgrounds showed longer-lasting effects relative to that measured with acuity targets having white-light backgrounds. These findings suggest that mechanisms involving color as well as spatial vision need to be assessed in the measurement of potential laser retinal injury.

The gross mechanisms of such injury may involve initial peripheral edema and swelling of retinal photoreceptors in the first two to three weeks after exposure (8). Such disturbances appear to have a generalized effect, altering both photopic and scotopic visual function (2). With time, retinal phagocytic processes remove debris and may allow adjacent photoreceptors to fill the area of the fovea that once contained damaged foveal receptors (8). In this manner, the ability to resolve fine detail may be preserved, although foveal chromatic sensitivity may be permanently altered.

A major limitation of these early investigations involved the use of anesthetized animals, because testing after exposure in such animals must be postponed at least 24 to 48 hr to allow for stabilization of behavior after anesthesia. Techniques to allow more immediate assessment of visual function loss beginning within the first 10 to 30 seconds after exposure were developed by studies with awake animals and exposures made under task-oriented conditions (7,9,10). Using such techniques for shuttered visible laser sources, single pulse 100-msec duration exposures produced transient changes in visual acuity well below levels that could produce gross injury to the retina. Comparable effects were found for spot sizes from 50 to 350 microns. Such effects could easily last from 2 to 20 min and longer as the transition zone from a temporary to a permanent effect was achieved. Such transition zones varied with spot size. For large spots, 350 microns in diameter, single 100-msec pulses of either Argon (514.5nm or Krypton 647.1nm) could produce permanent losses in acuity at levels approximately 10 times below the threshold level for retinal burn. For small spots, 50 microns in diameter, single 100 msec exposures produced a transition zone much closer to the threshold retinal burn level (9,10).

More recent investigations (11) have utilized repetitively pulsed frequency doubled neodymium laser sources. As in previous experiments, small-spot foveal exposures were made by making the beam coaxial with the gap in the a landolt ring acuity target subtending about 1 min of arc. Foveal lesions produced in this manner were observed centered on the fovea. Immediate effects within the first 30 to 60 seconds of exposure were obtained. At energy levels capable of producing small foveal punctate lesions, recovery times of 15 to 20 minute were

measurable. Paradoxically permanent changes were delayed in these studies. Even though initial exposures destroyed the integrity of the fovea, the visual acuity measurements were not permanently depressed. Only after multiple exposures was evidence of permanent change obtained. Furthermore, such change could only be measured when contrast sensitivity was used, because this visual task allows the measurement of visual sensitivity for both small and large acuity targets (12).

3.0 ACUTE HUMAN EXPOSURE

The data base for human acute laser exposure is much more limited than that available with animal subjects. The nature of visual function assessment is almost exclusively limited to high contrast clinical acuity and rarely have such measurements been made at the time or shortly after the time of exposure (1,13). While such data may lack the quantitative sensitivity of animal studies, occasionally they provide insights into such effects that have been unobtainable with the more quantitative data base. In one such accident (14), involving suprathreshold hemorrhagic exposure to a Q-switched Ruby laser range finder, the accident victim was exposed peripheral to the macular so that visual acuity for high contrast target clinical measurement returned rather rapidly after exposure. However, because the injury caused secondary mechanical traction effects within the retina, a "wrinkling" or "puckering" of the macula was produced, resulting in a secondary delayed loss in visual acuity, which only became apparent 6 to 12 months after exposure.

The necessity to obtain more quantitative human data has led to the development of various simulation techniques (15). In such experiments, where contrast sensitivity has been measured, artificial scotomas optically stabilized on the retina have been produced that depend on field size (16). For large fields, losses in contrast sensitivity are restricted to small targets; for small fields such losses are relatively independent of target size. Such results are consistent with immediate changes in contrast sensitivity observed in animal experiments (11,12), where small-field sizes were used. Such effects on contrast sensitivity also have been verified in human patients with foveal macular holes (17). These natural scotomas produce only small target losses in contrast sensitivity for large field measurements but generalized loss in contrast sensitivity for small field loss.

4.0 LOW-LEVEL LIGHT MECHANISMS OF DAMAGE AND VISUAL FUNCTION ALTERATION

Numerous investigations (18-24) suggest that low-level light exposure can alter retinal morphology and visual function. Photocoagulation of retinal tissue need not be produced for light especially in the short and near ultraviolet regions to produce

retinal damage to tissue and permanent change in visual function. Such light effects in the retina require no more than a 1 degree change in retinal temperature and in many cases much less than this amount. Such studies have demonstrated that low-level light exposure at levels well below that required for retinal photocoagulation can cause changes in retinal morphology, receptor cell structure, and visual function. Explanations of such phenomena are presently divided into two conceptual camps. One suggests a photochemical damage mechanism that is selective to one class of photoreceptors (19,21) while the other suggests a photochemical damage mechanism that is effective across photoreceptor systems (20,22).

Several such investigations (23-25) have also suggested the greater effectiveness of coherent light as compared to incoherent or time averaged laser light in inducing low-level effects from repeated light exposure. Such effects have been postulated to produce their effect through over stimulation of the neural layers of the retina. Recent experiments in our laboratory demonstrate that continuous low-level visible laser exposure for small spot laser exposure conditions, as low as a thousand times below the MPE, can produce significant suppression of visual acuity or contrast sensitivity for both large and small targets. Physiological investigations utilizing minimal spot continuous foveal exposure support retinal mechanism involvement in such effects (26).

5.0 VISUAL FUNCTION VERSUS VISUAL PERFORMANCE

In this paper, we have described the effects of acute and low-level laser exposure on visual function. But alteration in visual function is not the single determining factor in a complex perceptual motor task such as visual tracking. Alteration in a complex visual performance may depend upon motivational, motor, memory or training, and other sensory input from the visual system itself. We have schematized the relationships between laser exposure and visual function and performance loss in Figure 1. It is apparent that ocular or visual function loss simply involves the effect of light on the visual system whereas visual performance decrement involves a complex change in factors in addition to visual sensory input. Obviously performance loss will occur for those tasks having high dependence on visual input, such as visual tracking (27,28) with less effect on tasks that have more modest visual function requirements (29).

6.0 IMPLICATIONS

The possibility that subthreshold burn levels may produce permanent loss or change in visual function or even visual performance at levels much lower than the MPE has significant implications for development of laser ocular protection systems in the military. At present limited attention is given to protecting human

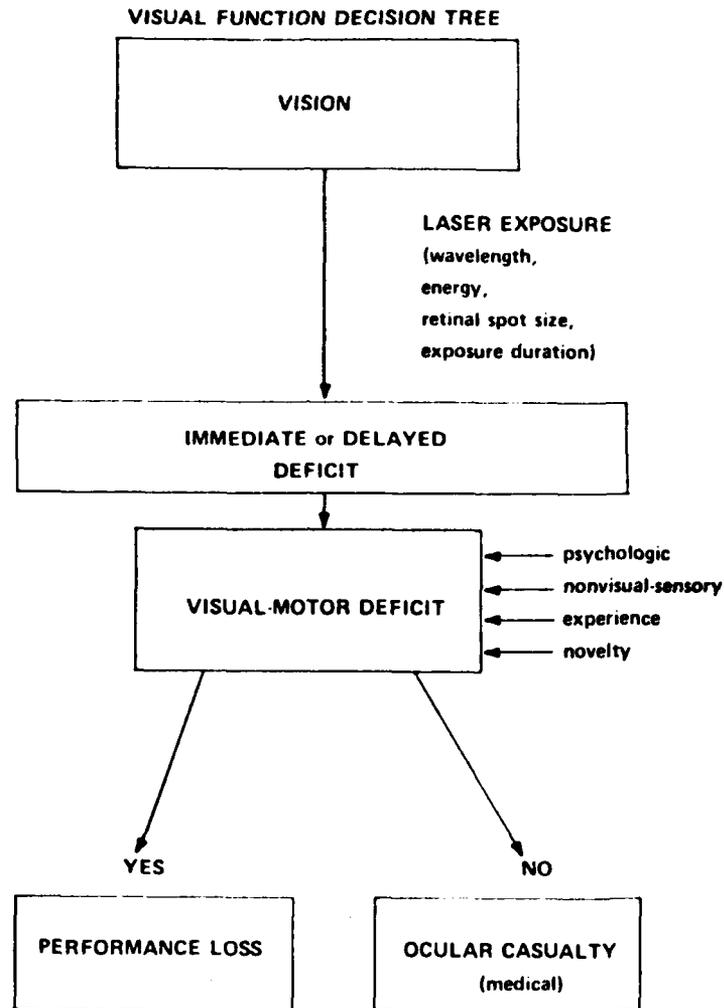


Figure 1: This diagram, notes the potential effects of laser exposure on vision and visual performance. Field laser exposure may result in two distinct types of visual loss. Primary loss of vision may occur as a direct consequence of retinal tissue damage via thermal or non-thermal photic damage mechanisms. This loss may be immediate or delayed. Such loss may result in a change in visual perception such as a loss in brightness, contrast, or color perception. Such losses in vision may or may not affect one's military job performance.

eyes from exposure levels below the Maximum Permissible Level. Good reasons exist for such limited concern. Materials development has not succeeded in formulating multiwavelength protection which does not seriously alter visual function. Requiring protection to the MPE and below is presently a near unobtainable task with conventional filter technology. Even fast switch technology can not operate both in the visible and at low-activation levels. An educated awareness that such effects can occur, the training of troops under simulated visual conditions following laser exposure (30), and development of visual function test methods and devices for clinical detection of such effects (12,23) may represent the only long range solution to this problem.

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