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**DELAYS IN LASER GLARE ONSET
DIFFERENTIALLY AFFECT TARGET-
LOCATION PERFORMANCE IN A
VISUAL SEARCH TASK**

M.D. Reddix, J.A. D'Andrea and P.D. Collyer

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13. ABSTRACT (Maximum 200 words) The present study examined the effects of low-intensity argon-laser glare on the visual search performance of aviators. Using a modified backward-masking paradigm, subjects were exposed to laser glare, either while seated in a cockpit simulation trainer with attached F/15 windscreen assembly. Brief exposure to laser glare, either 25 or 50 ms after a visual scene's onset, produced significant decrements in target-detection performance relative to a no-glare control whereas a 300-ms delay of laser glare onset had very little effect. The intensity of the light entering the eye ($.38 \mu\text{W}/\text{cm}^2$) and producing these effects was far below the Maximum Permissible Exposure (MPE) limit for safe viewing of coherent light. In addition, these effects were modulated by a target's distance from the center of the beam path (also center of the visual display). Specifically, targets closest to the center of the beam path were responded to the most slowly and with the least accuracy. This study demonstrated that the presence of laser glare is not sufficient, in and of itself, to diminish target-detection performance. The time at which laser glare is experienced is an important factor in determining the probability and extent of visually mediated performance decrements.			
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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.

FINDINGS

This study showed that the time at which laser glare is experienced, relative to initial acquisition of visual information, differentially affects the speed and accuracy of target-location performance. Brief exposure (300 ms) to laser glare, either 25 or 50 ms after a visual scene's onset, produced significant decrements in target-location performance relative to a no-glare control whereas a 300-ms delay of laser glare onset had very little effect. The intensity of the light entering the eye and producing these effects was far below the Maximum Permissible Exposure (MPE) limit for safe viewing of coherent light produced by an argon laser. In addition, these effects were modulated by the distance of the target from the center of the beam path (also center of the visual display). Specifically, subjects responded to targets closest to the center of the beam path more slowly and less accurately. This study demonstrated that the presence of laser glare is not sufficient, in and of itself, to diminish target-location performance. The time at which laser glare is experienced is an important factor in determining the probability and extent of visually mediated performance decrements.

RECOMMENDATIONS

Eye protection is needed to prevent mission disruption even at laser intensities that are not harmful to the eye. The type of eye protection most suitable for use in dawn/dusk and nighttime environments should be carefully scrutinized however, as most if not all available eye protection will reduce the amount of ambient light reaching the retina. Small reductions in ambient light during dawn/dusk flight may cause decrements in the acquisition of visual information both inside and outside the cockpit.

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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 exercises and as offensive weapons (1) poses additional threats to military aviators because of the potential to disrupt visually guided performance, namely the speed and accuracy of locating critical visual information both inside and outside the cockpit.

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 eyes. Many factors serve to attenuate laser power, thus modulating or eliminating the threat of permanent or lingering laser-induced visual deficits: atmospheric turbulence, laser-beam divergence, wavelength and pulse duration of the laser source, distance of the eye(s) from the light source, angle of incidence of a direct or reflected beam on the eye(s), duration of exposure, refractive properties of aircraft windscreens, and laser-protective eyewear. These factors may serve to increase the probability that laser-induced glare, the effects of which last only 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.

Glare can result from the combination of several factors, which include scattering of light inside the eye (intra-ocular scattering), forward light scattering by the atmosphere, aircraft windscreen, and spectacles or prescription contacts. Several recent studies have revealed that laser-induced veiling glare causes decrements in visually mediated human performance. In one study (3), subjects viewed a moving target while seated behind an aircraft canopy. Laser glare was produced by a laser beam propagated over an outdoor range producing a 1-m diameter glare pattern at the subject viewing distance of 1.5 km. Results of both day and night experimental trials showed that the portion of the field-of-view occluded by glare increased as laser-irradiance level increased. In another experiment (4), the masking effects of continuous wave (CW) laser glare on head-up-display (HUD) symbology was found to be wavelength dependent. Army field studies (5,6) demonstrated that laser glare interferes with TOW (Tube-launched, Optically tracked, Wire-guided missiles) gunners' target tracking ability. Interestingly, notable variations between individual subject responses to laser glare were observed in each of the aforementioned laser-glare investigations.

Our own recent investigations of laser glare (7-9) have shown that incident powers of laser illumination well below a threshold that would have produced ocular damage cause predictable decrements in visual search performance when ambient lighting is low ($\approx 1.56 - 6.0$ candelas/m²). These studies, which required subjects to locate target disks or rectangles in a complex visual array under several conditions of laser-induced glare, have revealed several important factors that affect an aviator's susceptibility to laser-glare performance decrements. First, low-level laser glare ($0.09-0.5 \mu\text{W}/\text{cm}^2$), under low ambient lighting, is very effective in disrupting target-location performance during a visual search task (7-9). Second, under these conditions, the shape of aircraft windscreen (curved FA/18 vs flat A4) is an important factor. Most important is the observation that a subject's speed and accuracy of target location is not disrupted by relatively low-level laser glare unless a windscreen is present in the visual (beam) path (7,8). The interaction of laser light and the windscreen must be present for the decrement in visual performance to occur at laser intensities less than or equal to $0.2 \mu\text{W}/\text{cm}^2$ (7). Third, as expected, the disruption of visual search performance was ameliorated at higher ambient lighting levels suggesting more intense laser irradiation is necessary to disrupt visual search performance in daylight conditions (8). Fourth, under low-ambient lighting conditions, visual search inside the cockpit on a CRT monitor mounted in the instrument panel is not disrupted by laser glare intensities that are disruptive of visual search through the windscreen (10). Fifth, the

chronological age and opacity of the eye's lens correlates well with speed and accuracy of target acquisition in the visual search paradigm (11). Generally, the older subjects were more susceptible to laser glare than younger subjects in spite of equal visual search performance of both groups without laser glare. Finally, the effects of laser glare on a visual search task designed to maximize visual attentional demands were investigated. Brief presentations of laser glare (irradiance: $.1\text{--}.5 \mu\text{W}/\text{cm}^2$), far below the ANSI maximum permissible exposure (MPE), significantly reduced the speed and accuracy of target-location responses relative to a no-glare control (9).

These previous glare studies have focused on laboratory studies of the effects of laser-induced glare under conditions of continuous laser irradiation. That is, laser glare was presented continuously during each visual performance trial. In an operational environment, however, laser glare can be experienced before, coincident with, or after the time at which critical visual information becomes available for inspection. Forward, simultaneous, and backward masking paradigms (e.g., 12, pp. 7-11) can be used to investigate each of these 'time of laser onset' scenarios, respectively. Our own, and most other laser-glare research can be conceptualized by a simultaneous masking paradigm where laser glare is presented coincident with the visual information to be inspected. In order to determine an accurate probability of target-location failure, however, target-location performance must be observed under both forward (i.e., glare precedes visual target information) and backward (glare follows critical visual target information) masking conditions. Understanding the *probabilistic* nature of laser-glare-induced performance decrements will be an important step toward enhancing the generalization of research findings in this area of investigation.

The present study continues our previous work of the effects of low-level laser glare on the speed and accuracy of target-location performance (7-11). A modified backward-masking paradigm similar to that of Thompson (13) was used to examine the effect of 'delay of laser glare onset' on the target-location performance of student aviators. 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 on 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 (dawn/dusk) conditions. As with Thompson (13), it was expected that the delay of a masking flash of light (300-ms duration coherent laser glare in the present study) would differentially affect target-location performance, with longer delays having the least detrimental influence.

MATERIALS AND METHODS

SUBJECTS

Ten male student naval aviator volunteers served as subjects. The ages of the subjects ranged from 22 to 27 years ($M = 23.6$; $SEM = 0.43$). 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, 20/17-20/12). Distant binocular acuity, measured with a Multivision Contrast Tester (model MCT-800, Vistech Consultants, Inc., Dayton, OH) ranged from 20/20 to 20/15 ($M = 15.5$; $SEM = 0.5$). 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 lenses in each subject's eyes was assessed before his 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 (left eye, $M = 10.28$, $SEM = 0.49$; right eye, $M = 10.68$, $SEM = 0.53$).

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, which was isolated from the laser. Subjects were illuminated with an infrared light source and 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 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 800 mW. 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 multimode fiber-optic cable (0.22-mm od) consisted of a single-strand core of acrylic polymer (1-mm id) with a fluorine-polymer sheath. The distal end of the fiber-optic cable, inserted through a hole in the center of a rear-projection screen, projected a 28.1° cone of laser light toward the cockpit. Beam diameter at the subject viewing distance of 182 cm was approximately 91 cm (measured at the cross section of the beam where the power per unit area is 50% that of the average power).

Laser-irradiance level. Subjects were exposed to one level of laser irradiance ($0.5 \mu\text{W}/\text{cm}^2$) for a maximum of 36 s in one 24-h period. Laser-irradiance level was 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 the irradiance level at 182 cm. The percentage of laser light transmitted through the laser power controller (LPC) necessary to achieve the irradiance level under these conditions was later used to 'software select' and maintain (approx. 0.05-0.02% drift) a desired subject-exposure level. The addition of the F/15 windscreen to the cockpit familiarization trainer reduced, by 24%, the radiant power incident on the subject. Total radiant exposure at the eye was $0.38 \mu\text{W}/\text{cm}^2$ when the windscreen was in place.

Laser Safety. Subject exposure level was correlated with laser irradiance at two fixed locations that were monitored while the subject was seated in the cockpit. One reading was taken 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 $0.063 \mu\text{W}/\text{cm}^2$ ($n = 15$, $SEM = 0.001$) 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) from 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 ($5900 \mu\text{W}/\text{cm}^2$ at the terminal end of the fiber-optic cable) for a maximum of 36 s.

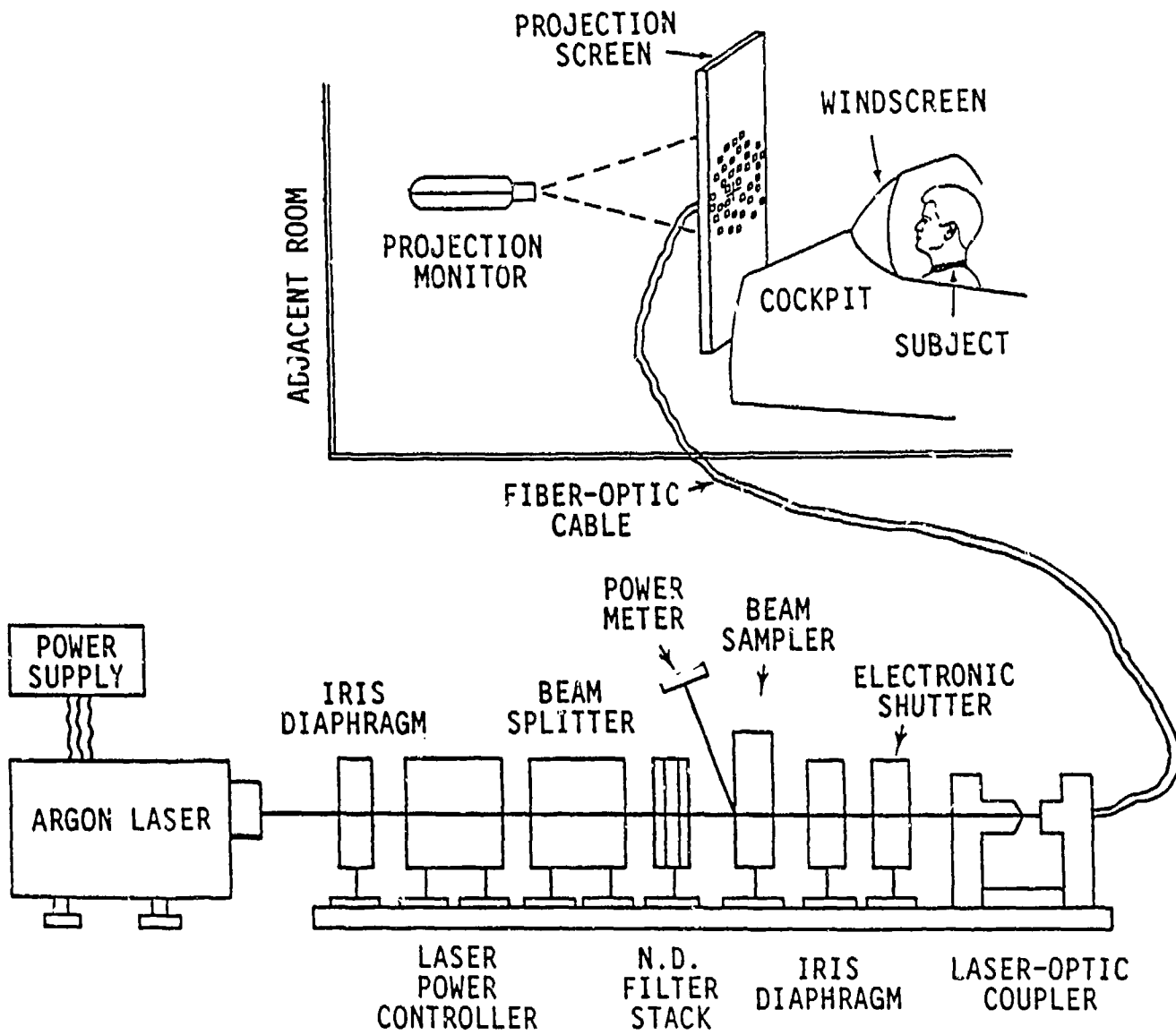


Figure 1. Schematic Representation of the laser beam path.

2. The subject experienced the $0.5 \mu\text{W}/\text{cm}^2$ exposure level ($1850 \mu\text{W}/\text{cm}^2$ at the terminal end of the fiber-optic cable) for a maximum of 36 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 (10 cm) and 2 (10 cm). Furthermore, the MPE level of $278 \mu\text{W}/\text{cm}^2$ (given an exposure duration of 36 s) was a factor of 556 times greater than that attainable at the maximum 36-s subject-exposure level of $0.5 \mu\text{W}/\text{cm}^2$.

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 24% 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, for the set of 40 stimulus arrays, 2 targets appeared at each of 5 eccentricities within a quadrant. Table 1 shows the average target-to-crosshair distance and corresponding visual angle at each eccentricity.

A Fritchard 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 $[(L_{\text{Max}} - L_{\text{Min}})/(L_{\text{Max}} + L_{\text{Min}})]$ at each target location across the 40 displays. Target, background, and distractor scotopic luminance varied systematically as a function of display quadrant and target eccentricity (see Table 2). A 4 x 5 (display quadrant x target eccentricity) ANOVA ($p < .05$), however, showed that neither target-background nor distractor-background brightness contrast ($M = 0.72, n = 40, SEM = 0.01; M = 0.74, n = 40, SEM = 0.01$, respectively) varied reliably as a function of target location within the visual display. The projection system provided ambient lighting of $1.56 \text{ cd}/\text{m}^2$.

Experimental Control and Data Acquisition

Experimental control and data acquisition were under microcomputer control (COMPAQ Deskpro 386/20, model 2571). 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 received a visual assessment battery to determine their visual acuity (Armed Forces Vision Tester), contrast sensitivity

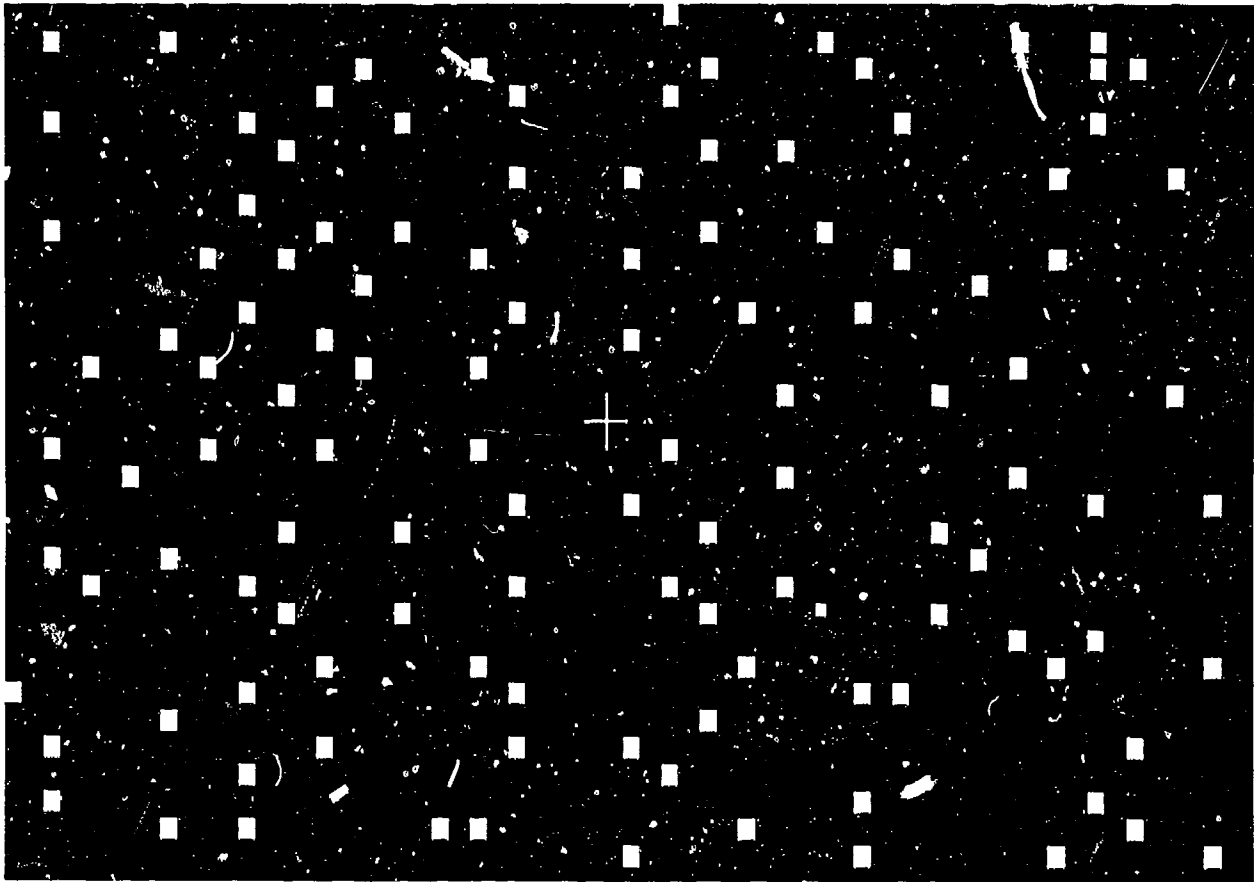


Figure 2. Example of a visual display with 119 distractor rectangles and 1 target rectangle.

TABLE 1. Mean (\pm SEM) Target Distance Measured as Degrees Visual Angle and Crosshair-to-target Distance.

Degrees visual angle	Viewing distance (cm)
1.602 (0.092)	5.089 (0.292)
3.719 (0.075)	11.828 (0.239)
5.903 (0.167)	18.814 (0.535)
6.667 (0.247)	21.273 (0.796)
8.091 (0.320)	25.875 (1.038)

Table 2. Mean (\pm SEM) Target, Background, and Distractor Scotopic Luminance (Candelas/m²) at Each Quadrant-by-Eccentricity Target Location.*

Target eccentricity	Quadrant			
	Upper left	Upper right	Lower left	Lower right
Target luminance				
1.6°	2.69 (.04)	2.53 (.08)	2.73 (.01)	2.57 (.02)
3.7°	2.57 (.23)	2.46 (.11)	2.37 (.12)	2.21 (.10)
5.9°	2.33 (.18)	2.08 (.17)	1.98 (.20)	1.81 (.14)
6.7°	2.19 (.11)	2.03 (.27)	1.60 (.07)	1.33 (.09)
8.1°	1.90 (.26)	1.56 (.28)	1.36 (.16)	1.25 (.21)
Background luminance				
1.6°	0.31 (.02)	0.55 (.01)	0.54 (.02)	0.41 (.09)
3.7°	0.45 (.09)	0.38 (.12)	0.48 (.00)	0.33 (.11)
5.9°	0.35 (.10)	0.21 (.01)	0.40 (.02)	0.37 (.19)
6.7°	0.30 (.08)	0.38 (.06)	0.34 (.04)	0.28 (.04)
8.1°	0.23 (.09)	0.22 (.01)	0.17 (.05)	0.12 (.09)
Distractor luminance				
1.6°	2.86 (.02)	2.74 (.01)	2.86 (.10)	2.80 (.04)
3.7°	2.70 (.04)	2.55 (.04)	2.63 (.22)	2.51 (.21)
5.9°	2.46 (.01)	2.12 (.08)	2.06 (.33)	2.41 (.22)
6.7°	2.48 (.22)	2.38 (.43)	1.73 (.33)	1.43 (.09)
8.1°	1.93 (.47)	1.71 (.40)	1.67 (.07)	1.61 (.15)

*Each mean is based on five observations.

(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).

PROCEDURES

Subjects were tested separately. Each subject 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 aviator's knee-board. Subjects responded with their dominant hand.

The display remained on until the subject responded or for about 900 ms ($n = 30$, $M = 903.53$, $SEM = 1.10$), whichever occurred first. A 1-s pause followed the subject response, after which 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.

Three delay-of-laser-glare-onset (DLGO) conditions were used in a modified backward-masking paradigm. The cockpit windscreen was illuminated for 300 ms by laser glare beginning either 25 ($n = 10$, $M = 25.00$, $SEM = 0.45$), 50 ($n = 10$, $M = 49.40$, $SEM = 0.79$), or 300 ms ($n = 10$, $M = 298.00$, $SEM = 0.67$) after visual display onset (see Fig. 3). A no-laser-glare condition served as a control. Figure 4 shows an example of a visual display viewed through the canopy with (lower figure) or without (upper figure) laser glare present. The control and three DLGO conditions were assigned equally to each of the 20 target locations. Thus, for the 160-trial display set, each DLGO condition occurred twice at each of the 20 target locations. The order of presentation of the 160-trial display set was randomized such that no target-location or DLGO condition occurred more than two times in succession. Twelve such quasi-random orderings of the 160-trial display set were generated. A display set was presented in 4 blocks of 40 displays separated by 1-min rest periods. The method of random selection without replacement was used to choose a display set to be viewed by a subject. Subjects viewed one display set each day.

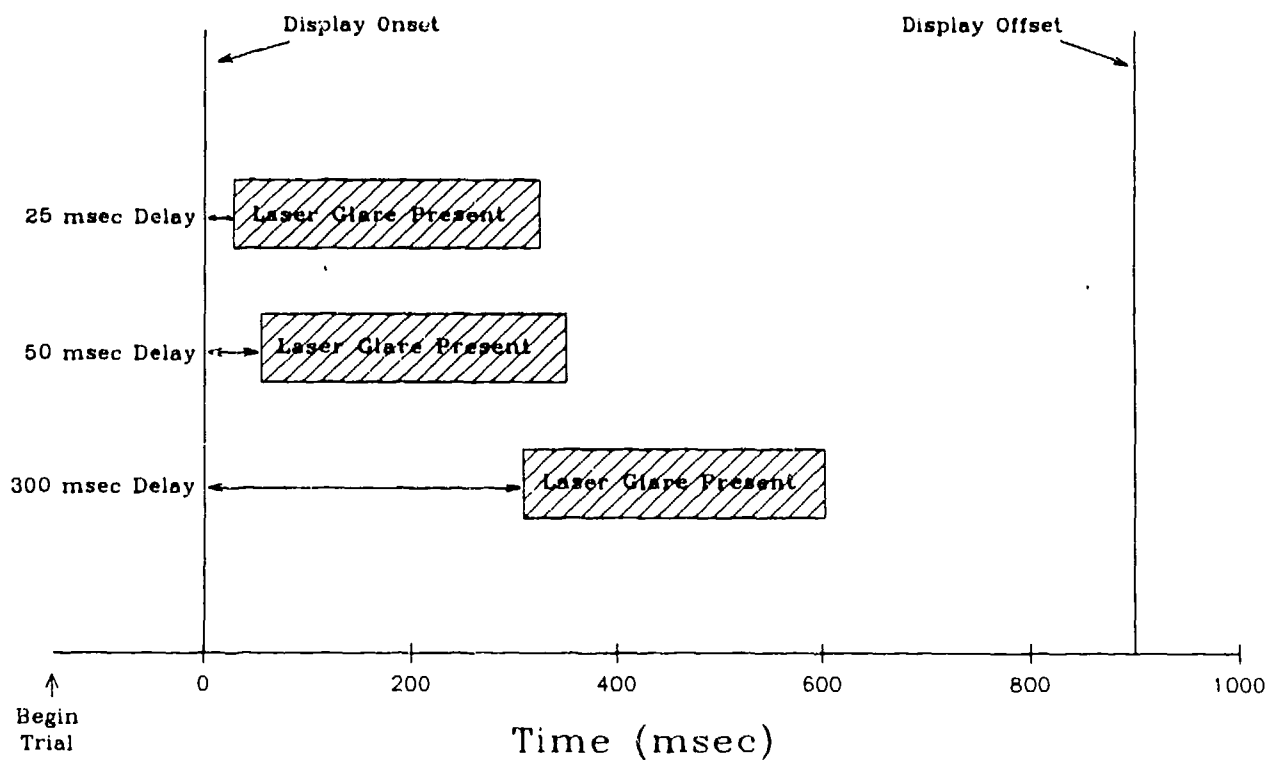


Figure 3. Time course of events for each delay-of-laser-glare-onset condition.

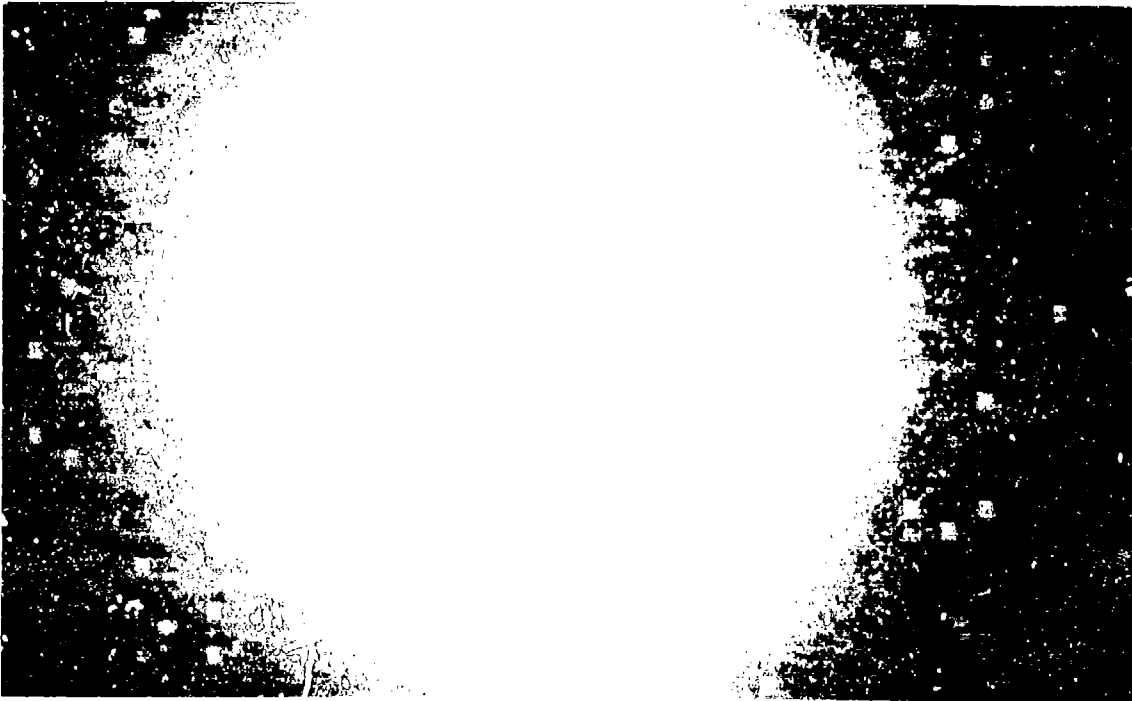


Figure 4. *Visual display viewed through the canopy with (lower figure) and without (upper figure) laser glare present.*

Days 1-3 were training days, serving to stabilize subject performance, and involved no laser exposure. On days 4 and 5, each subject viewed a display set that included the three DLGO conditions and a no-laser-glare control. Each subject was exposed to the same laser irradiance level ($0.38 \mu\text{W}/\text{cm}^2$).

Recording subject-response time to locate a target (speed of responding) was time-locked to visual display onset. In addition, DLGO was time-locked to visual display onset (see Fig. 3). 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 subjects.

RESULTS

Training and laser-exposure data were analyzed separately. Only correct target-location responses (accuracy of responding) 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 at the 0.05 probability level.

Training data consisted of speed and accuracy of target-location responses measured over 3 days (days 1-3) of practice. On each day, subjects responded to 160 briefly presented (≈ 900 ms) visual displays without concomitant laser exposure. Each target appeared at 1 of 5 eccentricities for a maximum of 32 correct responses at each eccentricity on each of the 3 training days.

Laser exposure data consisted of speed and accuracy of target location measured over 2 days (days 4-5). On both days, subjects experienced 3 DLGO conditions, as well as a no-laser-glare control while viewing 160 briefly presented (≈ 900 ms) visual displays. Again, each target appeared at 1 of 5 eccentricities for a maximum of 8 correct responses per eccentricity (5) per experimental condition (4) per day (2).

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 speed of target location varied reliably as a function of days of practice [$F(2, 18) = 36.87, p < .001$] and target eccentricity [$F(4, 36) = 87.08, p < .001$]. Post-hoc tests revealed that the mean ($M \pm SEM$) target-location time (in milliseconds) of subjects was significantly faster on days two (843 ± 34) and three (791 ± 31) compared to day one (998 ± 47). In addition, subjects responded fastest to targets near the center of the display (see Fig. 5, upper graph). That is, speed of responding was significantly faster for targets 1.6 and 3.7° from the center of the display (740 ± 31 ; 749 ± 32 , respectively) relative to targets 5.9 , 6.7 , and 8.1° from the center of the display (833 ± 35 ; 967 ± 42 ; and 1098 ± 47 , respectively). Targets appearing at an eccentricity of 5.9° from the center of the display were responded to significantly faster (833 ± 35) than targets appearing 6.7 and 8.1° from the center of the display (967 ± 42 ; 1098 ± 47 , respectively). Finally, subjects responded significantly faster to targets 6.7° from the center of the display (967 ± 42) compared to targets appearing 8.1° from the center of the display (1098 ± 47).

A significant three- (training day) by-five- (target eccentricity) way ANOVA [$F(8, 72) = 2.601, p < .01$] showed that training day and target eccentricity interacted to reliably affect accuracy of target-location performance. Post-hoc tests revealed, irrespective of a target's location, no significant difference in accuracy of responding between training days 2 and 3. However, accuracy of responding was significantly higher on days 2 and 3 relative to day 1 for targets appearing 3.7 , 5.9 , and 6.7° from the center of the display. In addition, day 3 training accuracy was significantly higher than day 1 accuracy for targets appearing 8.1° from the center of the display. Accuracy of target-location performance was not differentially affected by 'days of training' for targets closest to the center of the display (1.6°). Figure 5 (lower graph) summarizes these findings.

TRAINING

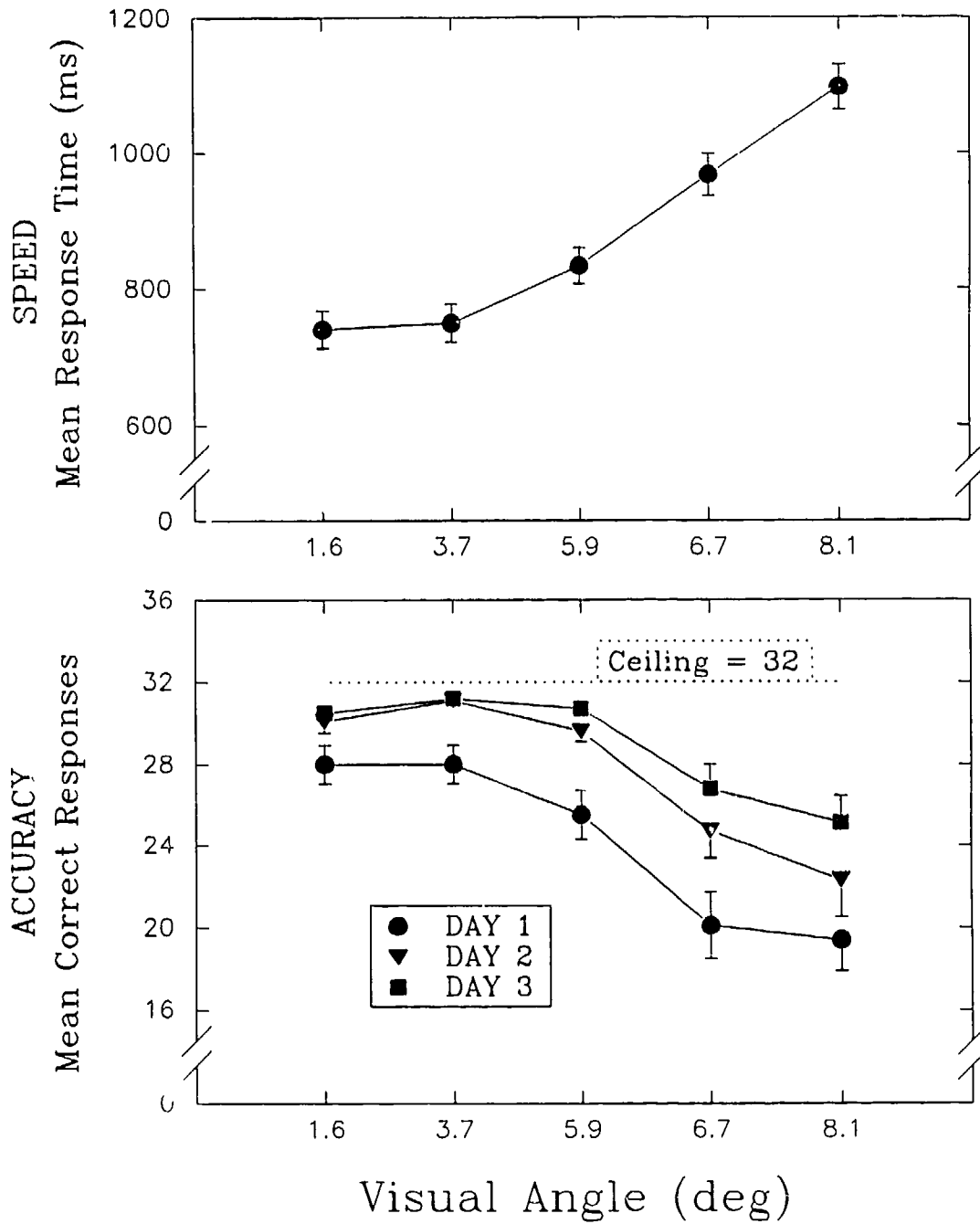


Figure 5. Speed (mean response time) and accuracy (mean correct responses) of target-location responses as a function of target eccentricity.

LASER GLARE DATA

The effect of DLGO on target-location performance was statistically examined using a two-by-four-by-five way repeated-measures ANOVA: day (4 & 5) x delay of laser onset (25, 50, and 300 ms delay and no-onset control) x target eccentricity (1.6, 3.7, 5.9, 6.7, and 8.1°). Two of the 40 cells in the experimental design were missing 1 of 10 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 for the missing observation in each case.

Day of testing significantly affected both the speed [$F(1, 9) = 11.53, p < .01$] and accuracy [$F(1, 9) = 11.09, p < .01$] of target-location responses. The mean (\pm SEM) speed of target-location responses (in milliseconds) was lower on day 5 relative to day 4 ($956 \pm 23; 1021 \pm 33$, respectively). Likewise, accuracy of target location was significantly improved on day 5 relative to day 4 ($130.7 \pm 3.4; 124.4 \pm 3.8$, respectively). Day of testing, however, did not interact with DLGO or target-eccentricity effects reported below. The main effects of DLGO and target eccentricity were significant for both speed [$F(3, 27) = 150.00, p < .001; F(3, 36) = 39.77, p < .001$, respectively] and accuracy [$F(3, 27) = 30.09, p < .001; F(3, 36) = 26.33, p < .001$, respectively] of target-location responses. An examination of DLGO and target-eccentricity effects were, however, limited to tests of the significant DLGO by target-eccentricity interaction for both speed [$F(12, 108) = 7.64, p < .001$] and accuracy [$F(12, 108) = 2.11, p < .05$] of responding. Figure 6 summarizes these findings for speed and accuracy of responding. Pairwise comparisons (Tukey's HSD; $p = .05$) were made among the means (DLGO) at each target eccentricity. Three pairwise comparisons at each target eccentricity were most important in this study: no-glare control versus DLGO of 25, 50, and 300 ms. Table 3 presents the means for speed and accuracy of responding for each DLGO condition across the five target eccentricities.

Table 3. Cell Means (\pm SEM) for the Delay of Laser Glare Onset by Target Eccentricity Interaction (Correct Responses Only).

Target eccentricity	Delay of laser glare onset (ms)			
	Control	25	50	300
	<i>Speed of responding (ms)</i>			
1.6°	653 (25)	1187 (29)	1052 (31)	702 (38)
3.7°	653 (22)	1105 (24)	1072 (36)	728 (34)
5.9°	717 (24)	1119 (23)	1100 (32)	797 (23)
6.7°	938 (39)	1184 (32)	1178 (32)	959 (36)
8.1°	1023 (39)	1259 (38)	1262 (33)	1078 (43)
	<i>Accuracy of responding</i>			
1.6°	7.6 (0.2)	6.2 (0.3)	6.1 (0.4)	7.7 (0.1)
3.7°	7.8 (0.1)	6.8 (0.3)	7.1 (0.2)	7.5 (0.2)
5.9°	7.6 (0.2)	6.3 (0.3)	6.1 (0.3)	7.5 (0.2)
6.7°	6.8 (0.3)	5.0 (0.3)	5.3 (0.4)	6.0 (0.4)
8.1°	6.6 (0.3)	4.2 (0.4)	4.5 (0.4)	5.2 (0.3)

EXPOSURE

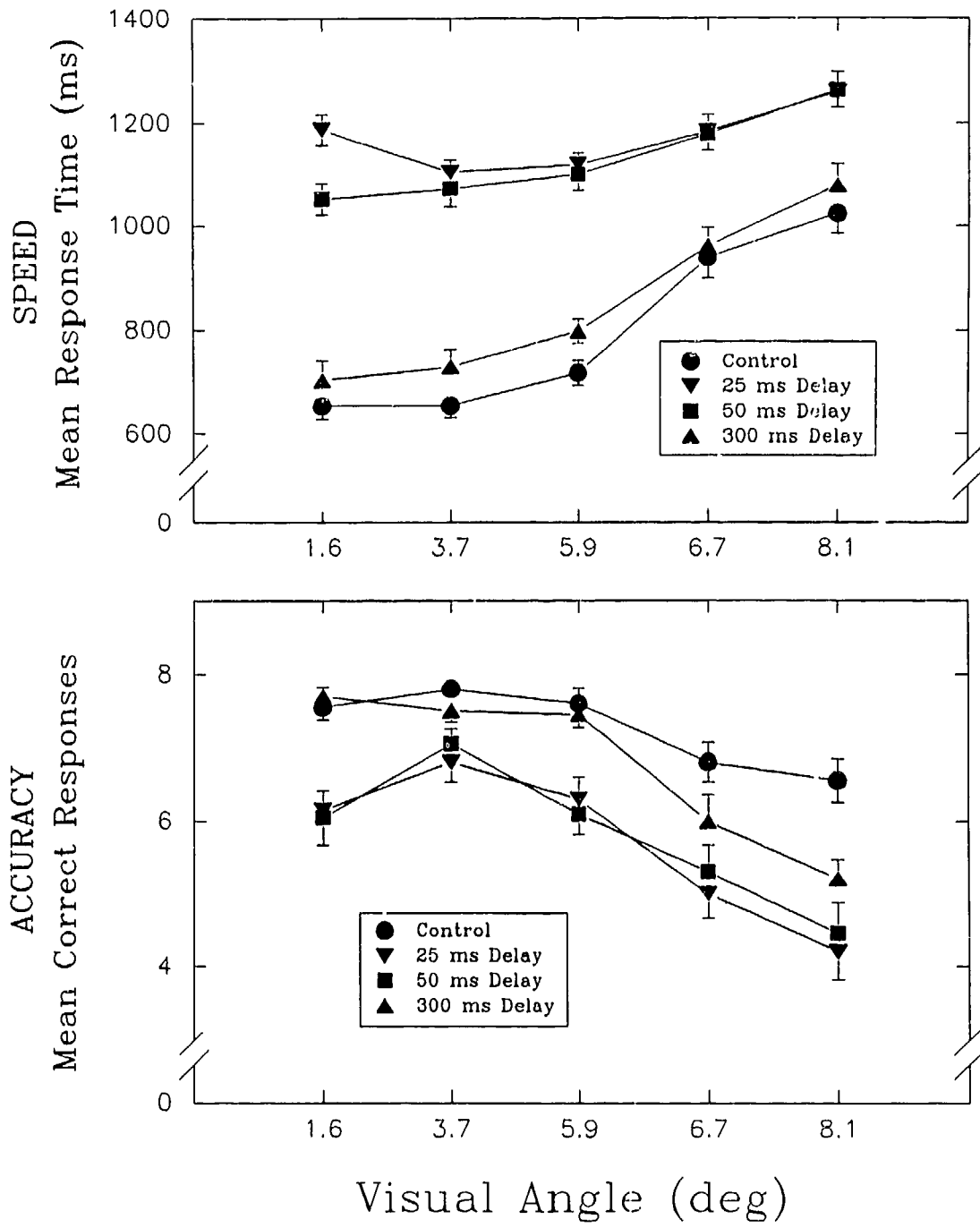


Figure 6. Speed (mean response time) and accuracy (mean correct responses) of target-location responses as a function of delay of laser glare onset and target eccentricity.

Relative to the no-glare control, speed of responding was affected by DLGO in the following manner:

The 25- and 50-ms DLGO condition produced significant decrements in speed of responding at every target eccentricity (1.6-8.1°)

No significant decrements in speed of responding were observed for the 300-ms DLGO condition.

Excluding target eccentricity 1.6°, speed of target location between the 25- and 50-ms DLGO conditions did not differ reliably across target eccentricities.

Notable as well is the observation that speed of responding slowed incrementally as the distance between the target and display center increased. For the no-glare control and 300-ms DLGO conditions, speed of target location was significantly slower for targets at eccentricities 6.7 and 8.1° relative to eccentricities 1.6, 3.7, and 5.9°. This 'eccentricity' effect was less pronounced in the 25- and 50-ms DLGO conditions. Targets 8.1° from the center of the display were responded to significantly slower than those at 3.7° and 5.9° in the 25-ms DLGO condition. In the 50-ms DLGO condition, speed of responding was significantly slower for targets at an eccentricity of 8.1° relative to 1.6, 3.7, and 5.9°. In addition, speed of responding was significantly slower for targets 6.7° from the center of the display relative to those 1.6° from the center of the display.

Delay of laser glare onset also affected accuracy of target-location performance. Each DLGO condition reduced accuracy of target-location performance relative to the no-glare control as follows:

Accuracy of target-location was significantly reduced in the 25-ms DLGO condition for targets appearing at eccentricities 1.6, 6.7, and 8.1°.

The 50-ms DLGO condition produced similar effects with accuracy of responding being significantly lower at target eccentricities 1.6, 5.9, 6.7, and 8.1°.

The no-glare control and 300-ms DLGO condition differed reliably only at target eccentricity 8.1°.

As with speed of responding, accuracy of target-location performance in the 25- and 50-ms DLGO conditions did not differ reliably. Finally, no reliable differences between the means were observed between the no-glare control and the 25-, 50-, and 300-ms DLGO conditions at target eccentricity 3.7°. That is, target-location accuracy was essentially the same across all conditions for targets appearing 3.7° from the center of the display.

As with speed of responding, accuracy of target-location performance varied as a function of a target's distance from the center of the display. For the no-glare control, accuracy of responding was significantly lower for targets appearing at eccentricity 8.1° relative to eccentricity 3.7°. The effect of target eccentricity was the same for the 25- and 300-ms DLGO conditions and showed that accuracy of target location was significantly lower for targets appearing at eccentricities 6.7, and 8.1° relative to 1.6, 3.7, and 5.9°. Targets appearing 8.1° from the center of the display were responded to less accurately than those at 1.6, 3.7, and 5.9° in the 50-ms DLGO. In addition, for the 50-ms DLGO, accuracy of responding was significantly lower for targets 6.7° from the center of the display relative to those 3.7° from display center.

Both speed and accuracy of responding were affected similarly by DLGO. This is probably due to subjects' ability to maximize both speed and accuracy of responding across DLGO conditions as instructed. In fact, the speed-accuracy operating characteristic curve (see Fig. 7) shows no evidence of a speed-accuracy tradeoff. Both speed and accuracy of performance decreased nearly proportionately for each DLGO condition.

VISUAL ASSESSMENT COMPARISONS

To determine any possible effects of laser light exposure on visual function, *t* tests ($p < .05$) 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.

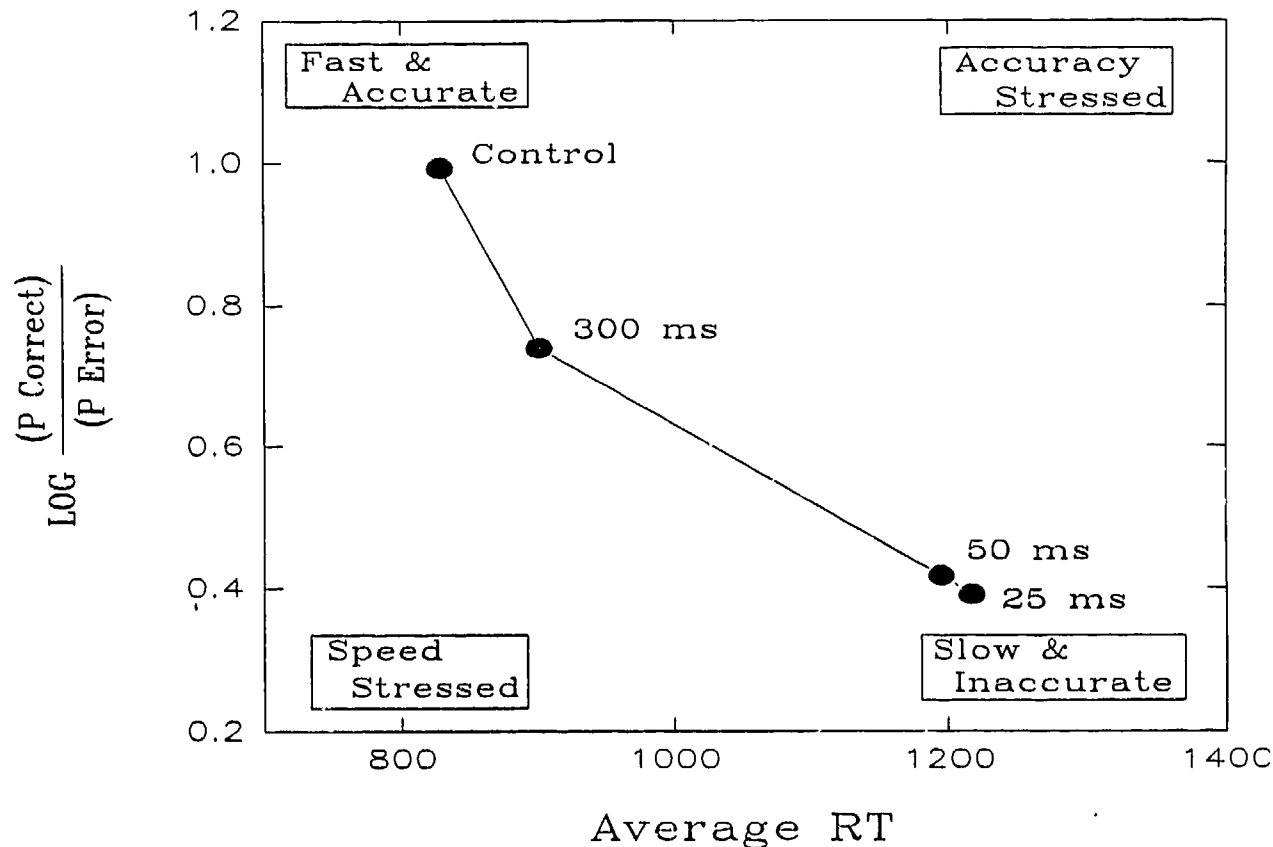


Figure 7. Speed-accuracy operational characteristic curve across the control and delay-of-laser-glare-onset conditions.

DISCUSSION

Speed and accuracy of locating targets in a briefly presented visual array were examined separately for nonlaser training trials and laser-exposure trials. 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. 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 the accuracy data would not have provided an appropriate baseline against which to judge performance under the DLGO conditions. Additionally, speed and accuracy of locating targets close to the center of the visual display were not differentially affected by the number of days an individual participated in the study. More importantly, performance on the final 2 days of training did not differ reliably. 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 periphery. D'Andrea and Knepton (7) and D'Andrea et al. (8) have made parallel observations regarding speed of target-location responses for a nearly identical visual array viewed by

subjects for a longer period of time. This is not an unexpected observation as early researchers of visual search (e.g., 14) found that subjects have a tendency to search the center of a display for a target more often than the edges.

Several general observations can be made with respect to the effect of laser-induced glare on target-location performance. Most interesting, DLGO differentially affected both the speed and accuracy of target-location performance. This occurred even though the visual array was clear, and not masked by glare, for the same amount of time (600 ms) under each of the DLGO conditions. Short delays in glare onset (25 and 50 ms), relative to display onset, were associated with decrements in both the speed and accuracy of target-location performance whereas a longer delay (300 ms) had no effect on speed of responding and a negligible effect on accuracy of responding. The detrimental effects observed in the 25- and 50-ms DLGO conditions were nearly identical. Figure 5 indicates that the increase in response time (relative to the no-glare control) in these two conditions averaged 350 ms ($SEM = 33$), which is the sum of laser glare duration plus DLGO. This observation suggests that visual information processing was disrupted by the onset of laser glare and did not resume until glare was terminated 300 ms later. Although the locus of this effect cannot be determined from these data, we believe that laser glare with these temporal characteristics interfered with either visual information persistence (e.g., iconic or short term visual memory) or subsequent higher-level visual information processes.

Decrement in both the speed and accuracy of performance, when they occurred, were not as severe as those found in studies where laser glare was present for the entire viewing period in a static-display target-location task (7-9). Interestingly, however, subjects' accuracy of target location under the 25- and 50-ms DLGO conditions was best for targets appearing 3.7° from the center of the display. In a study where glare of the same intensity was continually present for the entire 900-ms viewing time of the same visual array (9), accuracy was best at target eccentricities farther from the center of the display ($5.9-8.1^\circ$). In addition, speed of responding in the 25- and 50-ms DLGO conditions never equaled that of the no-glare control, even at target eccentricities far removed from the center of the visual array (beam path). However, when glare was present throughout the 900-ms viewing period (9), speed of target-location responses equaled that of the no-glare control for targets residing 6.7 and 8.1° from the center of the beam path.

A theoretical treatment of the potential backward-masking effects of glare may seem to be in order at this point. However, such a treatment of the data is difficult due to differences in the masking paradigm used here and that used in investigations of iconic memory (e.g., 15) and visual persistence (e.g., 16). Unlike the traditional backward-masking paradigm, our visual display was viewed not only before but also during and after the occurrence of laser-induced glare. The effect of DLGO might then be attributed to several factors other than the capacity and duration of visual iconic or short-term memory. The overlying question here is not one of visual persistence under conditions of laser-induced glare but rather, *What is the nature of target-location failure in a visual search task punctuated by brief pulses of laser glare?* We believe the present study shows that the presence of laser glare is not sufficient in and of itself to cause decrements in target-location performance. The time at which laser glare is experienced, relative to the time at which the visual array to be searched is acquired, differentially influences target-location performance. If a 900-ms duration visual scene is searched for 300 ms prior to a brief (300 ms) exposure to laser glare, target-location performance is negligibly affected. However, when laser-induced glare is experienced in closer temporal proximity to the onset of a visual scene to be searched, decrements in target-location performance are observed. An additional study that varies DLGO between 51 and 299 ms will be required to derive a function relating speed and time of visual scene acquisition to DLGO and target eccentricity. In addition, a forward-masking study is needed to address the effects of exposure to brief duration laser glare occurring prior to visual scene onset. Studies that have examined the effects of laser glare, when it is experienced prior to, coincident with (e.g., 9), or after visual scene onset will form the basis for predicting the probability of target-location failure in an environment where visual search is punctuated by brief pulses of laser glare.

This study also supports the conclusion that low-level argon laser-induced glare (556 times below the MPE for a 36-s cumulative exposure; 4867 times below the MPE for a 300-ms exposure), viewed through an aircraft windscreen causes significant decrements in visual search performance for briefly displayed visual

information. Again, the detrimental effects of laser-induced glare are contingent upon the time at which glare impacts a visual scene just acquired by an observer.

RECOMMENDATIONS

Eye protection is needed to prevent mission disruption even at laser intensities that are not harmful to the eye. The type of eye protection most suitable for use in dawn/dusk and nighttime environments should be carefully scrutinized however, as most if not all available eye protection will reduce the amount of ambient light reaching the retina. Small reductions in ambient light during dawn/dusk flight may cause decrements in the acquisition of critical visual information both inside and outside the cockpit.

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Other Related NAMRL Publications

Reddix, M.D., DeVietti, T.L., Knepton, J.C., and D'Andrea, J.A., *The Effect of Three Levels of Laser Glare on the Speed and Accuracy of Target Location Performance When Viewing a Briefly Presented Visual Array*, NAMRL-1359, Naval Aerospace Medical Research Laboratory, Naval Air Station, Pensacola, FL, November, 1990.