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**VISUAL COMPENSATORY TRACKING PERFORMANCE
AFTER EXPOSURE TO FLASHBLINDING PULSES:
II. SUB-DAMAGE-THRESHOLD LASER IRRADIATION
OF RHESUS MONKEY SUBJECTS**

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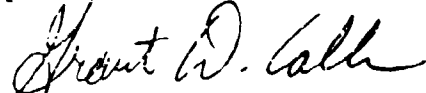
NOTICES

This final report was submitted by personnel of the Weapons Effects Branch, Radiation Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7757-05-42. Experiments were performed in a joint effort with the Department of Psychology, University of Texas at El Paso, El Paso, Texas 79968, under contract F33615-79-C-0600.

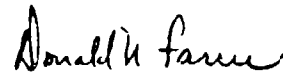
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The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act of 1970 and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

This technical report has been reviewed and is approved for publication.



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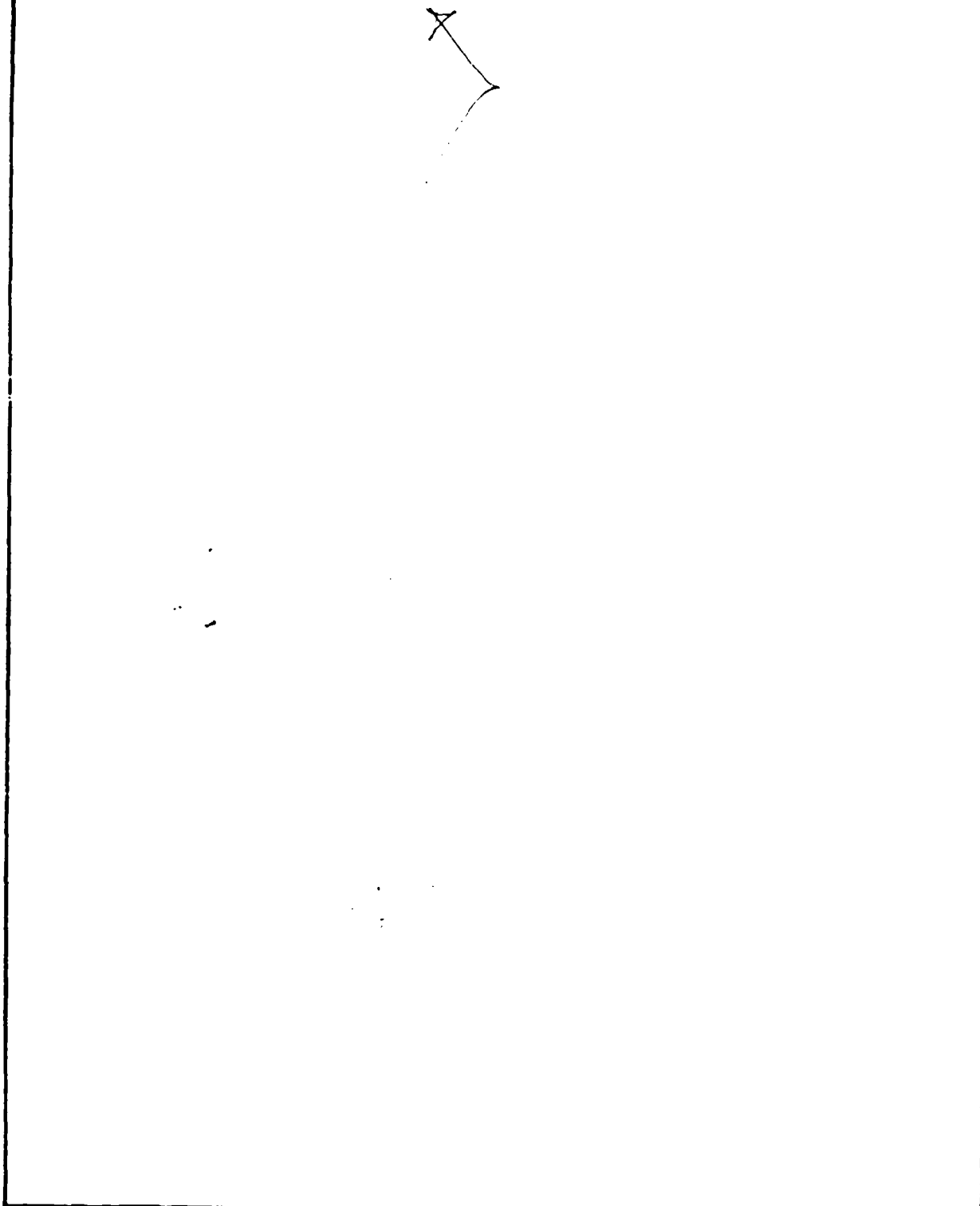
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20. ABSTRACT (Continued)

exposure-related events were indistinguishable in appearance from random startle events that occurred frequently during task performance. We concluded that, for these studies, the laser exposures caused momentary startles that were probably not true flashblindness incidents.



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VISUAL COMPENSATORY TRACKING PERFORMANCE AFTER EXPOSURE
TO FLASHBLINDING PULSES: II. SUB-DAMAGE-THRESHOLD
LASER IRRADIATION OF RHESUS MONKEY SUBJECTS

To maintain effectiveness in modern combat, Air Force flight and ground crews will be required to perform in an environment saturated with electromagnetic radiation. The environment will probably include laser radiation in visible wavelengths, either deliberately or accidentally directed into the eyes of combatants or support personnel.

Thresholds for minimally detectable eye damage have been predicted, but little is known about the reactions of people performing visually oriented tasks who are suddenly exposed to coherent radiation at energy levels near, but below, the thresholds. The experiments reported herein explore this problem by testing tracking performance immediately after exposure to such irradiation. Animal subjects were employed for this testing because the use of humans was inappropriate for such high-energy exposures, even though no eye damage was likely to be sustained.

BACKGROUND

Most studies of flashblindness have been generated during the past 30 years to try to characterize the ocular response after accidental viewing of nuclear fireballs in combat situations. These dealt with flashblinding sources subtending relatively large visual angles. The source images in these instances were large enough to completely cover the fovea centralis--the retinal area containing almost all of the functional cones of the visual system. Only recently has the subject of flashblindness due to combat lasers been raised by concerned investigators. If the eye were a perfect lens, an incoming laser beam would be focused to a very small point on the retina and flashblindness would not occur. The concern revolves about the fact that since the eye is not a perfect lens, it might scatter enough light so that off-center energy deposition would be significant. The few studies addressing this question have done so from an analytic standpoint, geometrically examining the laser beams spread on the fovea. Some of these indicate that the energy spreading would be insignificant (8,10), while others hold out the possibility that the off-center energy might be sufficient to cause flashblindness (2,11).

The present experiments examine the flashblindness question from an operational standpoint, using conscious animal subjects exposed during performance of a compensatory tracking task.

Rhesus monkeys were used as test subjects because of their conveniently small size, their ability to learn tasks analogous to those required of humans in combat, and the near identity of their retinal architecture and function to that of humans (4,5). In addition, a previous study in this laboratory has shown that, for testing of the particular type used here, the rhesus is an acceptable human analogue for estimating flashblindness recovery times (3).

Exposures were created with single pulses of a dye laser operating in one of two modes: green (513 nm) or white (combination of four wavelengths in blue, green, and red). The damage threshold for rhesus monkey eyes from exposure to such pulses is approximately 4-5 μJ ; this threshold appears to be relatively independent of wavelength in the visible spectrum (1,6,7,9). The present tests were conducted at energies just under this threshold (0.55-3.75 μJ) to allow for maximum possible results without causing eye damage.

Thus the overall experimental plan was to (1) train rhesus monkeys to perform a visual compensatory tracking task; (2) irradiate the subjects during tracking with laser light of near-damage threshold intensity; and (3) examine tracking performance immediately after exposure to determine if flashblindness had occurred.

METHODS AND MATERIALS

Task

The task was compensatory tracking of a one-dimensional trajectory generated by a Data General NOVA 800 digital computer with appropriate interfaces. A target ring and cursor were displayed on a video screen 1 m from the subject. The ring was 8 mm in diameter and remained stationary. The cursor was a 2-mm dot, driven in the vertical direction through a total range of 14 cm on the screen (a maximum of 7 cm above or below the center of the target ring). Target and cursor appeared black against a light background; contrast of target and cursor was 0.2 with respect to the background, as determined by densitometer measurements.

The subject attempted to keep the cursor inside the target ring with compensatory motions of a hand-operated control stick constrained to move in only one dimension. The plant was linear, so equal stick movements produced equal cursor movements regardless of stick position or velocity.

The task was performed with the subject using only the right eye; the left eye was blocked by a mask. Each task trial lasted 45 sec and was followed by a 15-sec rest period. A typical

training or test session consisted of 30 trials; subjects were limited to one session per day.

Ten forcing functions, all modified sinusoids, were used for these tests; one of the ten was chosen at random by the computer for each trial. Figure 1 shows plots of time vs uncorrected cursor position for five of the ten forcing functions; the remaining five were identical to these except for reversed signs of the Y-axis values.

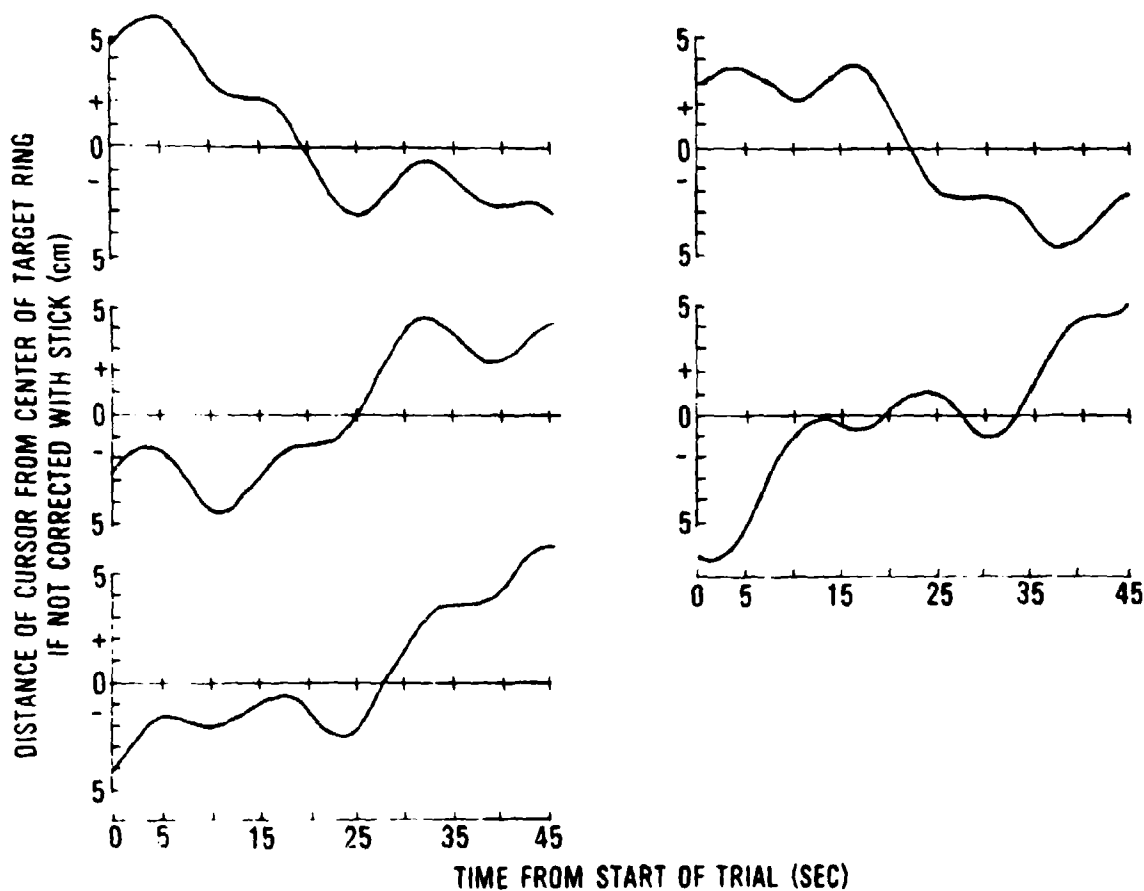


Figure 1. Forcing functions used in the compensatory tracking task. Ten forcing functions were used altogether; the above five, plus five identical to these except for reversed signs of the Y-axis values.

Subject Training

Two adult male rhesus monkeys (Macaca mulatta) were used in this experiment. They were trained to the task using standard operant techniques with a shock-avoidance paradigm; shock was administered through electrodes placed on the subjects' tails. Shock levels for all subjects were in the range of 3-5 mA during training and testing.

In preliminary training stages a subject was presented with a shock whenever the cursor moved outside the target ring. The shock continued until the cursor reentered the ring. However, to avoid the possibility of "shock tracking" during flashblindness tests, the paradigm was modified in the final stages to the following: When the cursor left the target ring, a clock was started by the computer and a time limit between 0 and 1.5 sec was chosen at random. If the cursor reentered the circle within the time limit, no shock was presented to the subject. If the cursor did not reenter within the time limit, a shock was given; the intensity of the shock was proportional to the time limit. As before, the shock ceased when the cursor reentered the target ring. The shock logic was inoperative during the first 3 sec of all trials to allow for initial target acquisition.

A subject was considered fully trained when it could maintain the cursor inside the target ring 80% of the time after the initial 3-sec acquisition period.

Experimental Apparatus

A simplified schematic of the experimental setup is shown in Figure 2. A subject performed the task sitting in a restraint chair in a light- and sound-attenuated enclosure. A Stanford Research Institute Purkinje eye tracker monitored right-eye position, using infrared light reflected from the first and fourth Purkinje surfaces (front corneal surface and rear lens surface, respectively). Information from the eye tracker was continuously fed to a decision box. When the eye was centered on the target ring at an appropriate time, a signal was generated to fire the laser. This caused the laser beam to impinge on the subject's retina during performance of the task. The decision logic withheld a laser firing signal during the first 5 and last 10 sec of a trial.

The above procedure required extreme accuracy to place and maintain the subject's eye in the center of the laser beampath. During experimental setup, the laser beam was exactly aligned with the image of the target display. An artificial monkey eye was then placed in the center of the beam, and the eye tracker was aligned so that the artificial eye registered zero deflection. At the beginning of each test session, the subject was placed in

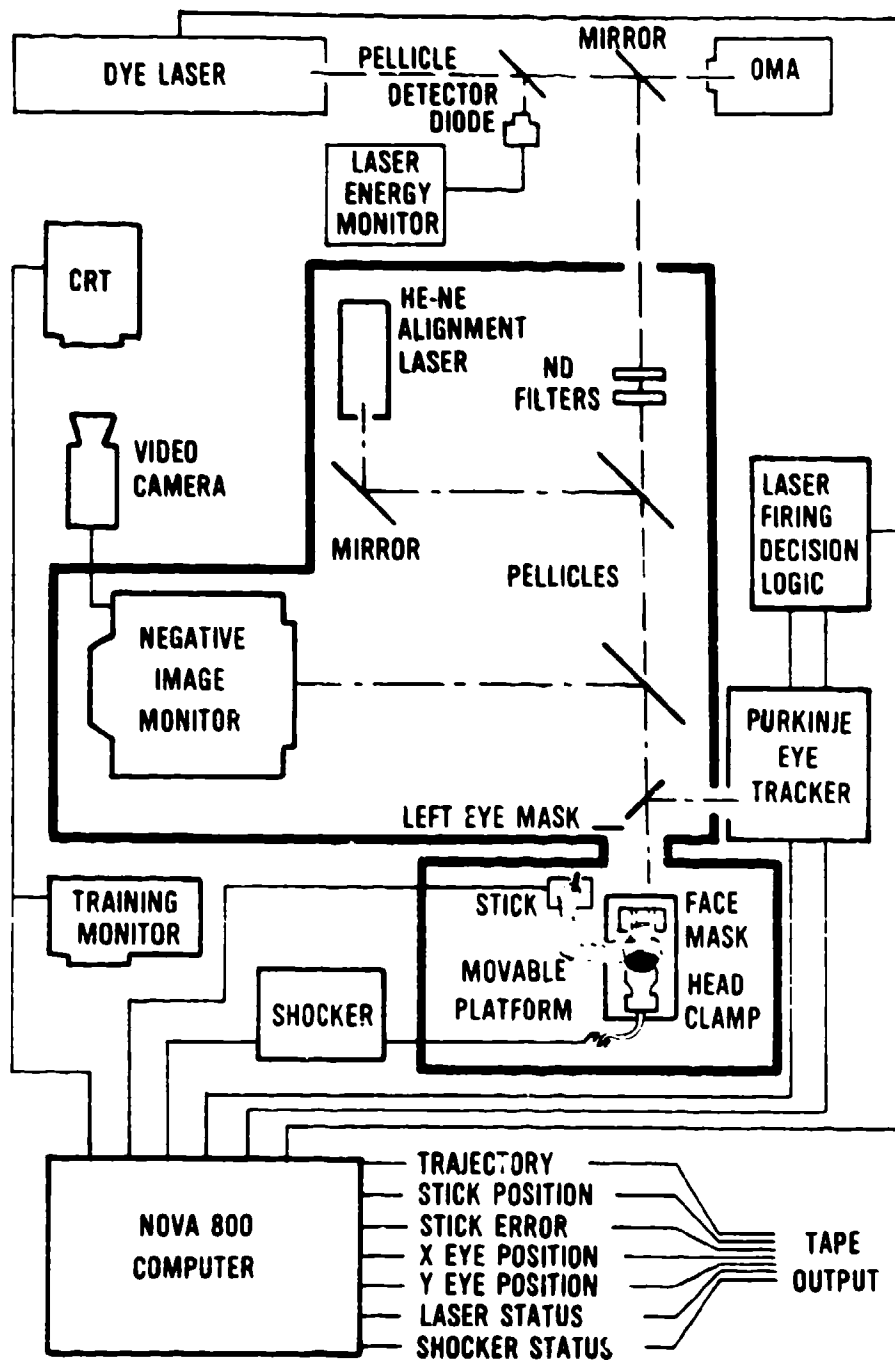


Figure 2. Simplified schematic of experimental apparatus. The heavy line encloses the subject's light- and sound-attenuated environment. The He-Ne alignment laser was used only for initial setup and periodic checks of beampath alignment; the laser energy monitor, to quantify each exposure; and the optical multichannel analyzer (OMA), to determine wavelength(s) of the laser beam line(s). Neutral density filters (not shown) could be placed between the dye laser and diode detector pellicle to vary the laser exposure energy.

a double-pillory neck-plate chair that positioned him in a rigid, molded face mask with large openings for eyes, nose, and mouth. This neck-plate/mask assembly was attached to a movable stage with controls outside the enclosure. The stage was then finely adjusted in three dimensions so that the monkey's right eye was brought to the same position as the artificial eye had occupied during initial alignment. The stage was adjusted while the subject was performing a task, so that the eye tended to remain fixated on the image of the target. This procedure assured that the laser beam would strike as closely as possible to the center of the fovea during task-performance exposures.

Exposure Parameters

The dye laser used for the green-light exposures was a Phase-R DL-32 coaxial, flash-pumped cavity tuned to oscillate at 513 nm; it provided pulses of approximately 200-nsec duration. For white light operation an intracavity prism and a split rear-cavity mirror were used to generate blue (480 nm) and green (508 nm) lines in a single beam; this beam in turn was used to pump a Phase-R IR-5 cavity, which oscillated at a red wavelength of 595 nm and also produced another green line at 528 nm. Each of the four lines was of approximately the same intensity, as determined by analysis of the beam with a Princeton Applied Research model 1205A optical multichannel analyzer. The beam, when viewed diffusely reflected, appeared white. A full description of this laser configuration is provided by Reed et al (9).

The energy of each exposure pulse was measured on-line with a fast diode detector/oscilloscope/camera arrangement, shown as "laser energy monitor" in Figure 2. This system was calibrated with a Laser Precision RKP 337 energy probe placed in the position of the subject's right eye; values from the probe were read by an RK 3230 RA energy meter. Beam energy was varied by placing neutral density filters between the laser and the detector diode pellicle. During testing with green irradiation, energy was varied from 1.7 to 3.75 μ J; irradiation with the white beam varied from 0.55 to 3.1 μ J. Postexperimental eye examinations revealed no visible foveal lesions in either of the subjects; angiograms and retinal fundus photographs were likewise negative.

Subjects were exposed a maximum of three times per day, and all exposures occurred during the daily 30-trial session. Only one exposure per trial was made; at no time did two exposure trials occur successively.

Experimental Procedure

Both subjects underwent one 30-trial session per day to maintain proficiency, even if no testing was to take place. An

experimental session was essentially identical to a training session, except that during the first 10 trials fine adjustments were made with the outside controls of the movable stage holding the subject's head. This was to align the right eye in the center of the beampath and the field of the eye tracker. Exposures were made during the final 20 trials of the session.

A total of 83 exposures were made on the two subjects in the green-light tests, and 16 exposures on one subject with the white laser configuration. For half of these the shock paradigm was turned off for 3 sec immediately after exposure. This was to eliminate, in at least half the tests, the possibility of the shock logic interfering with the subject's postexposure reactions or providing nonvisual clues (e.g., cessation of shock) as to when the cursor reentered the target ring. The "normal" and "3-sec no-shock" conditions were varied semirandomly, with the constraint that at least one of each condition be used for each test session with a given subject.

RESULTS

Figure 3 is a computer-generated plot of an exposure test trial with subject A. Tracking error vs time is shown along with the forcing function. The horizontal dashed lines indicate the vertical limits of the target ring. All data analyses originated from such plots. The time at which the laser pulse occurred was taken from header information and marked as P on the plot; then the point of resumption of normal tracking was adjudged and marked R. The elapsed time between these two points was taken as the flashblindness recovery time (FBT). Recovery was judged to have occurred if the subject performed a control movement to bring the cursor into the target ring (or its close vicinity) and then made a second control movement to keep the cursor in the ring or its near vicinity. Thus, in Figure 3, R was marked as occurring approximately 0.5 sec before the cursor actually reentered the target ring; this was because control was apparently reestablished in the near vicinity of the target.

Figure 3 represents an atypical exposure trial, in that an FBT was clearly present as the only outstanding event occurring in the 45-sec run. More typical is the trial shown in Figure 4, in which the "flashblinding event" appears as one of several events and would be indistinguishable from the others were the plot not labeled. Most typical of all, in terms of quantity, were plots of the type shown in Figure 5, in which the laser pulse had no apparent effect. Such exposures were labeled "O's." Six trials of the type shown in Figure 6 also occurred; in these, the laser exposures took place at a time when control had been momentarily lost for other (unknown) reasons. Such exposures were labeled "indeterminate" and were not used in subsequent analyses.

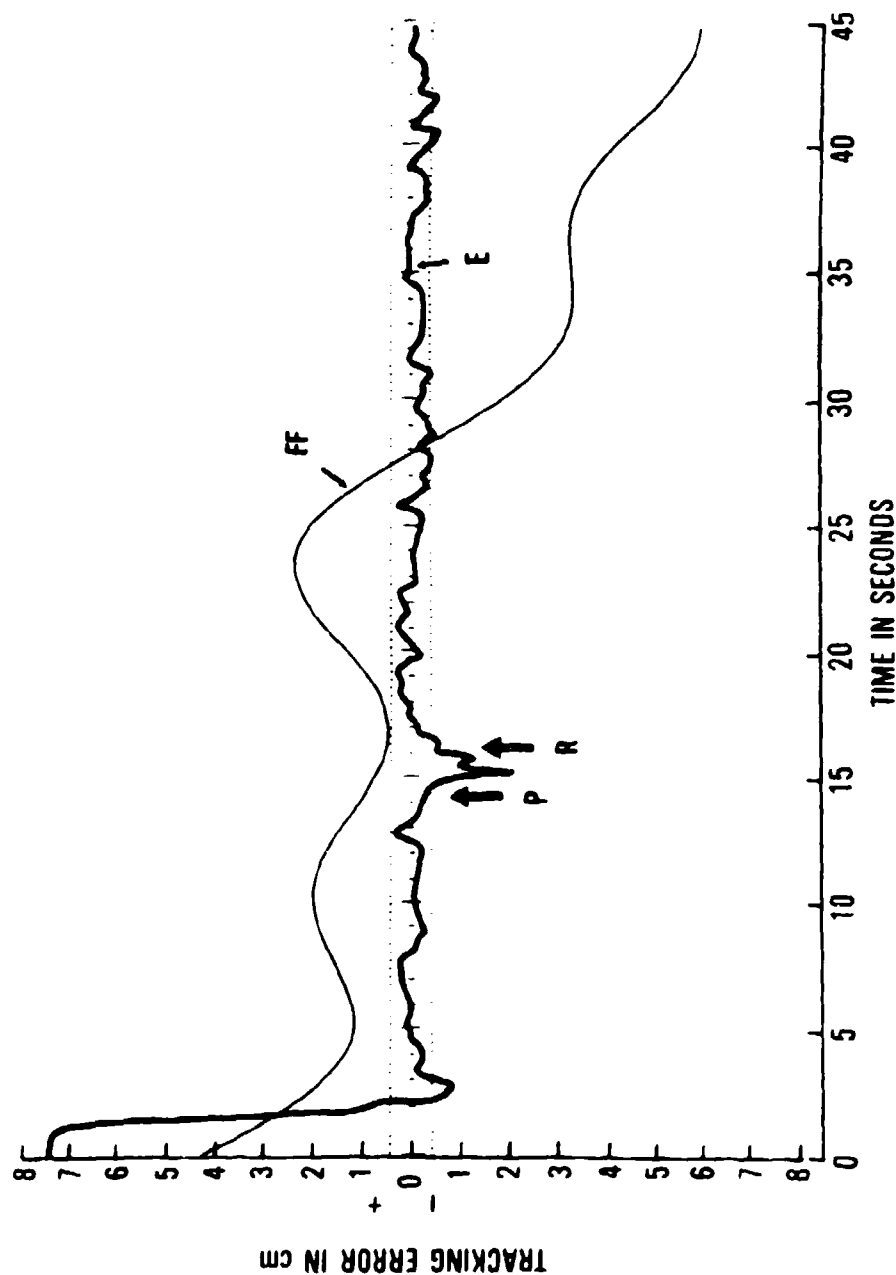


Figure 3. Computer-generated plot of an exposure trial with subject A. Time of trial vs cursor error is in cm. Markings on the plot, as follow, apply to Figures 3-6:

- FF - Forcing function: vertical distance of cursor from center of target ring if control stick were to be frozen throughout the trial.
- E - Error trace: actual vertical position of cursor with respect to the center of the target ring.
- P - Point in time at which laser exposure occurred.
- R - Point in time at which recovery was judged to occur.
- Dashed lines - Vertical boundaries of the target ring.

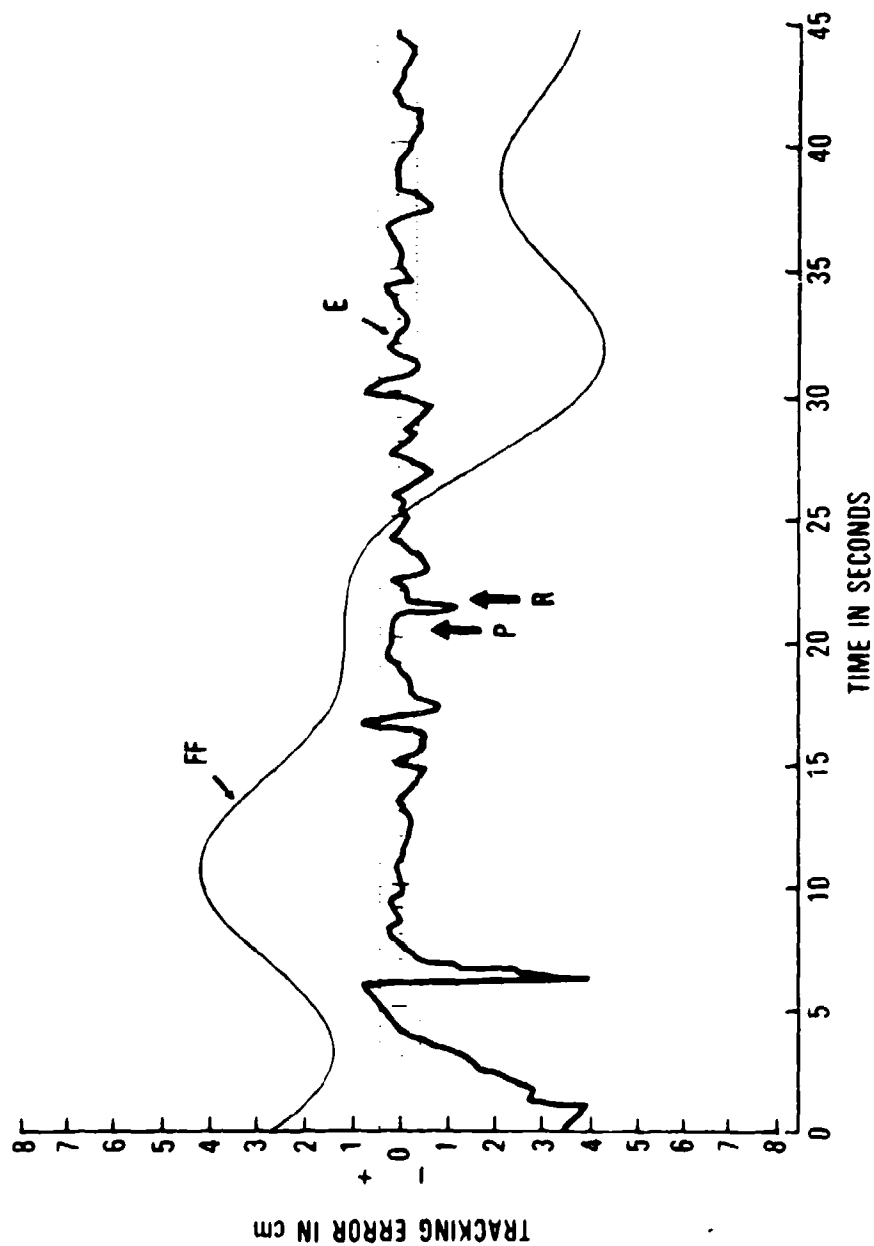


Figure 4. A typical exposure trial in which an FBT was measurable but indistinguishable from other events occurring within the trial.

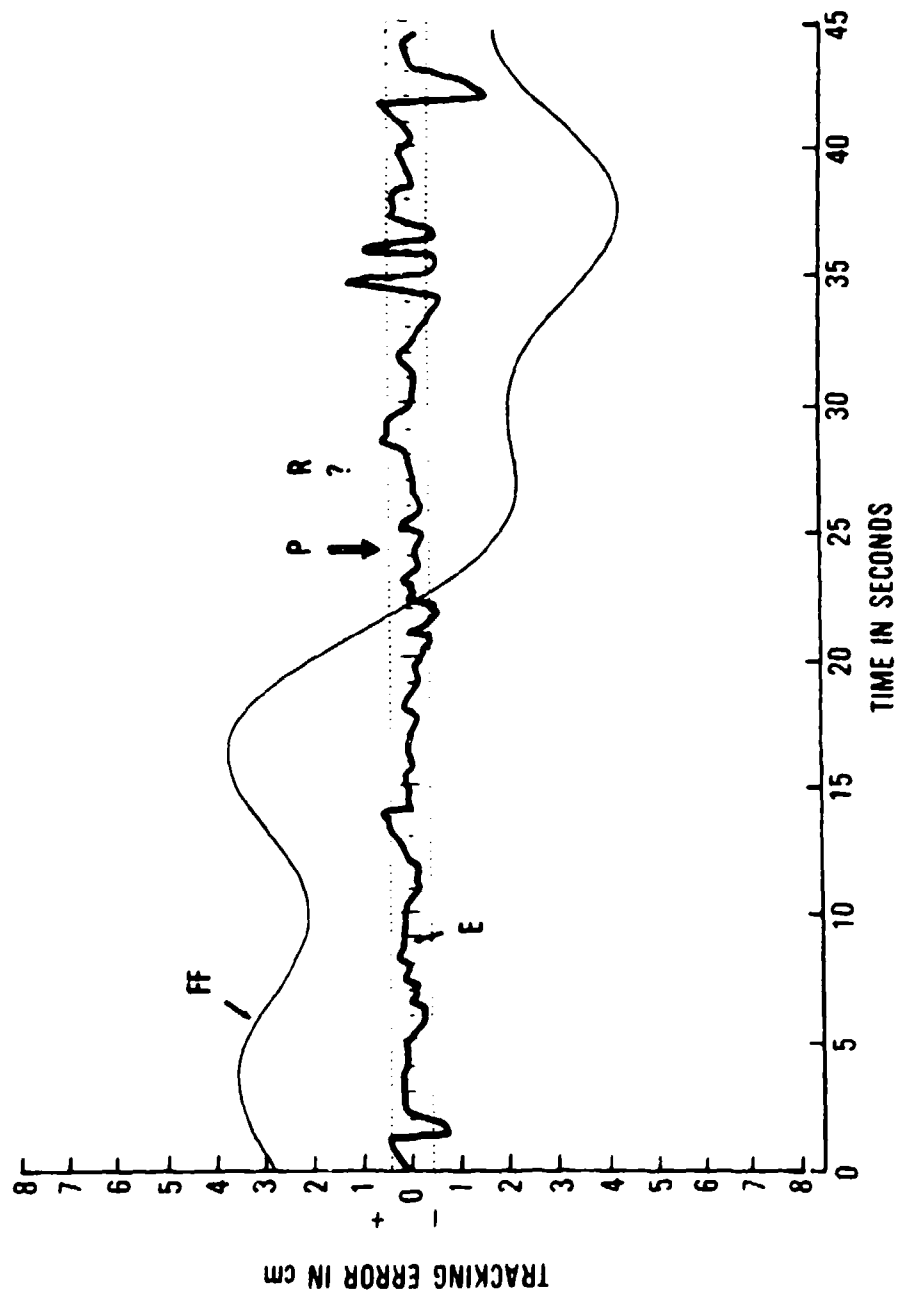


Figure 5. The most common type of exposure trial. No effect of the laser pulse exposure is apparent. This type of trial was labeled "0."

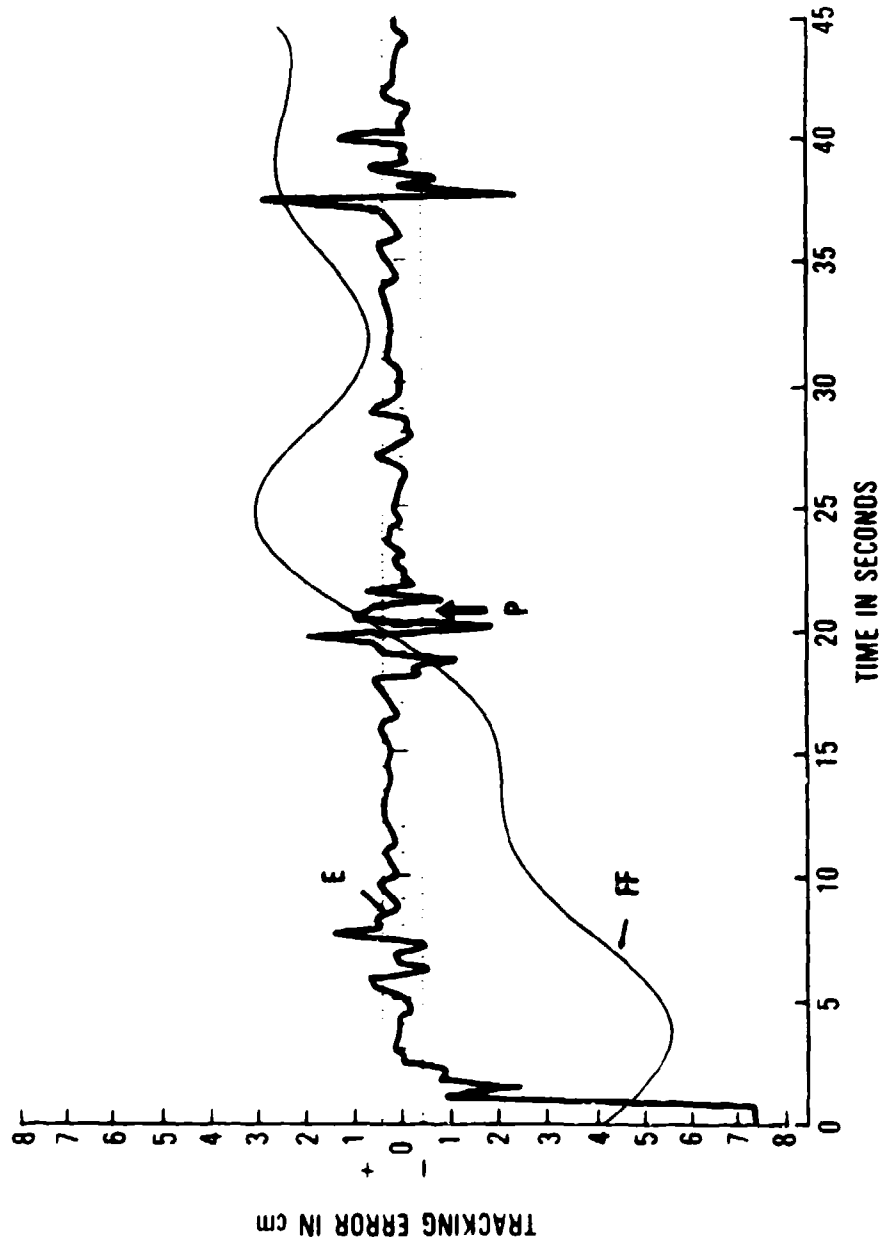


Figure 6. Example of an indeterminate trial. Here, the exposure occurred in the middle of an ongoing spurious event, so a cause-and-effect relationship could not be postulated. Such trials were discarded in data reduction.

Of the 83 exposures recorded for the green laser tests, 46 were 0's, 32 yielded FBT determinations, and 5 were indeterminate. Of the 16 white laser exposures, 6 were 0's, 9 yielded FBT's, and one was indeterminate. Plots of FBT vs exposure energy are shown in Figure 7. Figure 7A shows results with normal shock paradigm, and 7B graphs the 3-sec no-shock condition. Both plots display approximately equal numbers of 0's and FBT determinations; the only noticeable difference between them is that the 3-sec no-shock condition (7B) produced a slightly greater spread of FBT's. The grouped data are plotted in Figure 7C; no discernible dose-response relationship is evident in any of the plots.

Table 1 lists means and standard deviations of the FBT determinations, by subject and condition; the 0's were not used for these calculations.

TABLE 1. FBT MEANS BY SUBJECT AND CONDITION

<u>Subject</u>	<u>Laser</u>	<u>Paradigm</u>	<u># Data points</u>	<u>Mean</u>	<u>S.D.</u>
A	green	normal	10	1.5	0.5
B	green	normal	5	2.3	0.9
A	green	no-shock	11	2.5	0.9
B	green	no-shock	6	1.9	0.6
A	white	normal	5	1.1	0.3
A	white	no-shock	4	1.6	0.8
A,B	both	both	41	1.9	0.8

DISCUSSION

Three factors in the data combine to cast doubt on the assumption that the FBT's determined in these tests were actually flashblindness recovery intervals: (1) the large incidence of 0's, (2) the complete absence of a dose-response relationship (see Fig. 7), and (3) the striking similarity of FBT events to other events involving momentary loss of cursor control. For discussion purposes these other events shall be called "startle events."

Singly, these factors might be explained away. For instance, the large number of 0's might be due to poor alignment of the optics or to unavoidable eye movements. The lack of a dose-response relationship might be due to using too small a range of laser exposure energies; and similarities in appearance between FBT's and startle events might be coincidental. However, in combination these items tend to question the validity of assuming that a nondamaging laser pulse of the type used in these tests can create a measurable flashblindness interval.

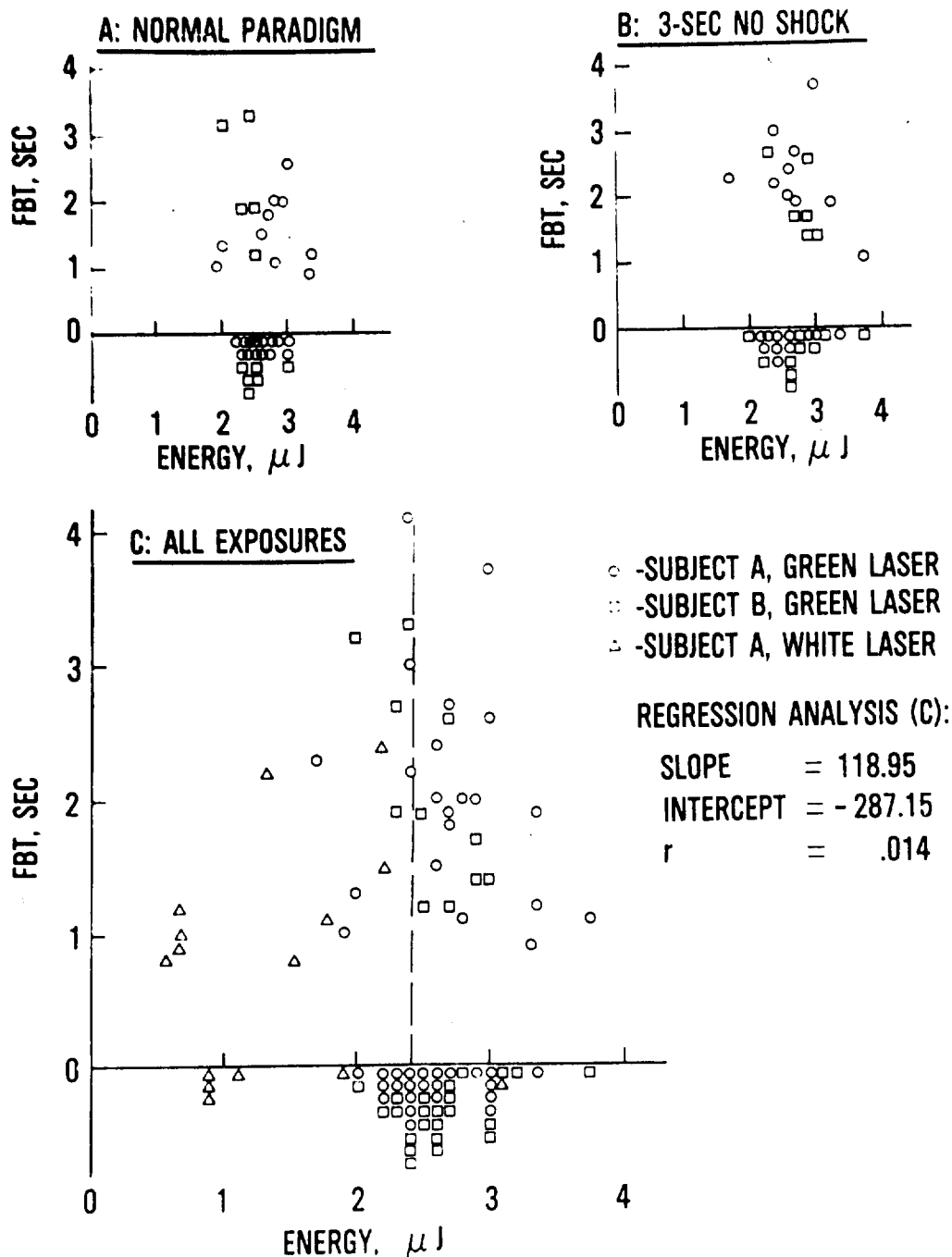


Figure 7. Scatter plots of FBT vs laser energy.

7A: All green laser exposures, both subjects, with normal shock paradigm.

7B: Same as 7A except with 3-sec no-shock paradigm.

7C: All data, including white laser exposures.

No dose-response relationship is evident. The white data appear to show a trend but only because the range of exposure energies was lower, resulting in the data set being shifted to the left on the abscissa.

The similarity of error traces delineating FBT's and startle events dictates at least a short discussion as to the nature of a startle event. In an earlier study that compared the performance of human and rhesus subjects in identical tests (3), startle events were almost nonexistent with human subjects but two or more such events occurred in most trials with rhesus subjects. This difference probably has to do with motor skill and ability (or motivation) to concentrate. A startle event appears to occur when the subject--for whatever reason--is momentarily distracted from the task. The cursor leaves the target ring and then must be brought back into the circle before normal tracking can resume. From examination of many error traces, we noticed that the hunting motion to bring the cursor back into the target ring consumes most of the time interval associated with a startle event. Thus the startle itself is usually momentary, and a startle event might be more aptly described as a startle recovery event.

As a counter to the assumption that laser exposures produce significant flashblindness, the hypothesis was set forth that FBT's were simply startle events. To test this hypothesis, control experiments (everything identical to Figs. 3-6, except that no exposures occurred) were arbitrarily assigned P's by random selection and examined for pseudo-FBT's in exactly the same manner as described in the Results section. Thus, if any pseudo-FBT's were recorded, they were caused only by random startle events. Control trials were examined in this fashion until 41 pseudo-FBT's were found and quantified. Figure 8 shows in histogram form the results of this search, along with the exposure data. The incidence of 0's was considerably higher for the random search than for the true exposures, but the mean FBT's and their distributions were nearly identical.

The relatively high incidence of events associated with laser exposures argues strongly for a cause-and-effect relationship. On the other hand, given the above discussion about what constitutes a startle event, the similarity of FBT's and pseudo-FBT's would argue strongly for assigning a zero (or very small) value for the true flashblindness recovery interval associated with these exposures. In approximately 40% of the tests, the firing of the laser apparently initiated a startle, and the exposure recovery times are startle recovery times rather than true FBT's.

This postulation of a very small--or nonexistent--flashblindness interval associated with nondamaging laser exposures supports the experimental findings of Stein and Elgin (11) and Polhamus et al. (8), which show that laser light entering the eye would be distributed over the retina in Gaussian fashion, with an energy half-width of only 5-15 μm . Thus, almost the entire laser energy is distributed over a very small percentage of the cone-rich fovea centralis, which has a radius of approximately 500 μm . Most of the fovea would remain unaffected and be available for tasks requiring normal visual acuity. Note that these studies were done

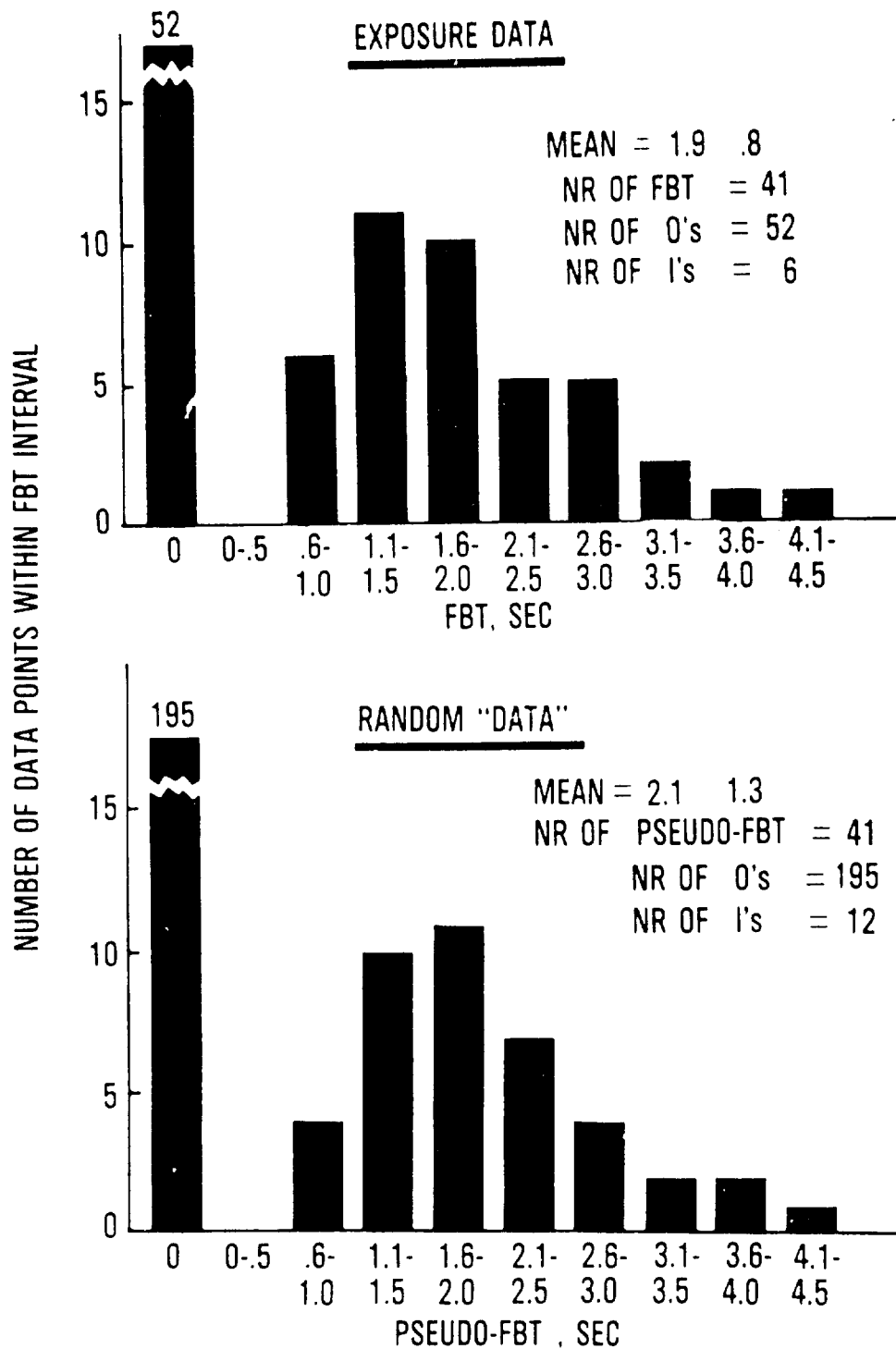


Figure 8. Histogram comparison of exposure FBT's with pseudo-FBT's generated by random selection of false flashblinding points in control trials. The random data were assigned FBT's, 0's, or 1's, using exactly the same procedure as for true exposure data.

using living organisms, whereas studies assigning a greater scattering were either theoretical or used excised preparations. Allen (1) points out that degeneration of preparations could create imperfect lens systems through which significant scattering might occur.

CONCLUSIONS

Two rhesus monkeys were exposed to green or white laser pulses of approximately 200-nsec duration, with energies ranging from 0.55 to 3.75 μ J impinging on the retina. These exposures occurred while the subjects were performing a visual compensatory tracking task. Examination of tracking error traces associated with the 99 exposures yielded the following results (6 indeterminate trials were not used in the analyses): (1) 52 exposures had no apparent effect; (2) 41 exposures produced related events, which showed an average recovery time of 1.9 ± 0.8 sec; (3) no dose-response relationship was evident; and (4) the exposure-related events were similar in appearance and duration to random startle events that occurred regularly throughout most trials.

Of the 99 laser exposures, 40% resulted in exposure-related events. We believe that these represented startle recovery times following momentary startles rather than FBT's from true flash-blinding incidents.

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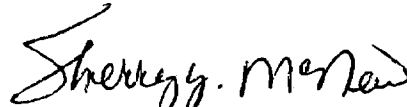
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Brooks City-Base TX 78235-5116

SUBJECT: Changing the Distribution Statement on a Technical Report

This letter documents the requirement for DTIC to change the distribution statement from "B" to "A" (Approved for public release; distribution is unlimited.) on the following technical report: AD Number ADB056771, SAM-TR-81-7, Visual Compensatory Tracking Performance After Exposure to Flashblinding Pulses: II. Sub-Damage Threshold Laser Irradiation of Rhesus Monkey Subjects. I am sending one corrected page which needs to be incorporated when you make this document Distribution A.

If additional information or a corrected cover page and SF Form 298 are required please let me know. You can reach me at DSN 240-6019 or my e-mail address is sherry.mcnew@brooks.af.mil.

Thank you for your assistance in making this change.


SHERRY Y. MCNEW
AFIOH STINFO Officer

Attachment
Corrected page (DD Form 1473)

cc:
USAFSAM/CA (Dr. Krock)
AFRL/HEOA