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FLASH/CRAZING EFFECTS ON SIMULATOR PURSUIT TRACKING PERFORMANCE

DAVID A. STAMPER, MA
DAVID J. LUND, BS
RICHARD R. LEVINE, PhD, CPT MSC
JEROME W. MOLCHANY, BS, SGT
and
PAUL BEST, PhD, MAJ MSC

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Flash/crazing effects on simulator pursuit tracking performance
--Stamper et al

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Day sights which are purposefully or inadvertantly irradiated with laser radiation may become nonfunctional due to cracking or crazing of the optical glass. The degree of performance degradation may be related to the amount of damage to the glass and possible flash blindness from reradiation. Thirty-two male enlisted men and officers tracked a scale model tank through a constant arc at a simulated distance of 1 km, using a laboratory constructed viscous-damped tracking device. There were four crazing groups (4 men/group) under bright and dim ambient light conditions for a total of eight groups. Each

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man tracked the target during three flash/crazing and three crazing only trials, which were randomly presented during 30 trials. The simulated countermeasure which included the flash and crazing had dramatic effects on tracking performance, even under daylight conditions. Under the most severe degree of crazing, tracking performance was not possible under either ambient light condition. The relatively small amounts of laser radiation used to craze the Bk-7 glass used in this study, which lead to significant performance decrements, demonstrates the potential impact of flash/crazing effects on operators of day sights.

ABSTRACT

Day sights which are purposefully or inadvertently irradiated with laser radiation may become nonfunctional due to cracking or crazing of the optical glass. The degree of performance degradation may be related to the amount of damage to the glass and possible flash blindness from reradiation. Thirty-two male enlisted men and officers tracked a scale model tank through a constant arc at a simulated distance of 1 km, using a laboratory constructed viscous-damped tracking device. There were four crazing groups (4 men/group) under bright and dim ambient light conditions for a total of eight groups. Each man tracked the target during three flash/crazing and three crazing only trials, which were randomly presented during 30 trials. The simulated countermeasure which included the flash and crazing had dramatic effects on tracking performance, even under daylight conditions. Under the most severe degree of crazing, tracking performance was not possible under either ambient light condition. The relatively small amounts of laser radiation used to craze the BK-7 glass used in this study, which lead to significant performance decrements, demonstrates the potential impact of flash/crazing effects on operators of day sights. Keywords: Pursuit tracking, Crazed Optics.

PREFACE

We express thanks to SGT Daniel Chang and Mr. Bill Van Sice for their technical support during the data collection phase of this project. We are indebted to Virginia Gildengorin, PhD, for her invaluable statistical assistance and to Lottie B. Applewhite for her expert editorial improvements.

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Operators of military weapon systems which include magnifying optics play a critical role in the success of each mission of a battlefield combat unit. These soldiers are primary targets for countermeasures. This is especially true for operators of active devices such as laser rangefinder/designators, which emit a signal which the enemy can use to detect these systems. Included among the possible countermeasures that operators of these systems may encounter is exposure to high energy infrared laser radiation.

The US military has evaluated (1) a tactical CO_2 laser system of medium intensity [i.e., the Close Combat Laser Assault Weapon (C-CLAW)]. The intended purpose for C-CLAW was to damage light sensitive electronic sensors. While a C-Claw type system would be out of band to most direct view optics, it could also produce sufficient heating on the surface of the optics to cause crazing and cracking. Among other reasons which led to the cancellation of the C-CLAW program was the extensive media coverage which noted the possibility that this system could also damage soldiers' eyes. We can not assume than our enemy will be subject to the same pressures which caused our C-CLAW program to be cancelled.

The results of an exposure to the eyes from a C-CLAW type weapon range from flash blindness to frank corneal damage. To the soldier, the results of such an injury would in the most severe cases be painful and debilitating.

Previous work by O'Mara et al. (2) studied the effects of full field flashes (approximately 11°) of incoherent light on a laboratory simulated pursuit tracking task. In that study (2) a Vivatar photoflash unit was used to produce a single 170 s, 538 nm (green), flash. The flash produced significant increases in standard deviation (SD) aiming error along both the horizontal and vertical axes when the postflash scores were compared with the baseline tracking rates. These differences were significantly greater under a dim ambient lighting condition. The average time to return to "normal performance" following the flash under the bright light condition was 2.58 seconds Under the dim ambient light condition it was not possible to measure the maximum excursion of the error or complete recovery to preflash tracking rates due to limitations of the system. However, the time to reacquire a one milliradian (mrad) square target was determined to be approximately 7 seconds. These findings, for a single flash well below the maximum permissible exposure level (MPE), demonstrate the possible adverse effects that such an exposure could have on tracking performance and how this effect would be enhanced in a dawn/dusk scenario.

The targets for a C-CLAW type system include not only magnifying optics, but windscreens of aircraft. Structural damage to these materials (i.e., usually quartz, BK-7 glass, and polycarbonate laminates) include melting, fracturing, vaporizing, crazing, and the induction of thermal stress. The structural damage to the windscreens or the collecting optics of daysights range from a slight amount of crazing to severe crazing and fracturing of the glass. The exact type and amount of damage depends upon a complex interaction which has been discussed in other work (3). The degree of damage to the optics is related to the parameters of the laser, atmospheric effects, and the physical properties of the optics.

Demske and Bell (4) evaluated the effects of infrared laser radiation on several glass and polycarbonate materials. Included in their report (4) is a five category classification of crazing effects which extend from slight to severe. This classification effectively covers a range of structural damage which extends from a slight swelling of the material to catastrophic cracking, swelling, and crazing due to surface ablation during the rapid heating and cooling process.

While studies have been conducted to determine the interaction of high energy laser radiation with optical materials (3), no systematic effort has been initiated to evaluate the effects of crazing on the soldier's ability to perform a military task. The present study assessed the effects of three levels of crazing on simulator pursuit tracking performance.

METHODS

Volunteers. Thirty-two experimentally naive enlisted men and officers (ages 18 to 35), from the Letterman Army Institute of Research, served as participants for this study. All of the volunteers had 20/20 visual acuity (or corrected to 20/20 visual acuity), normal color vision, and normal dark adaptation as measured by the Snellen Acuity Test (5), the Farnsworth Dichotomous Test (D-15) for colorblindness (6), and the Letterman Army Institute of Research Dark Adaptometer (7), respectively.

Apparatus. All tracking trials were conducted in the BLASER tracking simulator. This system is described by Stamper et al. (8). Briefly, the simulator includes a laboratory constructed viscous-damped designator tracking device that is mounted in a sandbag bunker. The tracking device contains a series of mechanical and optical enhancements which provides a tracking scenario with a simulated range of one kilometer. A scale model Warsaw Pact T-62 tank moves in a fixed arc and at a constant angular velocity of 5 mrad/sec. An infrared television camera, mounted coaxially with the tracking optics, images an infrared light-emitting diode in the center of an aiming patch located at the center of mass of the target. This signal, which is invisible to the operator, provides a reference point for a microprocessor and associated software to measure electronically the accuracy of performance. The maximum range of the system is 5 mrad for the horizontal axis and 2 mrad for the vertical axis.

To conduct this work two modifications were made to the basic system described (8). First, a Vivatar 124 photoflash unit was mounted in the designator and served as the flash source. A beam splitter directed the flash into the eye. A yellow Wratten No. 4 filter was placed over the output of the photoflash unit. This was done to produce a yellow flash similar in color to that observed earlier in our laboratory using a CO_2 laser to craze clear glass.

A spring-driven actuator was mounted on the designator to rapidly insert a piece of BK-7 glass in front of the objective lens of the designator telescope. The insertion time was approximately 1 ms and was synchronized with the flashlamp. The investigator could initiate the insertion of the window at any time during a trial. Four interchangeble pieces of BK-7 glass (three crazed pieces and one clear piece) could be mounted on the actuator, one at a time, for insertion. Immediately after each flash and crazing trial, or crazing only trial, the glass to be used during the next countermeasure trial was exchanged for the one that was just used.

Three 2x2 inch (5.8 x 5.8 cm) pieces of BK-7 glass, which had been irradiated with a laser at 10.6 microns, were obtained from the Directed Energy Directorate at Redstone Arsenal from contractual work conducted by Avco Evenett Research Corporation. The dosimetry for the four windows is presented in Table 1.

The damage to these pieces of glass was rated according to the Damage Classification Descriptions reported by Demske and Bell, (4). This classification system presents five damage modes ranging from 1 to 5, with Number 5 being the most severe. One of the three pieces approximated Damage Mode 2, and the remaining two Damage Mode 3-4. Despite the larger amount of total energy that was used to damage the Mode 3-4(a) piece of glass, this piece showed less damage than did the one labled Mode 3-4(b). The fourth clear piece of BK-7 glass was undamaged and served as the control for the other 3 pieces.

TABLE 1 LASER DOSIMETRY
Pulsed CO_2 laser - 10.6 microns - 15 us/pulse

Damage Level	Exposure Condition	Radiant Exposure (Energy/pulse)
Undamaged (Control)	-	-
Damage Mode 2	1 pulse-10 Hz	4.0 J/cm^2
Damage Mode 3-4(a)	2 pulses-10 Hz	4.0 J/cm^2
Damage Mode 3-4(b)	2 pulses-10 Hz	2.5 J/cm^2

Demske and Bell (4) characterized Damage Mode 2 as follows: "swollen-glassy appearance; partial or marginal volatilization; loss in visibility." They describe Damage Mode 4 as "Partial ablation with loss in visibility over most of the irradiated area. Melting and warping, softening and 'glassy' appearance over all of irradiated area not translucent." Figure 1, A-D presents the view of a scene taken through the four pieces of BK-7 glass. Some cropping seen at the edges of the pictures was due to the presence of the mounting plate and was not attributable to the crazing of the glass.

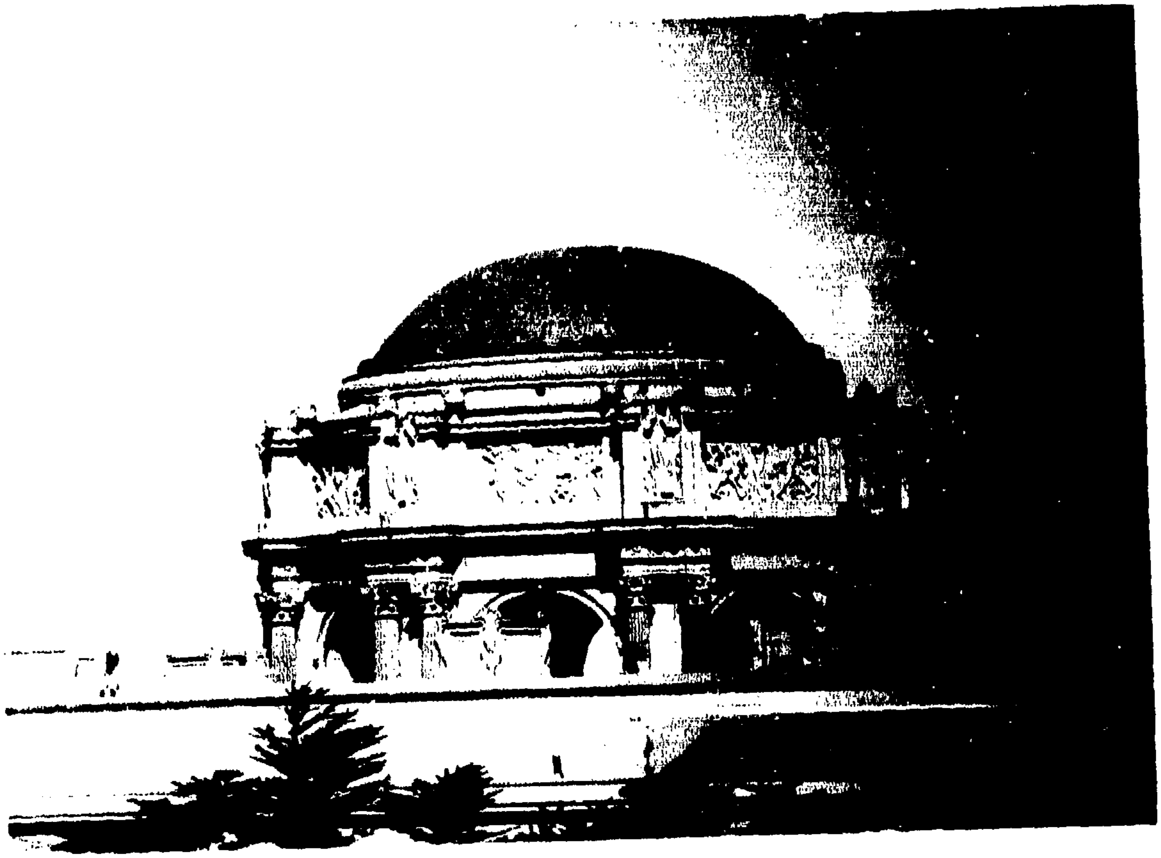

Figure 1(A). Undamaged glass.

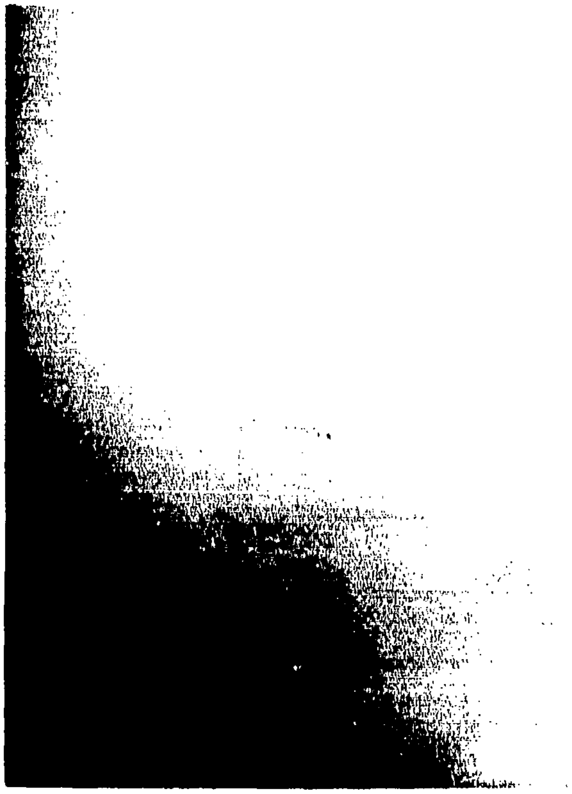

Figure 1(B). Damage Mode 2.

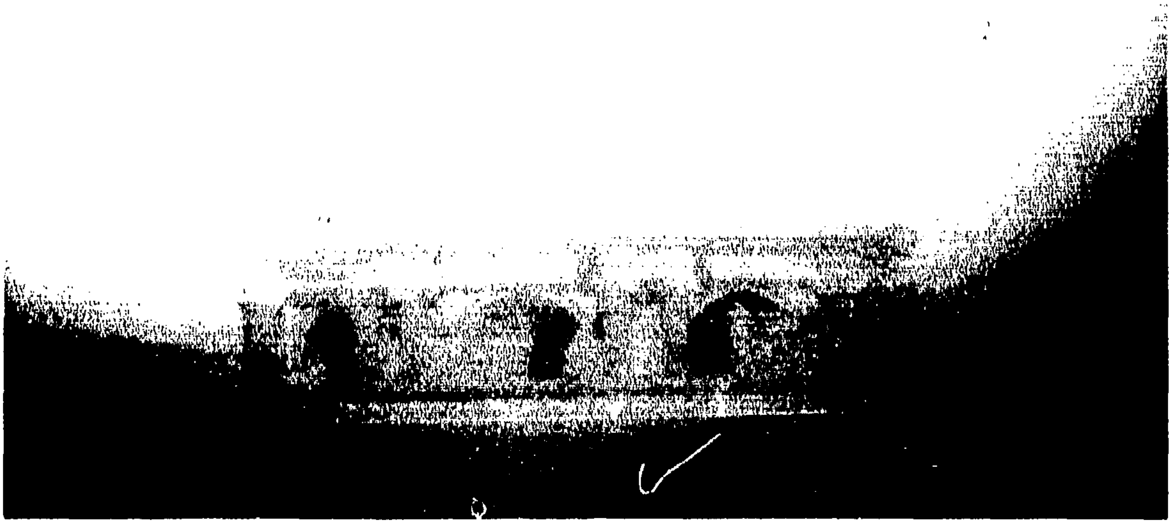

Figure 1(C). Damage Mode 3-4(a).

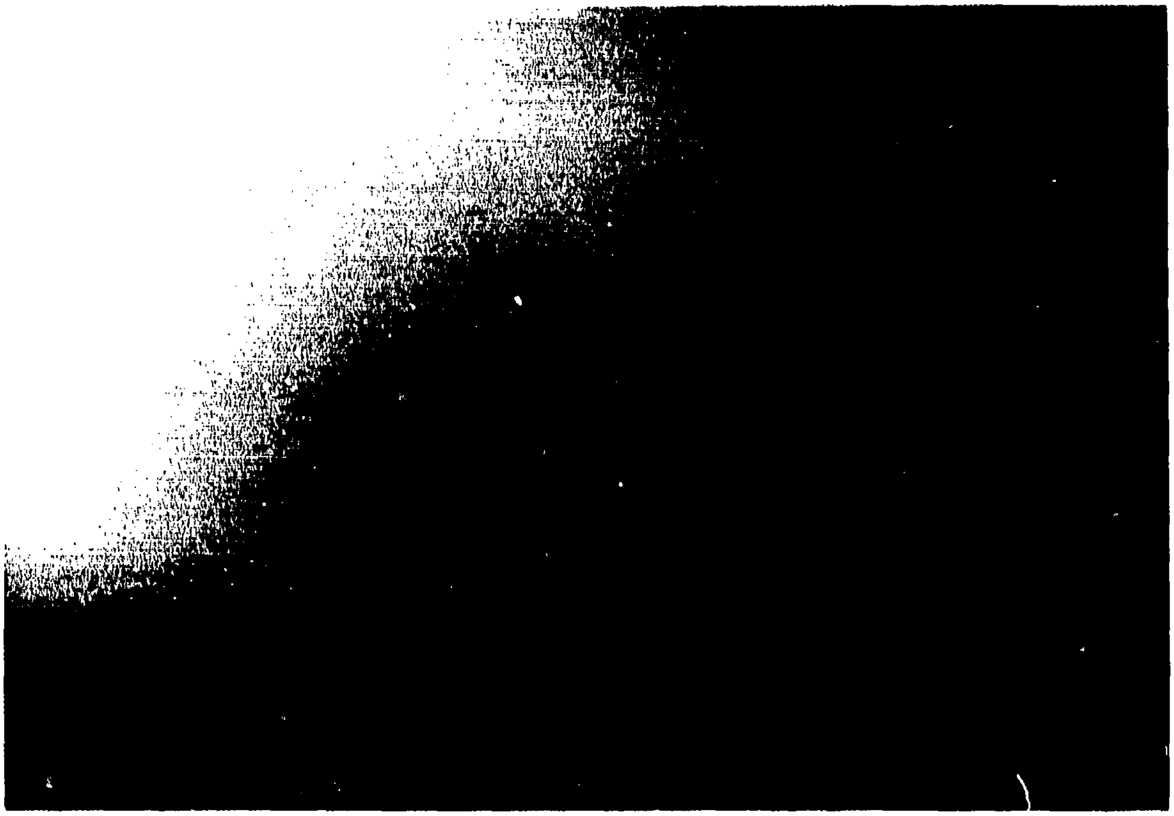

Figure 1(D). Damage Mode 3-4(b).

Within the BLASER system duration and intensity calibrations were obtained for the flash as viewed from the designator eyepiece. The flash duration was 170 s. The flash radiance was adjusted in accordance with the guidelines established in TB-MED 279 to insure that retinal exposure was held within the acceptable safe limits. The measured radiance at the eye was 0.10 J/cm^2 sr, which was 1/5 of the Maximum Permissible Exposure (MPE).

Tracking performance data were collected under two ambient light conditions. The dim ambient light condition was created by inserting a 2.7 OD neutral density filter in the optical pathway of the tracking device. The terrain luminance was measured with a Spectra Minispot Photometer. The average luminance at the objective of the the lens of the tracking device was 250 lm/m^2 with the filter removed and 0.8 lm/m^2 with the filter in place. No light from the terrain entered the bunker except through the eyepiece of the tracking device optics. During the dim ambient light trials the bunker light was turned off and the trackers sat in the semi-darkened bunker for approximately 10 minutes to allow their eyes to adjust to the low ambient light level.

Procedure. Following their ophthalmic examination, a brief question and answer period was conducted where the purpose of the study was explained to each volunteer. The volunteers were then alternately assigned to one of the two ambient light conditions (i.e., bright or dim). They were then randomly assigned in an exhaustive sequence to one of the four crazing groups. Each tracker was assigned to only one light level/crazing condition.

To begin the study, all volunteers received two days of training that followed a massed/distributed format. This schedule has been used extensively in the BLASER simulator and has been shown to provide stable tracking performance (9,10). The first training day consisted of twenty-two 1-minute trials. Eleven of these trials were conducted under the bright ambient light condition and eleven under the dim ambient light condition. The second training day consisted of thirty-two, 15-second trials. Again, half the trials were performed under the bright ambient light condition and half under the dim ambient light condition.

The test day consisted of thirty-five, 15 second trials. The trackers performed all 35 trials under their assigned ambient light group. Six countermeasure trials were presented during the first 30 of the 35 total trials. The flash presentation order was distributed across the 30 trials at a rate of one/five trials. Within each block of five trials the flash trials were randomly presented, but to avoid possible confounding effects each flash trial was followed by at least one no flash trial. The first three of these countermeasure trials presented during the first fifteen trials were "flash and crazing" trials. That is, they contained a flash and simultaneous insertion of one of the pieces of BK-7 glass. The second set of three countermeasure trials that were presented during trials sixteen to thirty were "crazing only" trials with no flash. The remaining 5 trials, 31 through 35, were performed with the crazed optics in place for the entire trial (These trials were designed to answer the question, "If a soldier found a damaged sight, could it be used effectively?") These trials will not be discussed in detail during this report, but the results paralleled the findings for each lens found during the first 30 trials for each tracker.

The tracking sessions began with the crosshairs aligned on the target patch and the target on the left side of the terrain board. Each trial was initiated with the commands "READY" and "GO". After each trial the volunteers were instructed to "RELAX" until the next "READY" command. Following each trial the trackers were given summary statistics (percent time-on-target and standard deviation scores) for that trial. All volunteers tracked in both directions (left-to-right and right-to-left), alternately. The investigator initiated the countermeasure event 3 to 5 seconds after the operator began tracking. (All countermeasure trials were tracked in the left-to-right direction).

Statistical Presentation. Based on earlier BLASER simulator studies which have shown the predominant horizontal nature of this tracking task (9,10), we will present only the results for the horizontal error scores. The two dependent measures used to describe the results of this study are: maximum horizontal tracking error for each trial, and time to reacquire the target after the countermeasure event. Both of these measures are related to the amount of disturbance created by the countermeasure and both are known from previous studies, to be very low and stable under normal tracking conditions (11).

RESULTS

During the data reduction process it was discovered that data for three of the trackers was invalid due to hardware problems which led to spurious data. These data were deleted and the results are based on N=29.

Maximum Horizontal Error: Flash + Crazing. The maximum horizontal error scores are illustrated in Figure 2, A-D. This figure presents the percent of observations which fall into four categories of maximum horizontal error: 0-1 mrad; 1-2 mrad; 2-3 mrad; and greater than 3 mrad (i.e., beyond the limits of the system). Figure 2, A and B (flash and crazing trials), shows that tracking errors for the control window under both ambient light conditions were generally 2 mrad or larger. During the bright light trials the maximum error for the undamaged, Mode 2, and Mode 3-4(a) groups were fairly evenly distributed across the four ranges of maximum error. However, with the Mode 3-4(b) lens, all errors were larger than 3 mrad. This was also true for the Mode 3-4(b) group under the dim light condition. Comparison of the maximum error scores between the bright and dim light conditions indicated that the dim light error rates were generally larger. In fact, under the dim ambient light condition except for the clear glass, there was only one instance of an operator reacquiring the target after the countermeasure (i.e., Mode 2). Under the dim light with any of the crazed pieces of glass most of the observations were greater than 3 mrad.

Maximum Horizontal Error: Crazing Only. For the crazing only trials (Figure 2, C and D), the maximum tracking error was substantially lower than the flash and crazing scores under both light levels. During the bright light the pattern of maximum error scores for the Mode 2 and Mode 3-4(a) pieces was highly similar to the undamaged (control) glass. For these three groups the majority of the maximum error scores were found to be less than 1 mrad. However, as with the flash and crazing trials no recovery was found when the Mode 3-4(b) glass was used under either light condition. Under dim light the distribution of error scores for the undamaged glass was similar (<1 mrad) to the bright light trials where this piece was used. The maximum error scores for the Mode 2 and Mode 3-4(a) pieces were alike under dim light. The scores were distributed relatively evenly across all error ranges.

Reacquisition Time: Flash + Crazing. The reacqusition times (time to reacquire the target patch) are summarized in Figure 3. These data represent the percent of observations which fall into five categories of reacquisition time: 0-2 seconds; 2-4 seconds; 4-6 seconds; 6-8 seconds; and, >8 seconds. For the bright light flash and crazing trials (Figure 3, A) reacquisition times using the Undamaged, Mode 2, and Mode 3-4(a) pieces were alike, but different from the Mode 3-4(b) reacquisition times. While the times for the Undamaged, Mode 2, and Mode 3-4(a) were generally less than 6 sec, the Mode 3-4(b) group never reacquired the target. This was also true for the Mode 3-4(b) trackers under dim light (Figure 3, B).

A different distribution of reacquisition times is seen when the dim light control is compared with the bright light control data. Under the dim light condition the reacquisition times were, with one exception, 4 seconds or longer as opposed to the bright light trials where they were generally 4 seconds or less. The reacquisition times for the dim light condition were consistently longer under dim light than under bright light for each level of crazing. Further, under dim light, reacquisition never occurred after the countermeasure event when any of the three crazed lenses were inserted.

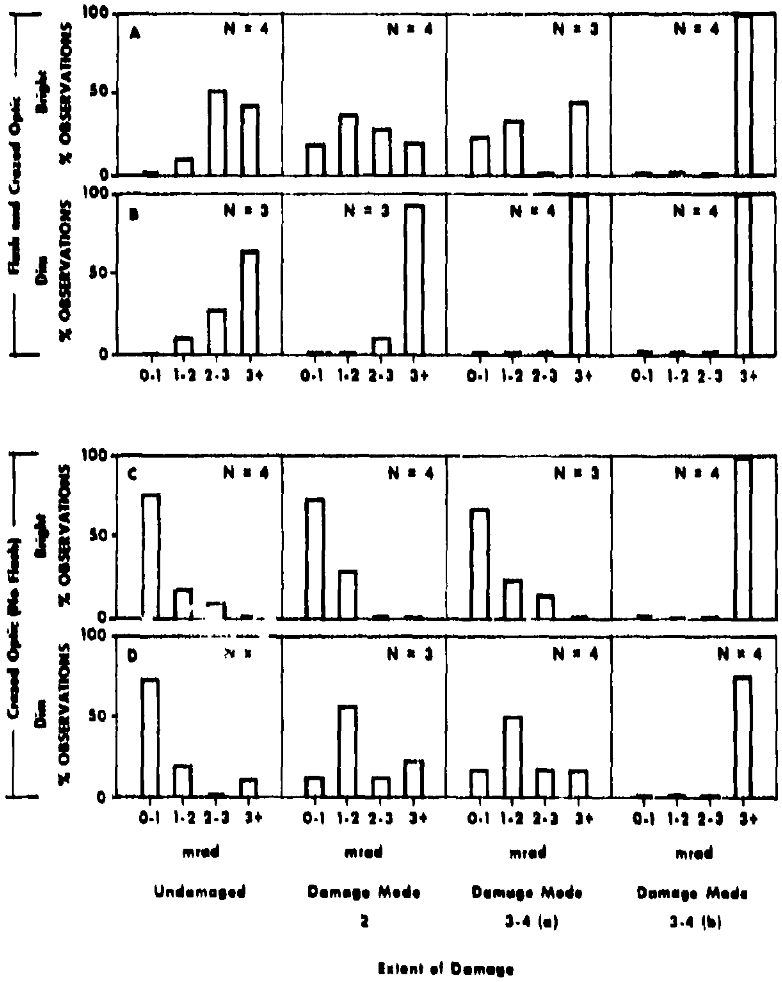

Figure 2. Distribution of maximum horizontal error scores within each of four range categories.

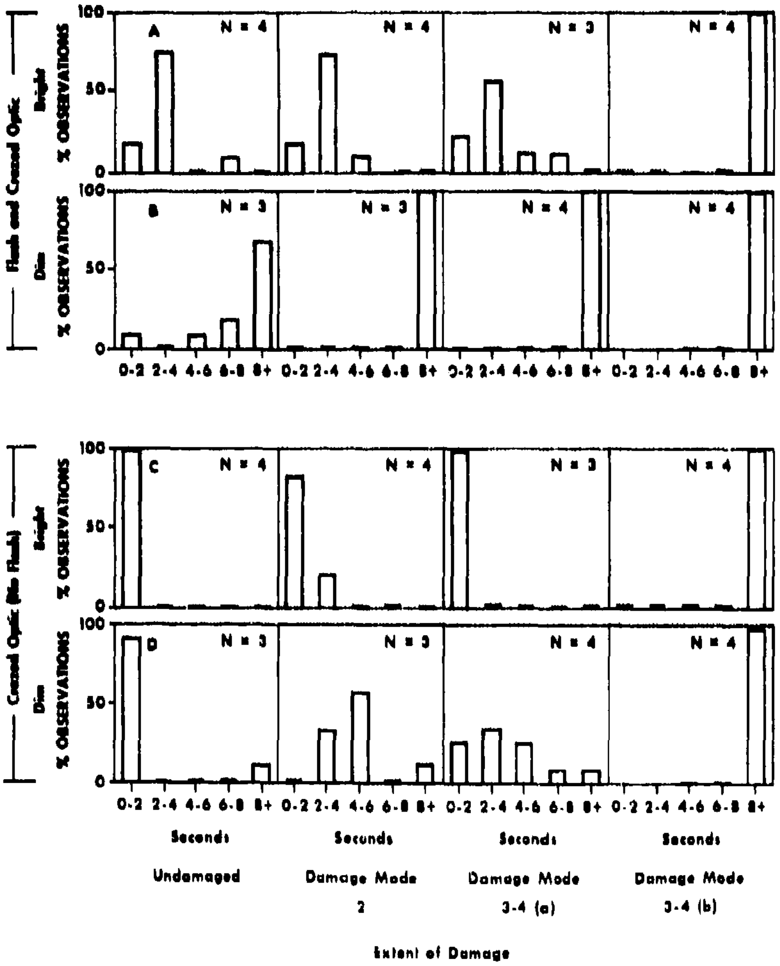

Figure 3. Distribution of reacquisition times across five time periods.

Reacquisition Time: Crazing Only. The reacquisition times for the crazing only countermeasure (Figure 3, C and D) presented a pattern of scores that differed from the flash-and-crazing countermeasure. Under the bright light condition, with the exception of one score (Damage Mode 2), the Control Group, Mode 2, and Mode 3-4(a) reacquisition times were all less than 2 seconds. The Mode 3-4(b) reacquisition scores were all in excess of 8 seconds indicating that they never saw the target again. That was also true for Mode 3-4(b) scores under the dim ambient light level.

While the control group reacquisition scores under the dim light condition were nearly identical to the bright light Control Group, under the dim light condition, the Mode 2 and Mode 3-4(a) lenses did effect reacquisition times. This is shown by the appearance of scores in several scoring categories from 2 to 8 sec.

DISCUSSION

The results of this study indicate that the combined effects of this simulated countermeasure which includes flash and crazing can have a very dramatic effect on tracking performance, even under daylight conditions. Comparison of the flash-and-crazing trials with the crazing only trials provides information concerning the relative contribution of the flash and each piece of crazed optic. During all bright light flash trials maximum error scores generally increased. In some cases the excursions were larger than 3 mrad. However, when the first two crazing levels were compared to the clear glass, the amount of change was the same. It was not until the Damage Mode 3-4(b) was encountered that an additional decrease in tracking performance was seen. When the Damage Mode 3-4(b) lens was encountered, tracking performance was no longer possible. This was true for both ambient light conditions. The crazing only trials support this observation since the maximum error scores did not change until the most severe level of crazing was encountered.

The reacquisition time scores are in accord with the results of the maximum error data. These data show that once the flash was over, the time needed to reacquire the target through clear glass, Damage Mode 2, and Damage Mode 3-4(a) lenses was approximately the same. When the degree of crazing represented the damage Mode 3-4(b) was reached, the ability to track ceased. Together, these findings indicate that under bright ambient light conditions, tracking performance was not severely effected by the increases in crazing represented by damage Mode 2 and 3-4(a). However, with damage Mode 3-4(b), tracking was no longer possible.

The trials conducted under dim ambient light conditions yielded a different pattern of scores. The strong effect of the flash found in the earlier study by O'Mara et al (2) was again found during these trials. Even with the clear glass, maximum error scores were generally larger than 2 mrad. During the dim light trials where the crazed optics were introduced, with one exception, all error scores were larger than 3 mrad. The reacquisition times supported this finding in that all scores for trials where crazed optics were used were greater than 8 seconds (i.e., they never reacquired the target).

The contribution of crazing to this dramatic effect can be determined by comparing the crazing only trials with the trials where the flash was used. Maximum error scores during dim ambient light trials where crazing only was used, indicated that the first two levels of damaged lenses did have an adverse effect on tracking performance. When the Mode 2 and Mode 3-4(a) maximum error scores were compared to the scores for the control group, increases in the number of larger errors are seen. The pattern of the reacquisition times for the dim ambient light, no flash trials is almost identical to these maximum error scores. When trackers were asked to perform under conditions where the visual system is already near the limits of its ability, the added effects of crazing can be seen.

From the above observations is it apparent that operators of visual tracking systems may be vulnerable during bright and dim ambient light conditions. During bright ambient light the effects of the flash seem to predominate until a threshold level of crazing is reached. Beyond this crazing level, the added effect of the flash becomes inconsequential with respect to decrements in tracking performance. These trials were performed in an uncluttered environment with a moving target. The effects of these levels of crazing on a detection task in a more cluttered environment may produce performance decrements. But in this tracking exercise where high spatial resolution is not critical, a threshold effect was found, and when it was reached, the trackers could not continue.

Tracking was severely affected by the flash and crazing event under dim light. All three experimental levels of crazing combined with a flash produced maximal disruption of tracking and reacquisition. In a combat situation where the eye has become accustomed to dim light, the reradiation effects can be expected to be dramatic and any degree of crazing which follows will severely reduce the likelihood of completing the mission.

CONCLUSIONS AND RECOMMENDATIONS

A important next step in this line of research is to characterize crazed optics with a metric that provides an index of the modulation of spatial frequencies by the optics. Such a metric would allow precise scaling between levels of crazing in terms of the optical ffect on vision.

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