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THE EFFECT OF THREE LEVELS OF LASER GLARE ON THE SPEED AND ACCURACY OF TARGET LOCATION PERFORMANCE WHEN VIEWING A BRIEFLY PRESENTED VISUAL ARRAY

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The effect of three levels of low-intensity laser glare on the visual search performance of student aviators was investigated. Subjects were exposed to laser glare while seated in a cockpit simulation trainer with attached F/15 windscreen assembly. The experimental task was designed to maximize visual attentional demands to a degree that might be expected in normal flight. Thus, speed and accuracy of performance were monitored while subjects located targets in a complex, briefly presented (about 1 s), visual array under simulated dusk conditions. Low-level argon laser-induced glare (a factor 3700 times below the ANSI maximum permissable exposure for a 902-ms laser presentation) caused significant decrements in visual search performance for briefly displayed visual information. Subjects indentified significantly fewer targets when experiencing low-intensity laser glare relative to a no-glare control. In addition, the speed with which correctly identified targets were located was significantly reduced relative to a no-glare control. As incident laser glare increased, significant decrements in the speed and accuracy of target location responses were observed at target eccentricities up to 8.1° from the center of the beam path.

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SUMMARY PAGE

THE PROBLEM

Lasers are now a common element in the tactical military environment. Many factors serve to increase the probability that laser-induced glare will be the most frequent source of laser-evoked visual disruption encountered by naval aviators. The present study examined the effects of low-intensity laser glare, far below a level that would cause ocular damage or flashblindness, on the visually guided performance of aviators. One aspect of visually guided performance was investigated; the speed and accuracy of locating stationary targets in a briefly presented complex visual scene.

FINDINGS

This study supports the conclusion that low-level argon laser-induced glare (3700 times below the MPE for a 902-ms exposure), when viewed through an aircraft windscreen, causes significant decrements in visual search performance for briefly displayed visual information. Subjects identified significantly fewer targets in a complex visual array when experiencing low-intensity laser-induced glare relative to a no-glare control. In addition, the speed with which correctly identified targets were located was significantly reduced relative to a no-glare control. These results were most pronounced for targets close to the center of the beam path. Furthermore, as incident laser glare (irradiance) increased, significant decrements in the speed and accuracy of target identification were observed at target eccentricities farther and farther away from the center of the beam path.

RECOMMENDATIONS

Low-intensity laser glare produced decrements in visually guided performance in a task designed to maximize the visual attentional demands placed on subjects. Eye protection is needed to prevent mission disruption even at laser intensities that are not harmful to the eye.

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INTRODUCTION

Lasers have become a common element in the tactical military environment (1). At a minimum, naval aircrews currently risk exposure to laser illumination from ground, ship, and air-based rangefinders and target designators (1,2). Furthermore, the use of lasers to simulate "live fire" during military training exercise and as offensive weapons (2) poses additional threats to military aviator because of the potential to disrupt visually guided performance. We investigated one aspect of visually guided performance, locating stationary targets in a briefly presented complex visual scene, while subjects were exposed to several intensities of visible laser light.

The disruption of visual performance due to ocular exposure to laser illumination can be placed into three general categories (2, pp. 9-10). These categories are graded with respect to the source of visual disruption: a) glare, b) flashblindness and afterimage, and c) corneal and retinal damage. The time-course and nature of the associated visual disturbance varies for each category. The latter two categories are set apart from the former (glare) in that their disruptive effects remain after laser stimulation ceases. Furthermore, the temporary but lingering effects of flashblindness, as well as the permanently damaging effects of corneal and retinal burns, depend on a rather well-focused, sufficiently powerful, and coherent light source striking the eye(s). Many factors serve to attenuate laser power, thus modulating or eliminating the threat of permanent or lingering laser-induced visual deficits: atmospheric propagation, laser-beam divergence, wavelength and pulse duration of the laser source, distance of the eye(s) from the light source, incidence of a direct or reflected beam on the eye(s), duration of exposure, reflecting properties of aircraft windscreens, and protective eye wear. These factors may serve to increase the probability that laser-induced glare, the effects of which last as long as the light source is present in the visual field, will be the most frequent source of laser-evoked visual disruption encountered by naval aviators.

A recent investigation of laser glare (3) showed that incident powers of laser illumination well below thresholds that produce ocular damage cause predictable decrements in visual search performance. The investigation allowed subjects 20 s to locate target disks in a complex visual array under several conditions of laser-produced glare. Results showed that incident laser illumination as low as 0.9 $\mu W/cm^2$ produced significant decrements in visual search performance. The present study investigated the effect of three levels of low-intensity laser glare on the visual search performance of student aviators. The research method was designed to a) extend the work of D'Andrea and Knepton (3) and b) enhance the generalizability of research findings in this area of investigation. Specifically, subjects participated in the study while seated in a cockpit simulation trainer with attached windscreen assembly. Furthermore, the experimental task was designed to maximize the visual attentional demands placed upon the subject to a degree that might be expected in normal flight. Subjects were required to locate targets in a complex, briefly presented (about 1 s) visual array. The effects of laser glare were maximized by conducting the study under low ambient light (nighttime/dusk) conditions.

MATERIALS AND METHODS

SUBJECTS

Eight male student naval aviator volunteers served as subjects. The age of subjects ranged from 23 to 27 years (*M* = 24.13; *SEM* = 0.51). Near binocular Snellen acuity, measured with an Armed Forces Vision Tester (model FSN 7610-721-9390, Braun-Brumfield, Inc., Ann Arbor, MI) of all subjects was at least 20/17 (range, 20/17-20/15). Distant binocular acuity, measured with an Multivision Contrast Tester (model MCT-800, Vistech Consultants, Inc., Dayton, OH) was 20/15 for all subjects. Because lens opacity (the clarity of an eye's lens) may cause decrements in visual performance independent of visual acuity (4), the clarity of the lens in both eyes of each subject was assessed before their participation in the study using an Opacity Lensmeter (model 701: Interzeag AG; Schlieren, Switzerland). No subject showed signs of pathological opacity of the lens. Furthermore, as a group, subjects had very similar lens opacity scores (right eye, *M* = 8.15, *SEM* = 0.78; left eye, *M* = 8.00, *SEM* = 0.62).

EQUIPMENT

Cockpit Simulator

Subjects participated while seated in a cockpit-familiarization trainer fitted with an F/15 aircraft windscreen assembly. The trainer was located in a separate room, isolated from the laser. Subjects were visually monitored using a low-light sensitive closed-circuit television camera (model 6415-2000/0000, Cohu Electronics Division, San Diego, CA). An automated intercom system located near the cockpit allowed the experimenter to maintain voice contact with the subject at all times.

Laser

A collimated beam of visible light with a peak spectral radiance of 514 nm was generated by an argon ion laser (Innova 70-2, Coherent Laser Products Division, Palo Alto, CA) and conducted by fiber-optic cable to the center of a visual display in an adjacent room. Peak spectral radiance of the beam was verified at 514 nm using a Spot Spectrascan-Fast Spectral Scanning System (Model PR-710, Photo Research, Burbank, CA).

The laser was operated at full power output of nearly 2 W. Laser-beam intensity was limited by a 1.99-mm aperture within the laser's protective housing as well as by passive (e.g., iris diaphragm, prisms, neutral density filters) electromechanical (e.g., electronic shutter), and electro-optical (i.e., electro-optical attenuator) devices external to the laser. Figure 1 shows a schematic representation of the laser beam path through these power limiting devices. The attenuated beam was focused on the polished end of an optical grade fiber-optic cable by a fiber-light coupler (model 714/965-5406, Newport Corp., Fountain Valley, CA). The fiber-optic cable (0.22-mm od) consisted of a single-strand core of acrylic polymer (1-mm diam.) with a fluorine-polymer sheath. The distal end of the fiber-optic cable was inserted through a hole in the center of a rear projection screen and projected a 28.1° cone of laser light toward the cockpit.

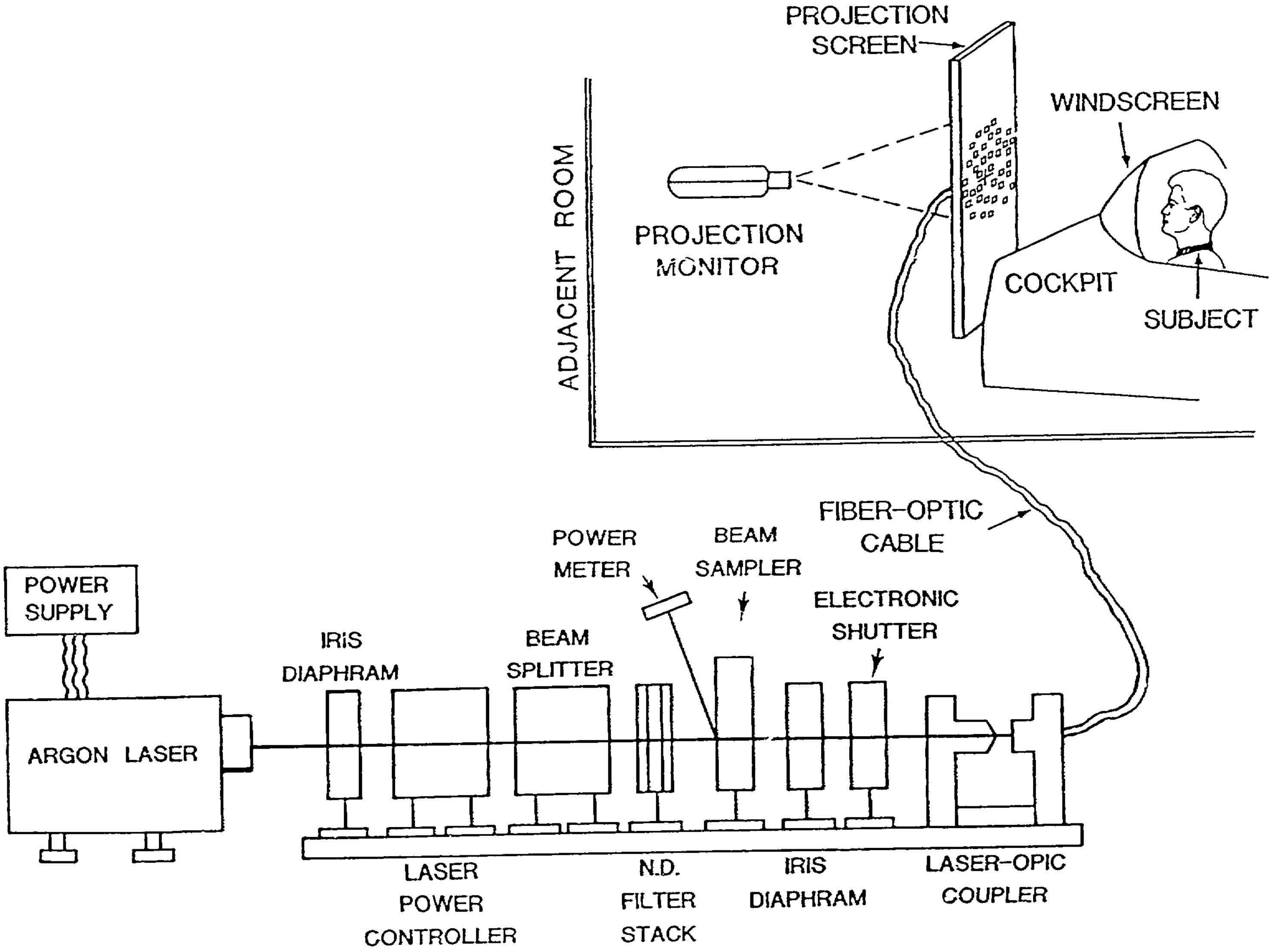

Figure 1. *Schematic representation of the laser beam path.*

Laser irradiance levels. Subjects were exposed to three levels of laser irradiance (0.1, 0.3, and 0.5 μW/cm²) for a maximum of 108.48 s in one 24-h period. Laser irradiance levels were established by placing a radiometer (model 161 with radiometric filter, United Detector Technology, Hawthorne, CA) in the horizontal plane of vision at the subject viewing distance of 182 cm with a) the cockpit windscreen removed and b) the laser providing the only source of illumination. A Laser Power Controller (model VIS, Cambridge Research & Instrumentation, Inc., Cambridge, MA) was used to attenuate the laser beam to achieve and maintain each of the three irradiance levels at the subject viewing distance of 182 cm. The percentage of laser light transmitted through the laser power controller (LPC) necessary to achieve each irradiance level under these conditions was later used to 'software select' and maintain (approx. 0.05-0.02% drift) a desired subject-exposure level. Table 1 shows that the addition of the F/15 windscreen to the cockpit familiarization trainer reduced the radiant power incident on the subject.

TABLE 1. Mean (*SEM*) Laser Irradiance Exposure (μW/cm²) Levels at a Subject Viewing Distance of 182 cm (Argon laser providing the only source of illumination).[a]

	Windscreen			
Requested irradiance level	Off		On	
0.1	0.11	0.003	0.09	0.003
0.3	0.32	0.003	0.24	0.003
0.5	0.50	0.008	0.37	0.006

[a]Each mean is based on five observations.

Laser Safety. Each subject-exposure level was correlated with a laser irradiance reading taken at two fixed locations that were monitored while the subject was seated in the cockpit. One reading was taken at a location in the cockpit near the subject's right shoulder using a radiometer (model 161 with radiometric filter, United Detector Technology, Hawthorne, CA). The second reading, a partial reflection of the laser beam, was measured with a laser power meter (model 45PM, Linconix, Sunnydale, CA) before it entered the fiber-optic cable. Fluctuations in either reading, as well as that of the LPC, would indicate that the power incident on the subject was not at the prescribed level. The laser operator was instructed to terminate the experiment if such an observation was made. A laser-defeat switch in the cockpit allowed the subject to terminate laser exposure at anytime during the experiment. In addition to the laser, subjects experienced additional illumination from a) the visual stimulus array projected onto a back projection screen and b) infrared (IR) emitting diodes used to provide sufficient illumination to monitor the subject with closed-circuit television. These illumination sources provided an average of 0.063 μW/cm² (n = 15, *SEM* = 0.001) additional irradiance measured in the horizontal plane of vision at the subject viewing distance.

The nominal hazard zone (NHZ) for ocular damage (ANSI Z136.1-1986) in the fiber-optic-projected laser beam was determined for the following two conditions:

1. The LPC failed, and the subject was exposed to unmodulated laser light (5900 $\mu W/cm^2$ at the terminal end of the fiber-optic cable) for a maximum of 108.48 s.
2. The subject experienced the 0.5 $\mu W/cm^2$ exposure level (1850 $\mu W/cm^2$ at the terminal end of the fiber-optic cable) for a maximum of 108.48 s.

While seated in the cockpit familiarization trainer (182 cm from the terminus of the fiber-optic cable), the subject was far removed from the NHZ calculated for conditions 1 (20 cm) and 2 (10 cm). Furthermore, the maximum permissible exposure (MPE) level of 92.2 $\mu W/cm^2$ (given an exposure duration of 108.48 s) was a factor of 184 greater than that attainable at the maximum subject-exposure level of 0.5 $\mu W/cm^2$.

Visual Stimulus Array

Each 66-cm high by 88-cm wide, computer-generated, visual stimulus array consisted of 119 randomly placed distractor rectangles (12-mm high, 10-mm wide) and one target rectangle (7-mm high by 6-mm wide). This computer-generated visual array was converted to an analog video signal and rear-projected onto a diffused projection screen using a High Resolution, High Brightness Monochrome Projection Monitor (model 38-B02503-71, Electrohome Limited, Ontario, Canada). The projected display occupied 10.77 vertical by 13.591 horizontal degrees of visual angle. At a subject viewing distance of 182 cm, a distractor rectangle spanned 0.378 vertical by 0.315 horizontal degrees of visual angle, whereas the target spanned 0.220 by 0.189 degrees of visual angle. Approximately 21% of the display area was occupied by the distractor and target stimuli.

Forty visual stimulus arrays were generated, each containing one target. A 3- by 3-cm crosshair was located at the center of each display, dividing the display into four equal quadrants (see Fig. 2). Targets occurred equally often in each of the four quadrants at each of five eccentricities measured from the center of the display. Thus, two targets appeared at each of five eccentricities within a quadrant. Table 2 shows the average target-to-crosshair distance and visual angle at each eccentricity.

A Pritchard Photometer with 6' arc aperture (model PR-1980A, Photo Research, Burbank, CA) was used to measure the luminance of a) each target rectangle, b) the distractor rectangle nearest the target, and c) the background midway between the target and its closest distractor. These measurements, made at the subject viewing distance with the windscreen in place, were used to compute target-background and distractor-background brightness contrast $[(L_{Max} - L_{Min})/(L_{Max} + L_{Min})]$ at each target location across the 40 displays. Target, background, and distractor luminance varied by eccentricity (see Table 3), however, background luminance was highly correlated with both target (*n* = 40, *r* = 0.89) and distractor (*n* = 40,

r = 0.90) luminance. Consequently, a four (display quadrant) by five (target eccentricity) ANOVA showed that neither target-background nor distractor-background brightness contrast (*M* = 0.200, *SEM* = 0.007; *M* = 0.235, *SEM* = 0.006, respectively) varied by location within the visual display.

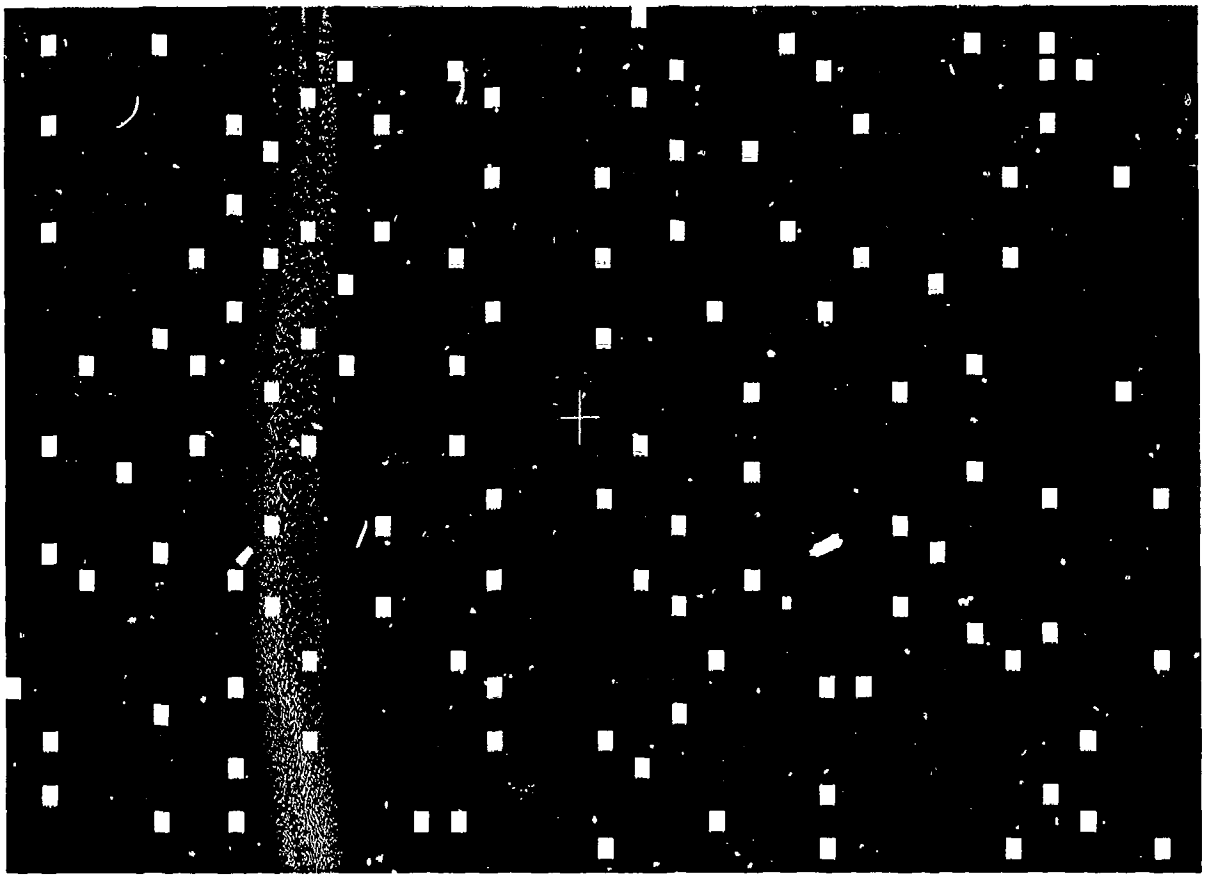

Figure 2. *Example of a visual display with 119 distractor rectangles and 1 target rectangle.*

Experimental Control and Data Acquisition

Experimental control and data acquisition were under microcomputer control (Zenith, model ZWX-248-62). An analog-to-digital I/O board (model DASCON-1, Metrabyte Corporation, Taunton, MA), multifunction timer (model CTM-5, DASCON-1, Metrabyte Corporation, Taunton, MA), and solid-state controllers (BRS/LVE, Inc.) were used to monitor subject responses and control the onset and duration of the visual display, laser exposure, and auditory feedback. A compiled algorithm written in GW-BASIC source code (Microsoft Corp., Redmond, WA) provided control over the function of these peripheral devices.

Visual Assessment

Subjects were monitored for potential decrements in visual capability caused by their exposure to low levels of coherent light. Before (on day 1) and after (on day 5) their participation, subjects were given a visual assessment battery that measured visual acuity (Armed Forces Vision Tester), contrast sensitivity (Vistech, Multivision Contrast Tester) with and without incandescent central glare, lens opacity (Interzeag, Opacity Lensmeter), and color sensitivity (Farnsworth-Munsell 100-Hue Test, Kollmorgen Corp., Baltimore, MD).

TABLE 2. Mean Crosshair-to-target Distance for each Eccentricity.

Target eccentricity	*n*	*M*	*SEM*
Distance (cm) of target from crosshair			
1	8	5.089	0.292
2	8	11.828	0.239
3	8	18.814	0.535
4	8	21.273	0.796
5	8	25.875	1.038
Degrees visual angle at a viewing distance of 182 cm			
1	8	1.602	0.092
2	8	3.719	0.075
3	8	5.903	0.167
4	8	6.667	0.247
5	8	8.091	0.320

TABLE 3. Average Target, Background, and Distractor Luminance (Candelas/m^2) at each Target Eccentricity.

	Mean (*SEM*) luminance		
Eccentricity	Target	Background	Distractor
1	2.99 (0.03)	1.88 (0.02)	3.07 (0.04)
2	2.78 (0.08)	1.92 (0.15)	2.90 (0.06)
3	2.25 (0.09)	1.50 (0.05)	2.47 (0.06)
4	2.06 (0.12)	1.36 (0.10)	2.26 (0.18)
5	1.72 (0.14)	1.20 (0.09)	1.92 (0.15)

PROCEDURES

Subjects were tested separately. They sat in the cockpit familiarization trainer in a completely darkened room for the first 5 min of each experimental session. At the completion of this dark-adaptation period, the center of the rear-projection screen was illuminated by the word 'GO.' Subjects were told that pressing the display-advance button, held in their nondominant hand, would reveal the visual display and that their task was to identify the location of the single target rectangle as quickly as possible (without sacrificing accuracy) by pressing one of four response keys. Each response key corresponded to a different quadrant of the visual display. The keys were placed in a 3.5-cm wide by 2.5-cm long grid on an aviators knee-board. Subjects responded with their dominant hand.

The display remained on until the subject responded or for about 950 msec (*M* = 952, *SEM* = .25), whichever occurred first. After the subject responded, the word 'GO' reappeared in the center of the display indicating that the response had been recorded and the next trial was ready to begin. Correct target-location responses were immediately followed by a high-pitched tone, whereas incorrect responses were followed by a low-pitched tone.

Each of the 40 displays appeared once in random order in each of 4 blocks of 40 sequentially presented displays. Each block of 40 displays was separated by a 1-min rest period. Five such randomizations were constructed for a total of five, 160-trial display sets. Subjects viewed one display set each day.

Days 1-3 were training days, serving to stabilize subject performance, and involved no laser exposure. Display sets 1-3 were viewed in numerical order on these days by all subjects. Display sets 4 and 5 were counterbalanced across subjects on days four and five. Each subject was exposed to 3 laser irradiance levels (0.1, 0.3, 0.5 $\mu W/cm^2$) and a no-laser control on each of these final 2 days, with a different irradiance level (including the no-laser control) randomly assigned to each block of 40 trials. The order of laser-exposure level presentation was randomized separately for each subject on days 4 and 5.

Recording of subject response time to locate a target was time-locked to visual display onset. In addition, laser-exposure onset and duration were time-locked to visual display onset and offset (see Fig. 3). Maximum laser exposure duration averaged 902 msec (n = 40, *SEM* = 0.25) under conditions where the subject always responded to the target location after display offset. Subjects were shown their performance after each session. Furthermore, on the following day, each subject was shown how his previous day's performance compared to that of the other seven subjects.

RESULTS

Training and laser exposure data were analyzed separately. Only correct target-location responses were considered for analyses in each case. A completely within-subjects repeated-measures analysis of variance (ANOVA) design was used to evaluate the effect of the experimental treatments on the speed and accuracy of target-location responses. All post-hoc pairwise comparisons among means were carried out using Tukey's HSD test (5, pp. 116-118) at the 0.05 probability level.

Training data consisted of speed and accuracy of target location measured over 3 days (days 1-3) of practice. On each day, subjects responded to 160 briefly presented (≈ 950 msec) visual displays without concomitant laser exposure. Each target appeared at 1 of 5 eccentricities allowing a maximum of 32 correct responses at each of the 5 eccentricities on each of the 3 training days.

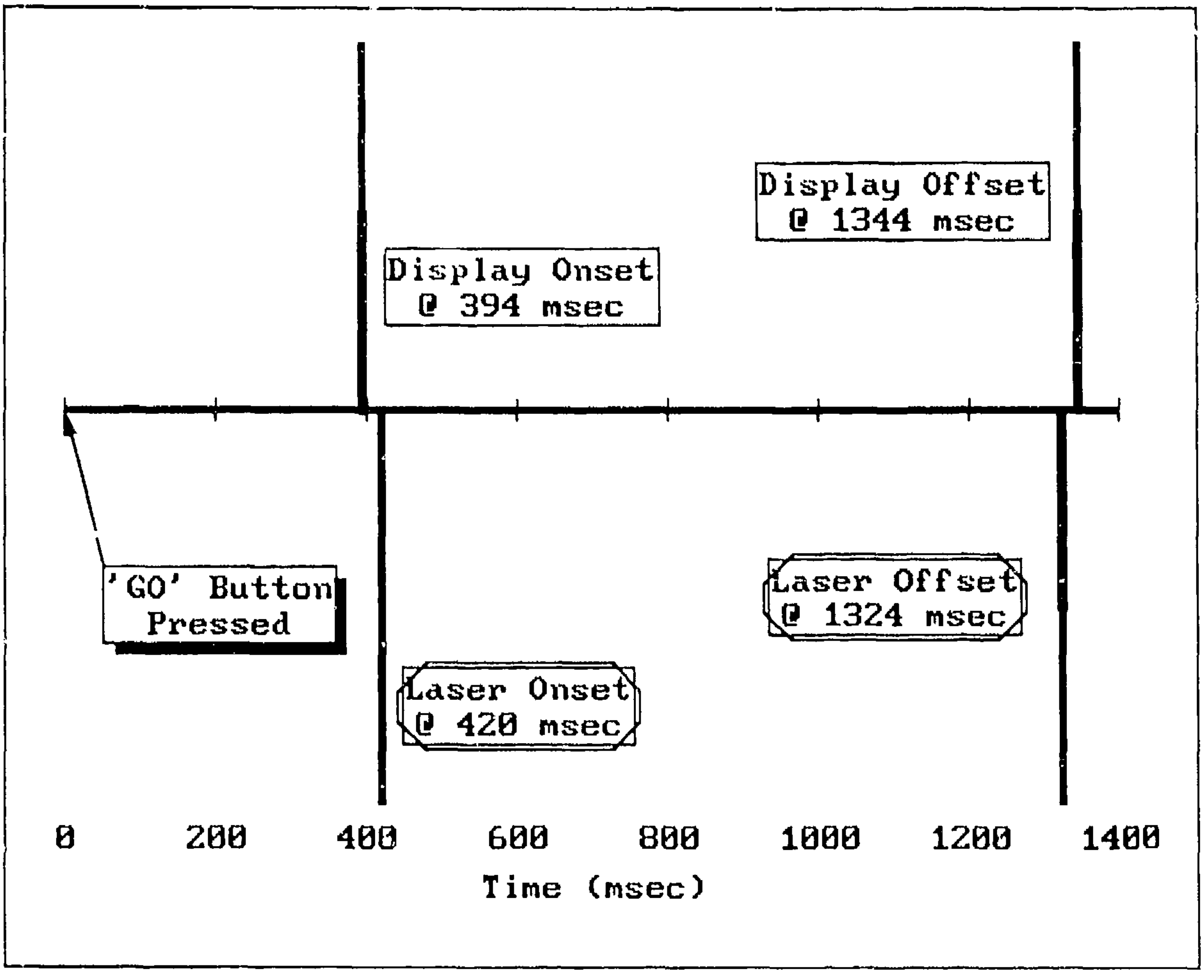

Figure 3. *Time course of events during a single trial.*

Laser exposure data consisted of speed and accuracy of target location measured over 2 days (days 4-5). On both days, subjects experienced 3 different levels of laser irradiance (e.g., glare), as well as a no-laser (e.g., no-glare) control while viewing 160 briefly presented (≈ 950 msec) visual displays . Each experimental condition was randomly assigned to a block of 40 experimental trials. This allowed for a maximum of eight correct responses per eccentricity (five) per experimental condition (four) per day (two).

TRAINING DATA

Individual subject performance, both speed and accuracy, improved over the 3-day training period. A three-by-five way repeated-measures ANOVA (training day by target eccentricity) of the data revealed that both speed and accuracy of target location improved as a function of practice [$F(2, 14) = 22.15$, $p < .01$; $F(2, 14) = 7.07$, $p < .01$, respectively]. Specifically, subjects responded significantly faster to targets on days two (*M* = 1013, *SEM* = 26) and three (*M* = 905, *SEM* = 28) compared to day one (*M* = 1271, *SEM* = 24). In addition, accuracy of responding improved significantly on practice day three (*M* = 27.7, *SEM* = 0.8) relative to day one (*M* = 24.4, *SEM* = 0.9).

Speed and accuracy of target location responses also varied as a function of target eccentricity [$F(4, 28) = 38.2$, $p < .01$; $F(4,28) = 31.0$, $p < .01$, respectively]. Speed of responding to targets was significantly slower at eccentricity five (*M* = 1319, *SEM* = 45) relative to eccentricities one (*M* = 881, *SEM* = 53), two (*M* = 919, *SEM* = 53), and three (*M* = 1021, *SEM* = 51). In addition, speed of responding was significantly slower at eccentricity four (*M* = 1174, *SEM* = 57) relative to eccentricity one. Accuracy of responding showed a nearly identical pattern with accuracy being significantly lower at eccentricity five (*M* = 19.4, *SEM* = 1.0) relative to eccentricities one (*M* = 29.1, *SEM* = 0.8), two (*M* = 29.3, *SEM* = 0 7), and three (*M* = 28.2, *SEM* = 0.7).

The interaction between training day and target eccentricity was not a significant source of variance for either speed ($F(8, 56) = 0.574$, $p = .78$) or accuracy ($F(8, 56) = 0.684$, $p = .70$). Figures 4 and 5 summarize these observations for speed and accuracy of responding respectively.

LASER GLARE DATA

The effect of laser irradiance on target-location responses was statistically examined using a two-by-four-by-five way ANOVA (mean target eccentricity, 1.6, 3.7, 5.9, 6.7, 8.1° by day, 4 & 5, by level of irradiance, 0.0, 0.1, 0.3, 0.5 µW/cm^2). Three of the 40 cells in the experimental design were missing 1 of 8 observations as a result of a subject never correctly identifying a target at a particular location within the visual array. A different subject was responsible for each missing observation. The mean of the cell was used as an estimated source of variance in each case.

As would be expected from the training data results, day of testing did not affect target location performance, but laser-irradiance level significantly affected both the speed [$F(3, 21) = 24.6$, $p < .01$)] and accuracy [$F(3, 21) = 79.0$, $p < .01$)] of target location responses. In addition, target eccentricity produced significant effects on both the speed [$F(4,28) = 5.6$, $p < .01$)] and accuracy [$F(4, 28) = 4.2$, $p < .01$)] of responding as well.

The laser irradiance (e.g., laser glare) by target eccentricity interaction was significant for both speed and accuracy of responding [$F(12, 84) = 11.3$, $p < .01$; $F(12, 84) = 7.9$, $p < .01$, respectively]. Tests for simple main effects (5, pp. 365-371) revealed that speed of responding was significantly affected by level of laser glare at target eccentricities 1 thru 4. Accuracy of responding was significantly affected by level of laser glare at all five target eccentricities. Figures 6 and 7 summarize these findings for speed and accuracy of responding, respectively.

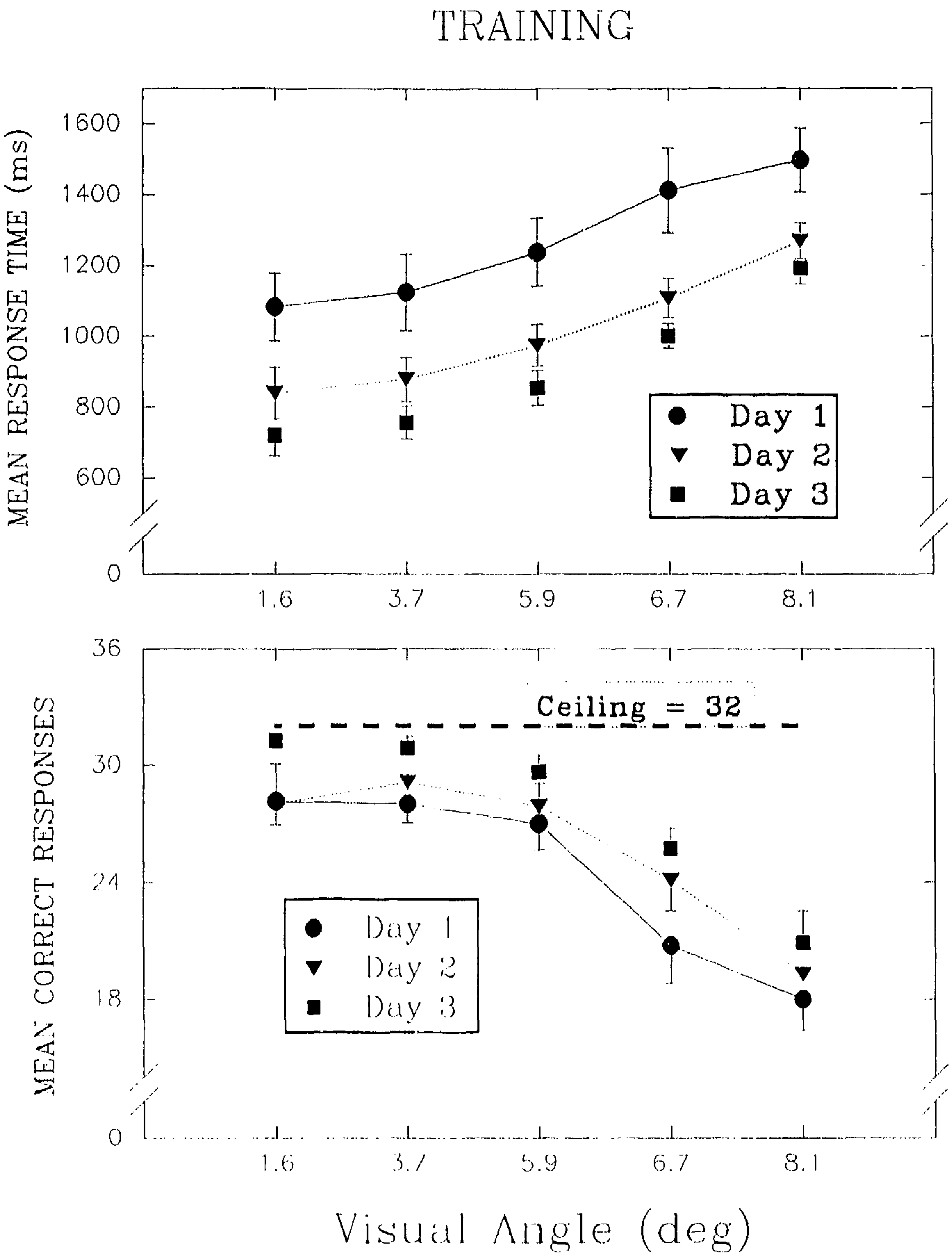

Figure 4. *Mean speed and accuracy of target location responses as a function of target eccentricity for each training day.*

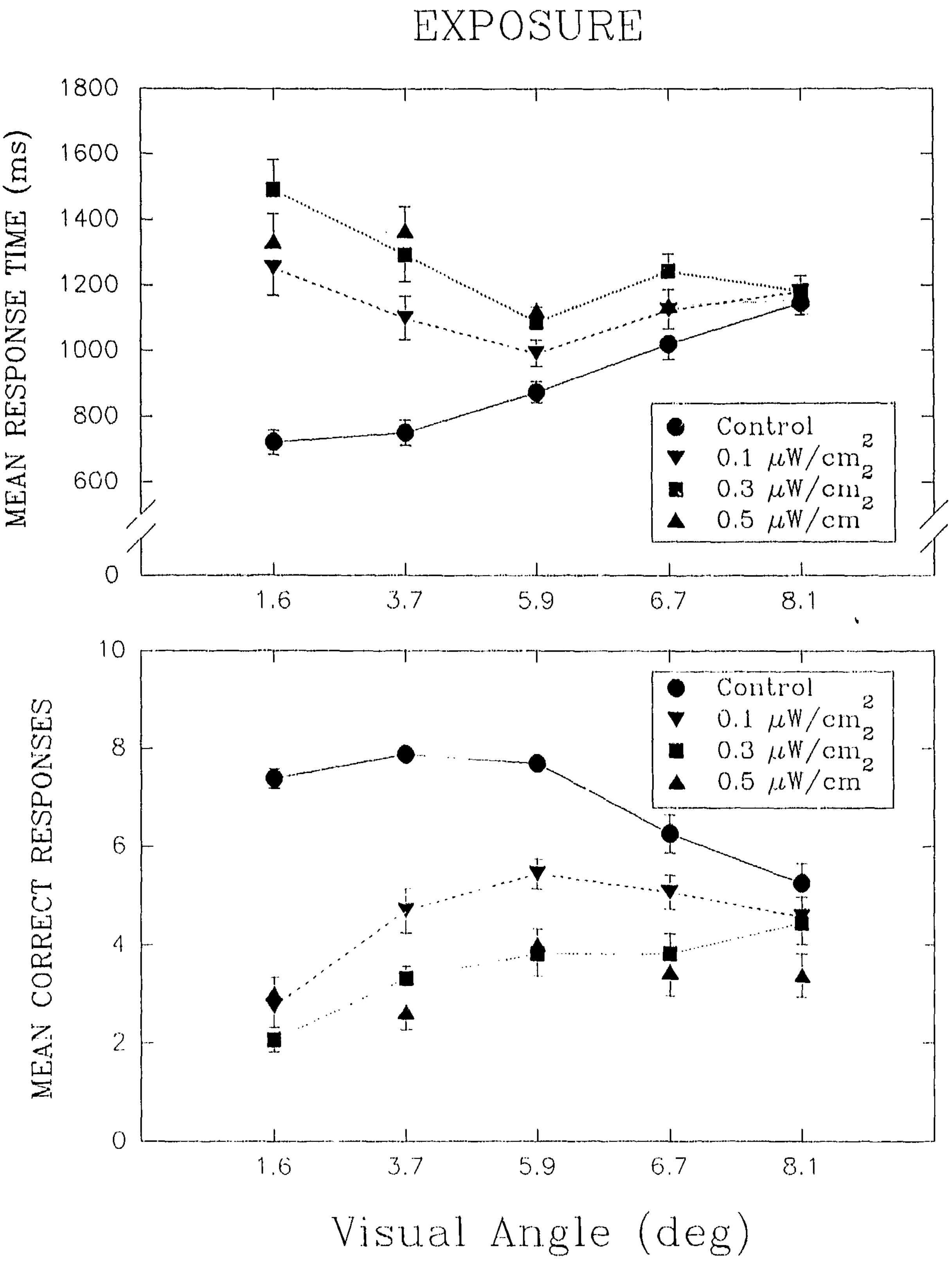

Figure 5. *Mean speed and accuracy of target location responses as a function of laser power (glare) and target eccentricity.*

Pairwise comparisons (Tukey's HSD; $p = .05$) were made among the means (laser-irradiance levels) at each target eccentricity. Three pairwise comparisons at each target eccentricity were most important for the purposes of the present study. They were no-glare control versus laser glare produced by the 0.1, 0.3 and 0.5 μW/cm² irradiance levels. Table 4 presents the means for speed and accuracy of responding at each irradiance level across the five target eccentricities.

TABLE 4. Cell Means (*SEM*) for the Laser Power by Target Eccentricity Interaction.

	Laser power level (μW/cm²)			
Target eccentricity	0.0	0.1	0.3	0.5
		Speed of responding (ms)		
1	720 (38)	1252 (85)	1490 (92)	1332 (85)
2	750 (38)	1099 (67)	1292 (82)	1366 (72)
3	873 (32)	992 (41)	1089 (46)	1123 (59)
4	1021 (48)	1125 (57)	1243 (53)	1138 (49)
5	1146 (37)	1180 (46)	1182 (46)	1155 (58)
		Accuracy of responding		
1	7.4 (0.2)	2.8 (0.4)	2.1 (0.2)	3.0 (0.3)
2	7.9 (0.1)	4.7 (0.5)	3.3 (0.3)	2.6 (0.4)
3	7.7 (0.2)	5.4 (0.3)	3.8 (0.5)	4.0 (0.3)
4	6.2 (0.4)	5.1 (0.3)	3.8 (0.4)	3.4 (0.5)
5	5.2 (0.4)	4.6 (0.4)	4.4 (0.4)	3.4 (0.4)

Regarding speed of responding, the 0.1, 0.3, and 0.5 μW/cm² glare conditions produced significant decrements in performance relative to the no-glare control at target eccentricities 1-2, 1-4, and 1-3, respectively. In addition, the 0.3 and 0.5 μW/cm² glare conditions produced significantly greater decrements in speed of responding relative to the 0.1 μW/cm² glare condition at target eccentricities 1 and 2.

The 0.1, 0.3, and 0.5 μW/cm² glare conditions produced significant decrements in accuracy of target localization relative to the no-glare control at target eccentricities 1-3, 1-4, and 1-5, respectively. Furthermore, the 0.3 and 0.5 μW/cm² glare conditions produced significantly greater decrements in accuracy of responding relative to the 0.1 glare condition at target eccentricities 2, 3, and 4.

VISUAL ASSESSMENT COMPARISONS

To determine any possible effects of laser light exposure on visual function, t tests for related means were conducted on pre- and postvisual assessment measures of a) visual acuity, b) contrast sensitivity, c) lens opacity, and (d) color sensitivity. As expected, no significant differences were found between the pre- and posttest means for any of these measures.

DISCUSSION

Speed and accuracy of responding to targets in a briefly presented visual array were examined separately for nonlaser training trials and laser-exposure trials. Both sets of data provided important observations.

Given the rate of increase in performance shown during training, these data support the view that subjects were performing at or near their maximum ability before experiencing laser-exposure trials. We stress here that 3 training days served to improve performance significantly, without producing a ceiling effect. Had subjects been able to attain error-free performance, then this accuracy data would not have provided an appropriate baseline against which to judge performance under the laser-glare conditions. Additionally, speed and accuracy of locating targets at each eccentricity was not differentially affected by the number of days an individual participated in the study. Finally, subjects responded to targets closer to the center of the visual display more rapidly and with greater accuracy relative to targets in the display's outer perimetry. D'Andrea and Knepton (3) made a parallel observation regarding speed of target location responses for a nearly identical visual array viewed by subjects for a longer period of time.

The relationship between the intensity of laser-produced central glare and the speed/accuracy of target location responses appears very straightforward. Generally, laser glare produced a graded effect upon visual search performance with the lowest level of central glare examined (0.1 $\mu W/cm^2$) causing decrements in performance when targets to be identified were within 3.7° of the glare source. As laser illumination level increased, decrements in performance were seen across a broader visual angle relative to the glare source (up to 8.1° from the source under 0.5 $\mu W/cm^2$ induced glare). Specifically, an inverse linear relationship between laser glare level and accuracy of target location responses was observed. Speed of responding correctly to localized targets was similarly influenced by central glare with targets near the center of the visual array being responded to most slowly. Unlike accuracy of responding, however, the midrange glare condition (0.3 $\mu W/cm^2$) produced farther reaching effects in speed of responding across target eccentricities than did 0.5 $\mu W/cm^2$ induced glare. This is likely due to the possibility that subjects confined their visual scanning to only a limited (outer) portion of the visual array when exposed to 0.5 $\mu W/cm^2$ glare, reducing overall accuracy but increasing speed of responding to outer targets.

This study supports the conclusion that low-level argon laser-induced glare (184-922 times below the MPE for a 1.8-min cummulative exposure; 3700 times below the MPE for a 900-ms exposure), viewed through an aircraft windscreen causes significant decrements in visual search performance for briefly displayed visual information. Subjects identified significantly fewer targets in a complex visual array when experiencing low-intensity laser-induced glare relative to a no-glare control. In addition, the speed with which correctly identified targets were located was significantly reduced relative to a no-glare control. As would be expected, these results were most pronounced for targets close to the center of the beam path. Furthermore, as incident laser glare (irradiance) increased, significant decrements in the speed and accuracy of target location responses were observed at target eccentricities farther and farther away from the center of the beam path.

The speed of responding results of the present study are similar to those observed by D'Andrea and Knepton (3) who used 20-s duration laser glare exposures of 0.09, 0.14, or 0.20 $\mu W/cm^2$ as subjects viewed a visual display for an indefinite time through an aircraft windscreen. Their observations and those in the present study support the conclusion that low-intensity laser induced-glare *far below* a level that would produce ocular damage or flashblindness will produce significant decrements in the visual search performance of pilots. The present study also shows that accuracy of target location responses is severely reduced in the presence of low-intensity laser glare when the visual scene to be inspected is available for a short period of time. The results of the present investigation did not, however, establish a *lower bound* of incident laser illumination that produces decrements in visually guided performance.

How should future research in this area proceed? Mission success depends on a pilot's ability to a) identify stationary targets in a complex visual scene, b) vigilantly identify unpredictable targets, and c) maintain visual contact with (tracking) a moving object. Studies to establish relationships between laser-induced glare and visually guided performance should address the effects of laser glare on each of these search behaviors separately and in concert with other environmental and cognitive factors (e.g., level of ambient light, target-background brightness contrast, glare onset relative to the time that visual information becomes available for inspection, cognitive load) that can be expected to influence the visual search performance of pilots under a variety of flight conditions.

RECOMMENDATIONS

Low-intensity laser glare produced decrements in visually guided performance in a task designed to maximize the visual attentional demands placed on subjects. Eye protection is needed to prevent mission disruption even at laser intensities that are not harmful to the eye. Because laser glare can be experienced before, coincident with, or after the time at which visual information becomes available for inspection, future research should consider the time that a pilot (aircrew) experiences laser glare (its onset) relative to the time that visual information becomes available. From this perspective, several important *thresholds* that define the time-course of the disruptive effects of laser glare on visual information processing can be identified. Each threshold would yield an estimate of how long visual information processing will be disrupted under the following circumstances: laser glare a) precedes, b) coincides with, or c) follows the onset of visual information to be examined.

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Other Related NAMRL Publications

None are applicable.