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VISUAL COMPENSATORY TRACKING PERFORMANCE AFTER EXPOSURE TO FLASHBLINDING PULSES: I. COMPARISON OF HUMAN AND 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.

The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

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

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To assess the validity of using macaques as human analogues in further flash-blindness studies, three rhesus monkeys and eight human subjects were exposed to identical flashblinding light pulses while performing identical visual compensatory tracking tasks. The light source was a 3400-K tungsten-halogen lamp; optics and shutter were arranged so that a 0.1-sec flash deposited a total energy of 20.7 μJ over a 3-mm-diameter spot on the retina. Flashblindness recovery time was determined by examining the tracking error trace immediately after treatment. A total of 160 human and 97 rhesus treatments were

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recorded. Average recovery time for the humans was 2.8 ± 0.6 sec; for the rhesus, 3.2 ± 1.1 sec. This close agreement was found in spite of different tracking control strategies used by human and rhesus subjects. Rhesus monkeys were judged acceptable as human analogues for this specific type of testing.

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CONTENTS

VISUAL COMPENSATORY TRACKING PERFORMANCE AFTER EXPOSURE TO FLASHBLINDING PULSES: I. COMPARISON OF HUMAN AND RHESUS MONKEY SUBJECTS

INTRODUCTION AND BACKGROUND

To be effective in modern combat, Air Force flight and ground crews will be required to maintain performance in an environment saturated with electromagnetic radiation. This environment may well include laser light, either deliberately or accidentally directed into the eyes of combatants or support personnel.

Thresholds for minimally detectable eye damage have been predicted (5, 6), but little is known about the reactions of people performing visually oriented tasks when they are suddenly exposed to visible coherent radiation at energy levels below the threshold. To explore the immediate effects of laser radiation near the threshold, future experiments will use rhesus monkey subjects in compensatory tracking tasks during which their eyes will be exposed to coherent light. Performance immediately after irradiation will be monitored to detect possible flashblindness effects. Because of the high levels of radiation, the use of human subjects is inappropriate for such exposures even though no eye damage is likely to be sustained. Using monkeys as human analogues, however, is subject to problems of extrapolation; therefore, a verification of the validity of this procedure is necessary. Such is the objective of the present experiment.

A considerable body of flashblindness literature exists, most of it generated in attempts to quantify and protect against the effects of accidentally viewing a nuclear fireball. The research was conducted primarily in the 1950's and 1960's, and was plagued by lack of standardization and inconsistencies in results (2, 7). Most of this literature concerns effects of extremely high intensity light sources, producing flashblindness recovery times of the order of minutes. Such exposures are not germane to the present research; preliminary exposures of rhesus monkey subjects to laser light of sub-damage-threshold intensities indicate that the flashblindness times of interest will be of the order of 0-4 sec.

A recent study by Dickson, using a tungsten-halogen lamp and illuminating a 3-mm-diameter retinal spot with a total energy of 26 μJ, produced flashblindness recovery times of 3-5 sec in human subjects viewing static targets (4). We decided to duplicate these conditions for the present tests, with a slightly reduced energy (21 μJ), to attempt to produce recovery times of 2-4 sec. Performance in a compensatory tracking task was used to assess the dependent variable because the rhesus subjects were already well trained in compensatory tracking.

Thus the plan for this study was to train monkeys and humans to perform identical compensatory tracking tasks, irradiate their retinas with light spots of identical size and energy during tracking, then examine postirradiation performance.

MATERIALS AND METHODS

Rhesus Monkeys

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 3 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; contrasts of target and cursor were 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 the right eye; the left eye was blocked with a shutter. 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 forcing functions; the other five were identical to these except for reversed signs of the Y-axis values.

Subject Training--Three adult male rhesus monkeys *(Macaca mulatta)* were used for this experiment. They were trained to the task using standard operant techniques with a shock avoidance paradigm; shock was administered via electrodes placed on the monkeys' 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 continuing until the cursor reentered the ring. However, to avoid the possibility of "shock tracking" during flashblindness tests, the paradigm was modified in the final training 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 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.

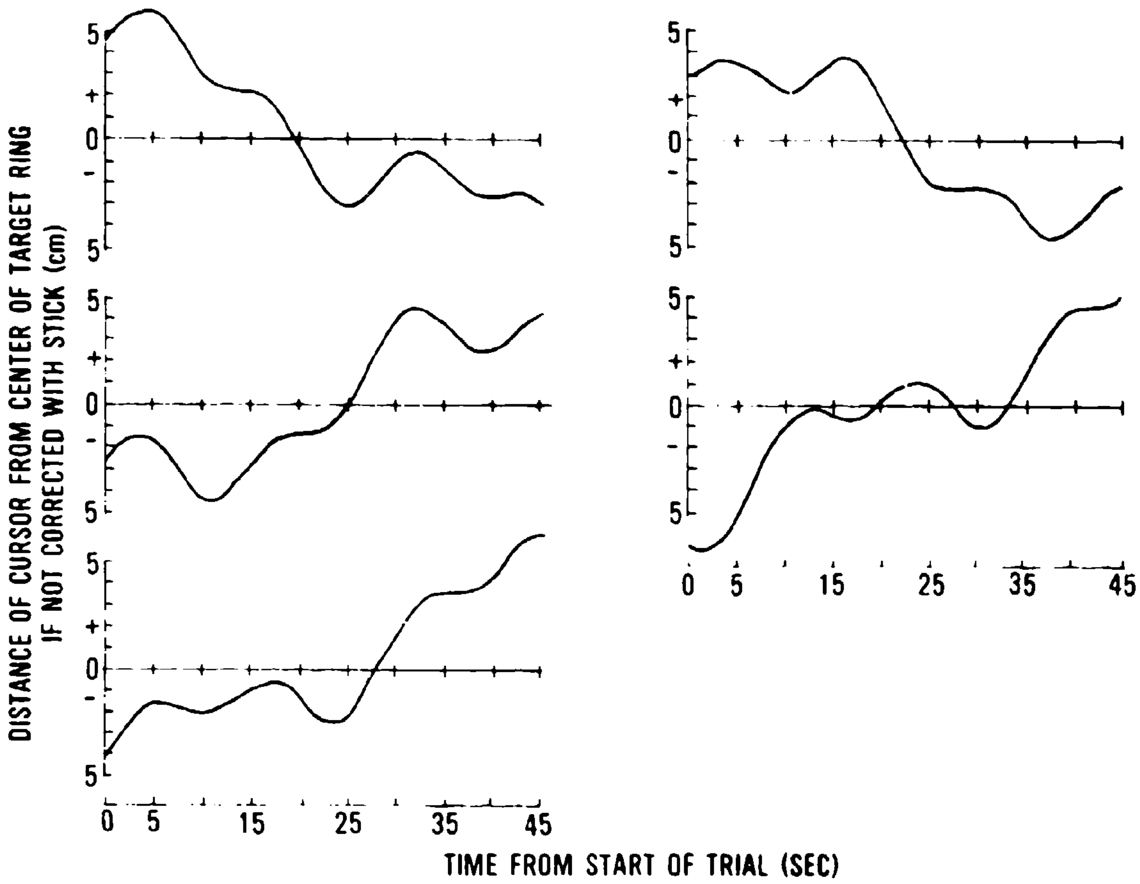

Figure 1. Forcing functions used in rhesus-monkey and human tasks. Ten forcing functions were used: the above five, plus five identical to these except for reversed signs of the Y-axis.

Experimental Apparatus--A simplified schematic of the experiment 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 of the eye (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 open a precision shutter (Vincent Associates, Uniblitz model) for 0.1 sec. This allowed a light beam from a slide projector lamp to impinge on the subject's retina during performance of the task. The decision logic withheld a shutter activation signal during the first 5 and last 10 sec of a trial.

The above procedure required extreme accuracy in placing and maintaining the subject's eye in the center of the light path. During experimental setup,

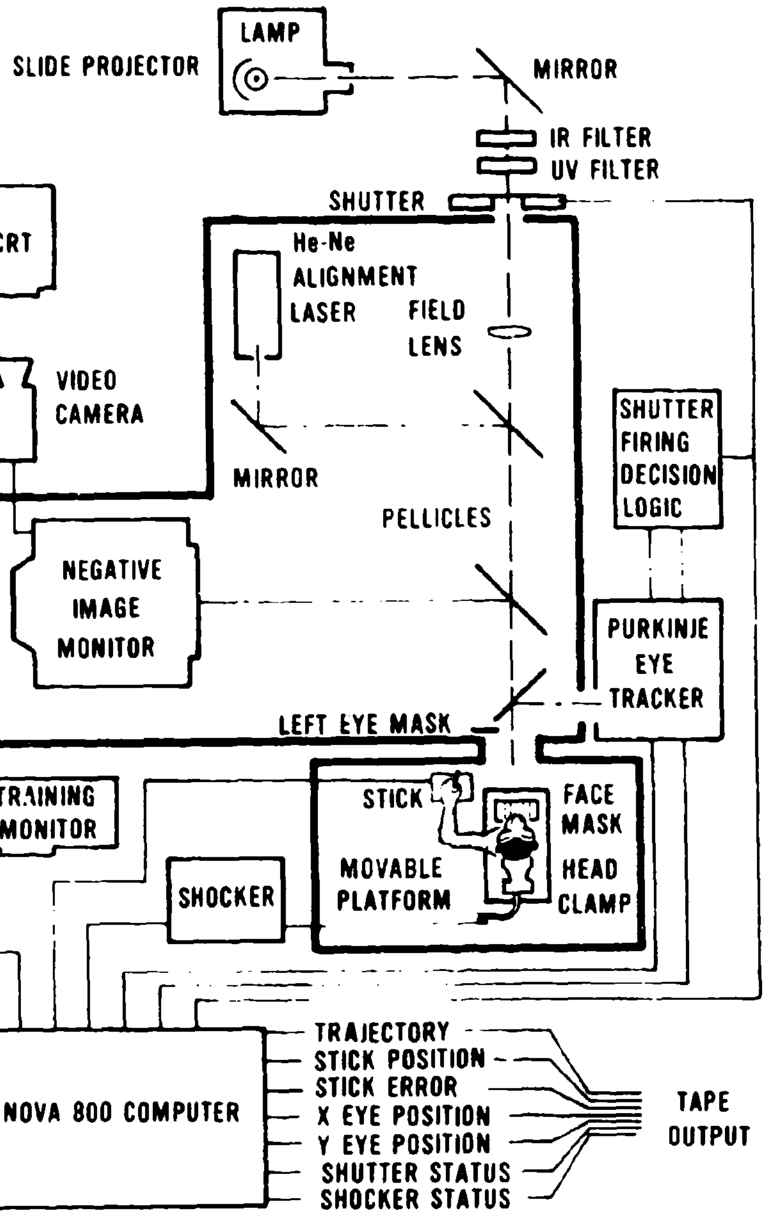

Figure 2. Simplified schematic of experimental apparatus used for rhesus monkey experiments. The heavy line encloses the light-attenuated environment of the subject. The He-Ne alignment laser was used only for initial setup of the apparatus. Lamp voltage could be varied with an adjustable regulator (not shown); this was used to fix the exposure energy at 20.7 μJ. The ultraviolet (UV) and infrared (IR) filters limited the exposure pulse to visible wavelengths (400-700 nm); lamp color temperature was 3400 K.

the projector light 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 a zero deflection. At the beginning of each test session, the subject was placed in a double-pillory neck-plate chair which positively positioned him in a rigid, molded face mask (with large openings for eyes, nose, and mouth); the mask 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 occupied by the artificial eye during initial alignment. This adjustment was made 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 light beam would strike as closely as possible to the center of the fovea during task-performance exposures.

Exposure Parameters--The light source was a tungsten-halogen slide projector lamp with a color temperature of 3400 K at the intensity used for these exposures. Ultraviolet and infrared filters provided wavelength cutoffs at 400 and 700 nm so that only visible light impinged on the cornea. The field lens (see Fig. 2) was adjusted to produce a 3-mm-diameter spot at the focal plane of an artificial monkey eye (equivalent to the surface of the retina). With the shutter open, a United Detector Technology model 80X power meter was placed at the retinal position; then lamp intensity was adjusted with a line voltage regulator to produce a measured continuous output of 0.207 mW. During tests the shutter was normally closed and the lamp turned on to this calibrated setting; for exposures, the decision logic activated the shutter for 0.1 sec to provide the flashblinding pulse. Thus an experimental treatment consisted of a 0.1-sec pulse depositing a total energy of 20.7 μJ on the retina. The power meter was used to check exposure energy at regular intervals throughout the testing period.

The 5-mm diameter of the artificial monkey-eye pupil was determined by observing and measuring pupil sizes of subjects during task performance. For this purpose, an infrared video camera was placed in the position of the field lens shown in Figure 2. The video-monitor image was calibrated with an artificial eye of known dimensions, then videotapes of the performing monkeys were used to measure pupil diameters. All were very close to 5 mm in the light-attenuated environment of the testing enclosure.

The exposure energy of 20.7 μJ was benign. Retinal energy density required to produce minimum visible lesions in 50% of macaques exposed to white light under similar conditions (3-mm retinal spot, 0.1-sec flash) is approximately 0.42 cal/cm^2 (8). The energy used in the present experiments converts to 7.0×10^{-5} cal/cm^2 (see Appendix A); therefore, the exposures of these tests fell below the damage threshold by a factor of 6000.

Subjects were exposed a maximum of four times per day; all exposures occurred during the daily 30-trial session. Exposures were limited to one per trial; at no time did two exposure trials occur successively.

Experimental Procedure--All three subjects underwent one 30-trial session per day to maintain tracking proficiency, even if no exposure 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 beam path and the field of the eye tracker. Exposures were made during the final 20 trials of the session.

Alignment was not always possible. The eye tracker was designed for use with cooperative human subjects, and making it perform satisfactorily in these experiments was difficult; therefore, a planned test session often became merely a training session. During a 4-week period, 97 exposures were made on the three subjects. For half the exposures the shock paradigm was turned off for 7 sec immediately after treatment. 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 cues (e.g., cessation of shock) as to when the cursor reentered the target ring. The "normal" and "7-sec no-shock" conditions were varied semirandomly, with the constraint that two of each condition be used for each test session with a given animal.

Humans

Task--Identical task displays were used for human and macaque subjects. The 10 forcing functions used for the rhesus subjects were also used for the humans (see Fig. 1). The humans were also given tasks in which the frequencies were increased by a factor of four; this created a more difficult series of forcing functions, shown in Figure 3. A tracking session for a human subject consisted of 15 trials with "easy" tasks (identical to those used for the monkeys) and 15 trials with "hard" tasks. In half the sessions the "hard" tasks followed the "easy" tasks; in the other half, this order was reversed. The purpose of the "hard" trials was to approximately equalize the relative demand on motor skills required for humans and monkeys. Thus, when raw test scores (time in target) were compared for humans and monkeys, human scores for "easy" tasks were much higher than those of monkeys; but for "hard" tasks, human scores were approximately equal to those of monkeys performing the "easy" tasks.

Subject Training--Eight adult male volunteers were used as subjects. All were in good physical condition and able to clearly visualize the target and cursor at the 1-m display distance without artificial eye aids. Pretest training consisted of 5-10 trials with both "easy" and "hard" forcing functions. The subjects learned the task very rapidly. By the end of the single training session, all were performing at 85-95% of their eventual raw score averages. Extensive training was not considered necessary for these tests since the only relevant data were the tracking error traces during the first few seconds after a flashblinding treatment.

After each trial, each subject received feedback in the form of a numerical raw score. This was provided by a computer count of data points in which the cursor was inside the target ring: The computer collected data at 60 Hz, so a total of 2700 points was possible for each 45-sec trial. Typical raw-score averages were above 2600 for the "easy" tasks, and 1600-2200 for the "hard" tasks. Subject motivation was maintained by frequent verbal encouragement (between trials) by the investigator, peer pressure from fellow subjects, and prizes given for the best single scores and averages for "hard" and "easy" tasks.

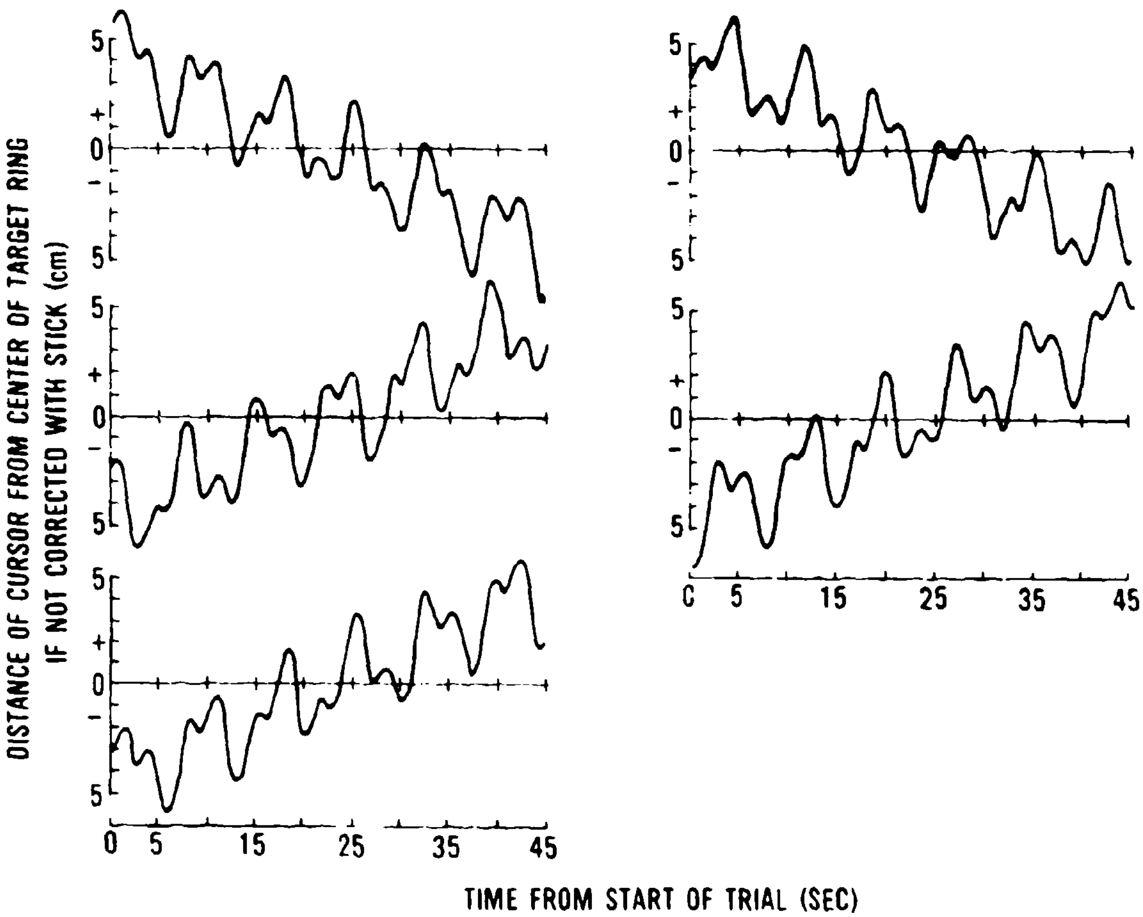

Figure 3. The series of "hard" forcing functions used for half the trials for human subjects. Ten functions were used altogether: the five above plus five that were identical except for reversed Y-axis signs.

Experimental Apparatus-- A simplified diagram of the experiment is shown in Figure 4. The beam from the projector lamp was initially aligned so that it impinged on an artificial human eye (pupil diameter, 3.5 mm; focal length, 17 mm) placed in the eventual position of the subjects' right eyes during testing. The field lens was then positioned to produce a 3-mm spot at the focal plane, and the lamp voltage was adjusted to produce a continuous output of 0.207 mW with the shutter open (see "Monkeys--Experimental Apparatus" for details).

During testing a chin rest was used to position a subject's head; the device was adjustable in the vertical and left/right directions. At the beginning of a daily session, each subject placed his chin in the rest. The lamp was then turned on at very low power and the shutter was opened. This produced a dim light spot in the subject's field of vision, and he adjusted

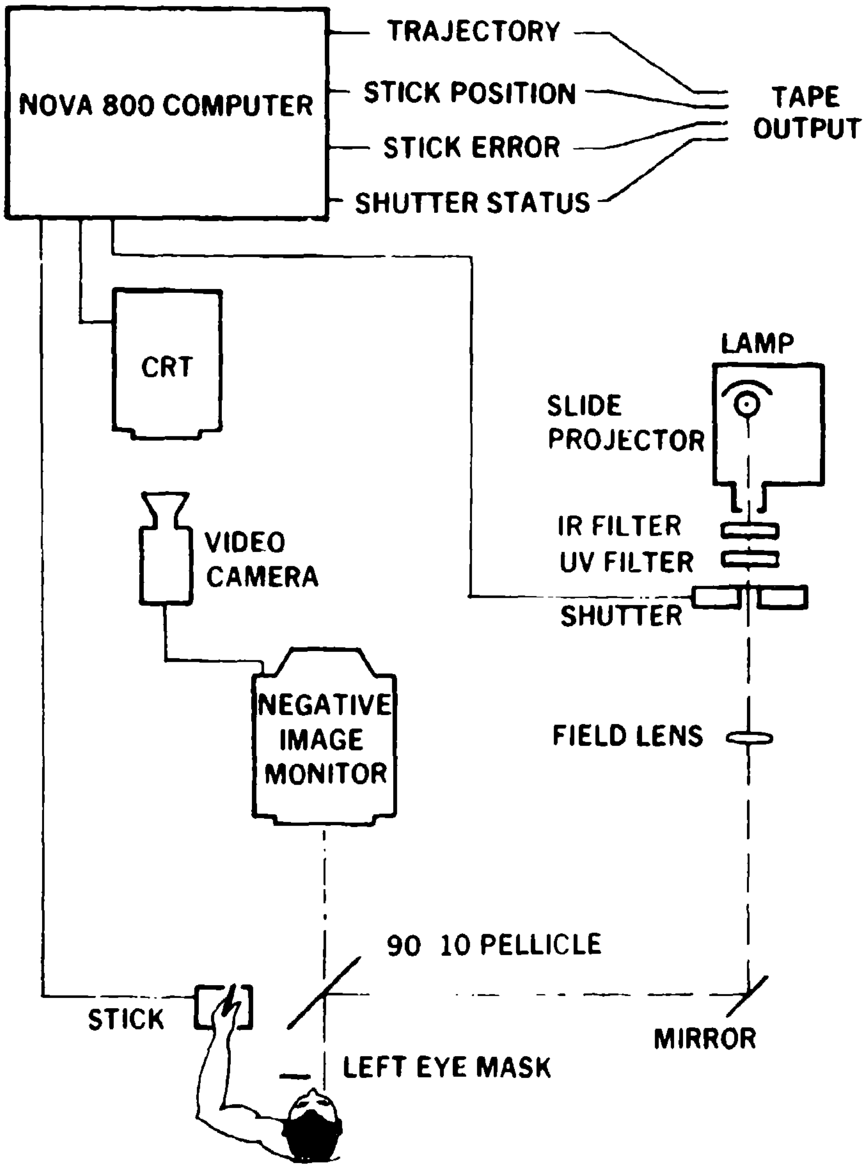

Figure 4. Simplified diagram of experimental apparatus for human testing. All equipment items are identical to those shown in Figure 2 except for the control stick, which was larger to accommodate subjects' larger hands.

the chin rest so that the image of the target ring on the TV monitor was centered in the light spot. Since the light-beam path length remained constant, these adjustments did not affect the retinal spot size or energy. After this initial alignment, the shutter was closed and the lamp voltage turned up to its calibrated value for testing.

Subjects performed in an open room, with doors closed for isolation. Room light was adjusted to produce pupil diameters of 3.5 mm in all subjects. For exposures, the shutter was manually activated at times predetermined by the investigator. As with the monkey subjects, the 0.1-sec shutter activation time produced an energy pulse of 20.7 μJ at the retina.

Retinal power levels were checked daily with the 80X meter; an artificial eye was used in place of the subjects' right eyes (see "Monkeys--Experimental Apparatus"). Maximum power measured was 0.214 mW; minimum, 0.199 mW.

Exposure Parameters--Exposure conditions for humans were identical to those for the macaque subjects, except that the human pupils were at 3.5 mm instead of 5.0 mm; therefore, human exposures consisted of 20.7 μJ deposited in a 3-mm retinal spot over a 0.1-sec timespan. There are no ANSI safety standards for exposures of this type. So for evaluation purposes, these exposures were compared to those produced by two commonly used laboratory devices--the indirect ophthalmoscope and the fundus camera--and to the ANSI standard for extended laser beams or diffusely reflected laser sources in the visible region. All calculations are contained in Appendix A and produce the following results:

1. Indirect Ophthalmoscope: This instrument continuously illuminates the retina with a power density 34 times that which would be produced if the shutter were to remain open continuously in these tests.

2. Zeiss Fundus Camera: This device, at its highest setting, produces a flash that deposits energy 341 times the density of energy deposited by the exposures used in this study.

3. ANSI Standard: If the light source used in the present experiments were an extended or diffusely reflected laser beam of identical power, the corneal energy density would fall below the ANSI maximum permissible exposure by a factor of 422.

These comparisons show that the exposures used in these experiments did not place the subjects at risk during testing. As with the monkeys, each subject was limited to four exposures per day, with at least one no-event trial between exposures.

Experimental Procedure--Each subject underwent 5 days of testing. For each session the projector beam was aligned with the target ring, then 15 trials of either "easy" or "hard" tasks were performed; during this time two exposures occurred. Subsequently 15 trials of the other type were run, with two more exposures occurring. Subjects performed in a room isolated from investigator and monitoring equipment. After each trial, the subject's score for that trial was given to him verbally by the investigator--who entered the room for that purpose, then exited before the next trial commenced. During the 5-day testing period, each subject was exposed 20 times: a total of 160 exposures for the eight subjects.

RESULTS

Human Data

Figure 5 is a plot of tracking error vs time for a typical trial with "easy" forcing function; the function is also plotted. This plot illustrates the normal strategy of the human trackers in these tests: when flashblinded and unable to visualize the display, subjects merely held the control stick motionless. This strategy is demonstrated by the fact that the error trace parallels the forcing function during the flashblinding interval. When sight returned, the subjects immediately moved the control stick to place the cursor back within the target ring. The interval between shutter activation (arrow F in the figure) and the appropriate control motion to bring the cursor back to the target (arrow R) was taken as the flashblindness recovery time (FBT) for each exposure.

Sometimes the entire flashblinding incident fell within an interval in which the forcing function was such that the cursor never left the target ring. This kind of exposure is shown in Figure 6. The smoothness of the error trace during the F-R interval, the fact that it parallels the forcing function, and the sudden control motion toward the center of the target provide sufficient clues to assign an FBT to this exposure. Such is not the case with the trial shown in Figure 7. No distinct control movement is evident for several seconds after exposure; therefore, it could not be assumed that a flashblinding event occurred in this trial even though the shutter was activated at F. Twelve such incidents occurred among the exposures with "easy" forcing functions.

Figure 8 illustrates an exposure trial with "hard" forcing function. Note that the error trace shows a considerably larger rms deviation here than for the "easy" tasks. Nevertheless, the subject used the same strategy (holding the stick motionless) when flashblinded as shown in Figure 5. This was typical behavior for all subjects.

Forcing function velocities for the "hard" tasks were such that none of these trials exhibited the phenomenon shown in Figure 6. For all "hard" trials in which F-R intervals could be distinguished, the cursor could be seen to leave the target circle. However, in 14 trials of the type shown in Figure 9, no FBT could be distinguished.

Initial data reduction was accomplished by examining computer-drawn error traces such as shown in Figures 5-9. Each curve was examined and assigned a recovery point; if no recovery point was evident, a 0 was assigned the trial (e.g., Figs. 7 and 9). Then using computer output information, the shutter activation point was determined and subtracted from the recovery point. The resulting interval was taken as the FBT for that exposure. This procedure yielded 61 FBT's and 12 0's for the "easy" trials and 64 FBT's and 14 0's for the "hard" trials; data were lost in nine exposure trials.

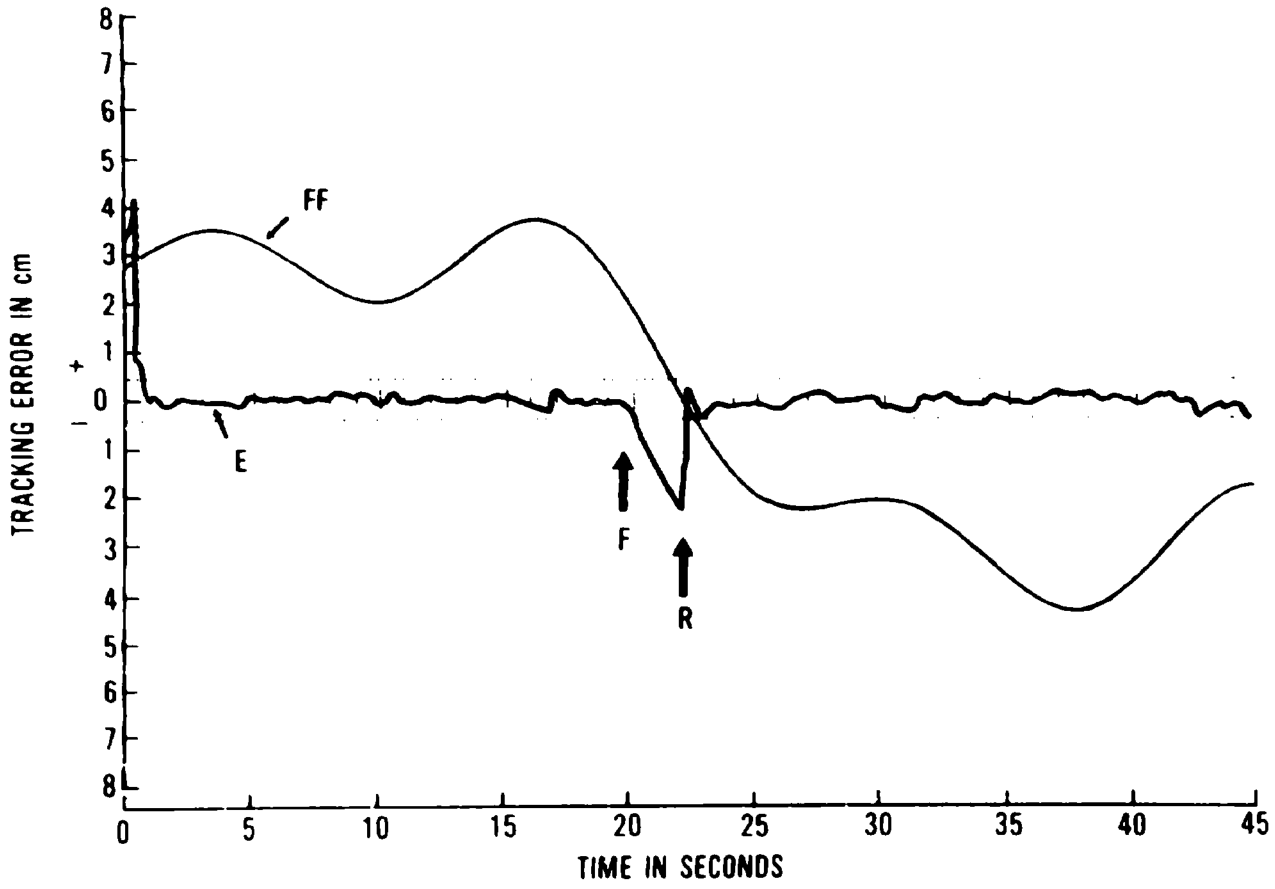

Figure 5. A typical exposure trial for a human subject (H6) with "easy" forcing function. Markings on plot apply also to Figures 6-15.

FF - Forcing function (vertical distance of cursor from center of target ring if control stick were to be held motionless in the center of its travel throughout the trial)
E - Error trace; actual vertical position of cursor with respect to center of target ring
F - Point in time at which flashblinding exposure occurred
R - Point in time at which recovery was judged to occur
Dotted lines mark vertical boundaries of the target ring.

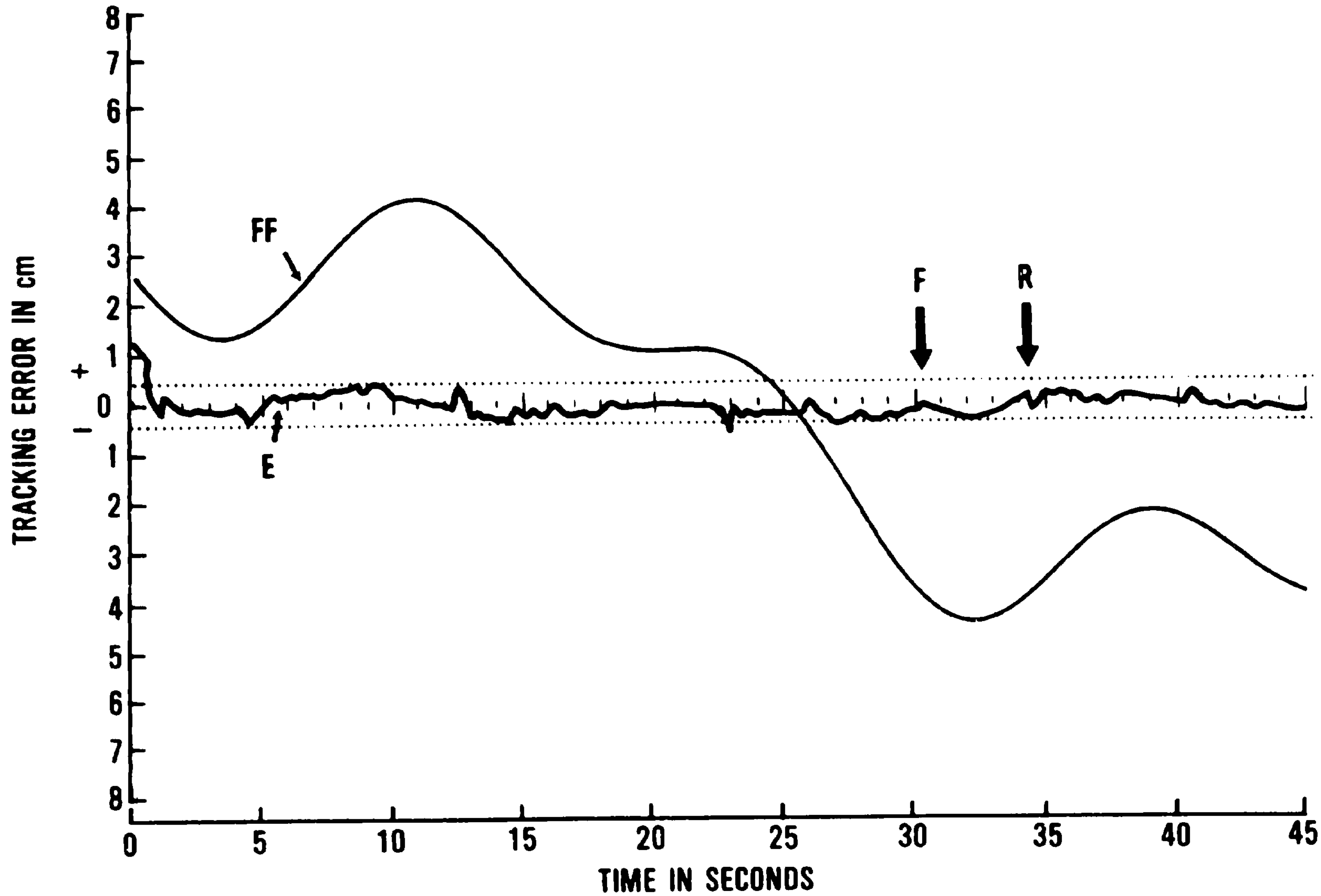

Figure 6. An exposure trial of a human subject (H4) in which the entire flashblindness interval occurs with the cursor remaining inside the target ring.

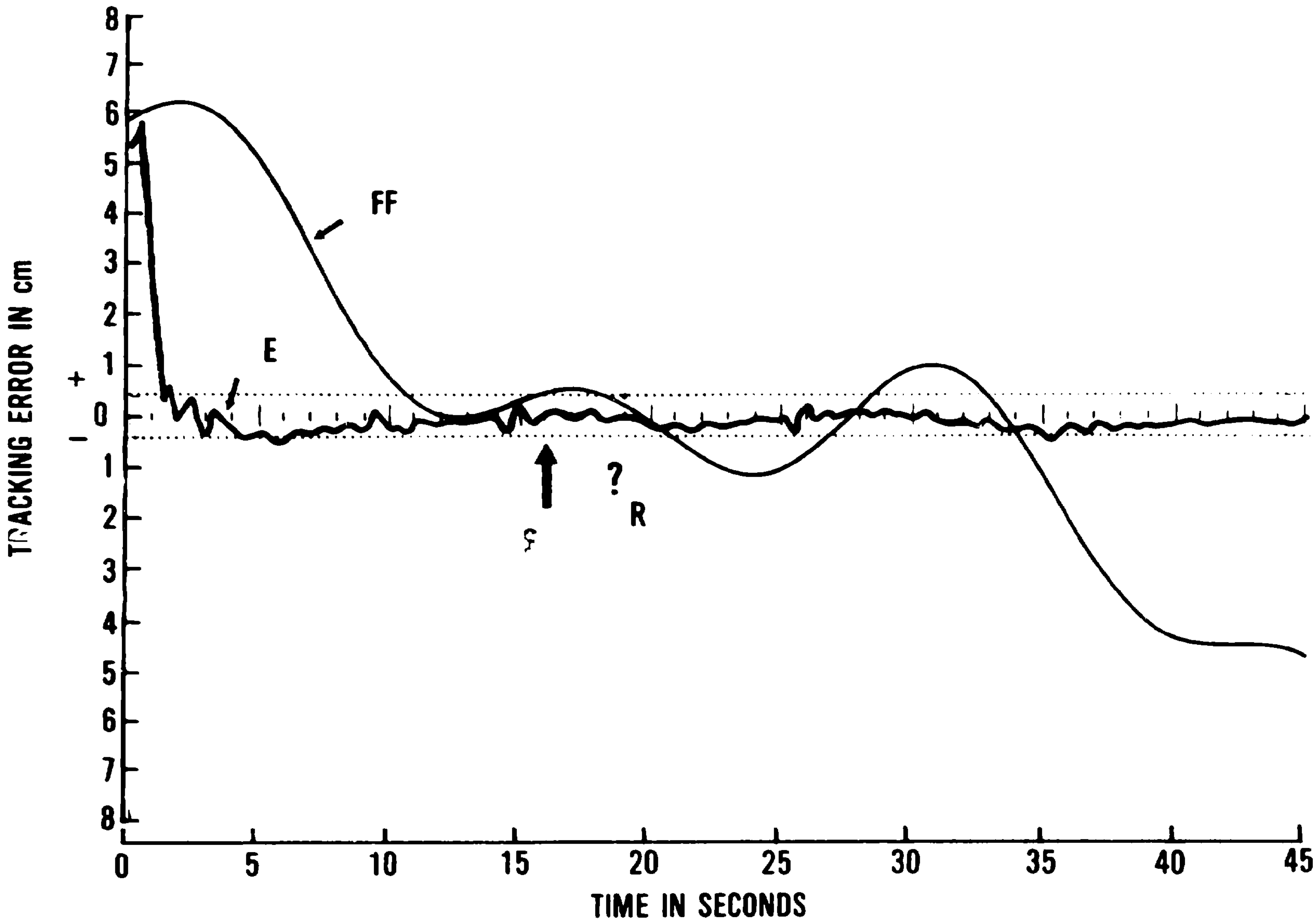

Figure 7. An exposure trial of a human subject (H5) for which it could not be established that a flash-blinding event occurred. This type of exposure was labeled as "0."

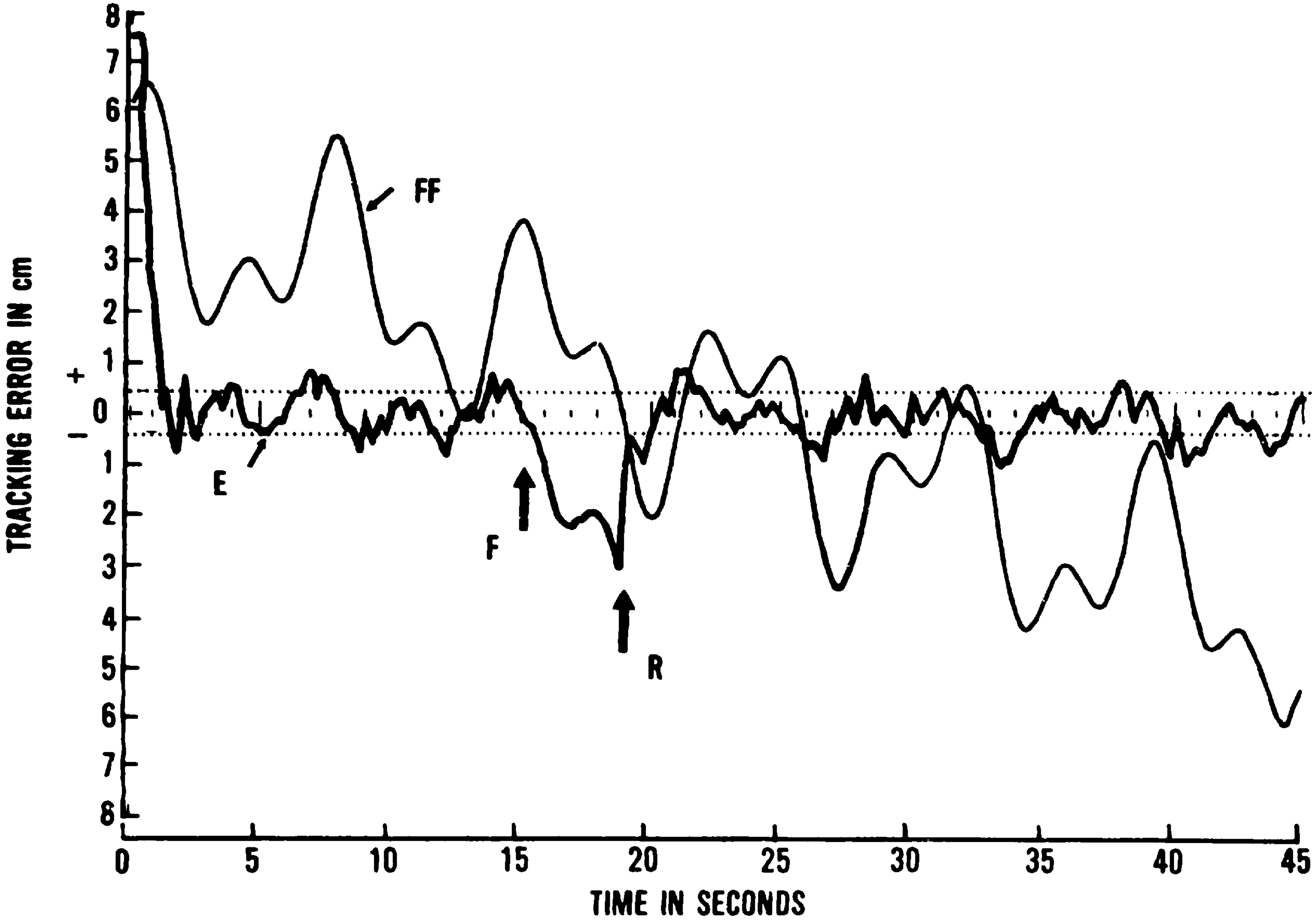

Figure 8. A typical exposure trial for a human subject (H4) with "hard" forcing function. The error trace shows that "hard" trials were difficult for the subjects; nevertheless, the location of the recovery point is evident.

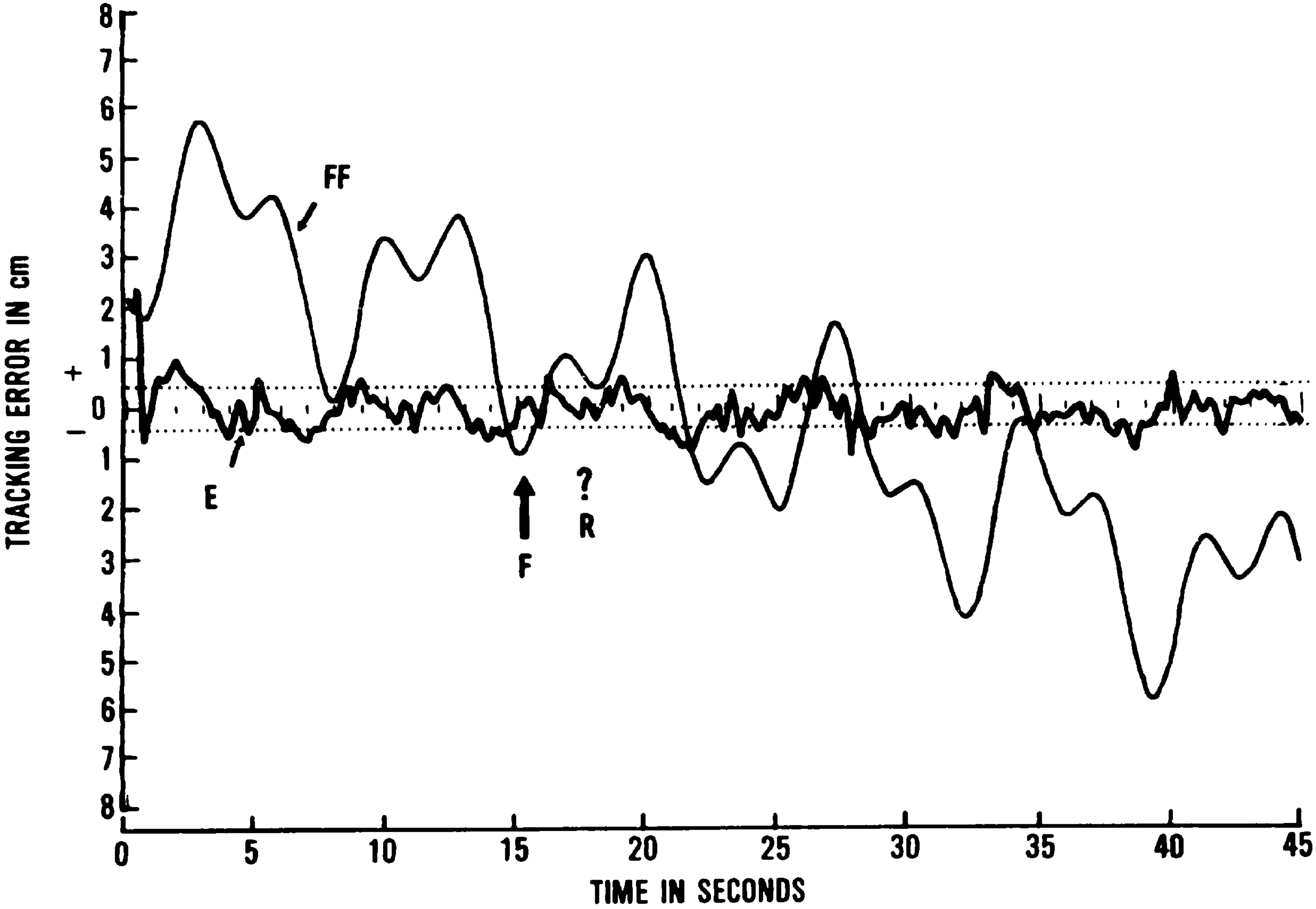

Figure 9. Example of a "hard" exposure trial (subject H3) for which no recovery point could be determined; this was labeled "0."

Table 1 is a statistical breakdown of FBT's by subject and task difficulty. In calculating mean FBT's, the 0's were ignored. This appeared to be justified because in the initial examination of the data, the 0's were a distinct group: 1) the set of FBT's ranged from 1.3 to 4.3 sec, with only 11 data points below 2.0 sec; and 2) there were no FBT's between 0 and 1.3 sec. The 0's were apparently caused by eye movements and/or blinking at the moment of exposure; neither of these were under control, although subjects were instructed to maintain focus on the target ring at all times.

TABLE 1. HUMAN FLASHBLINDNESS RECOVERY TIMES

Subject	"Easy" Tasks # Expos	"Easy" Tasks FBT ± SD	"Hard" Tasks # Expos	"Hard" Tasks FBT ± SD	All Tasks # Expos	All Tasks FBT ± SD
H1	7	2.7 ± .3	9	2.7 ± .3	16	2.7 ± .3
H2	8	3.5 ± .3	9	2.8 ± .5	17	3.2 ± .5
H3	8	3.5 ± .3	9	3.8 ± .4	17	3.7 ± .4
H4	8	2.2 ± .6	7	2.1 ± .2	15	2.2 ± .5
H5	5	2.3 ± .5	4	2.5 ± .6	9	2.4 ± .6
H6	9	2.2 ± .3	8	2.2 ± .3	17	2.2 ± .3
H7	7	3.0 ± .3	9	2.8 ± .4	16	2.9 ± .3
H8	9	2.9 ± .2	9	2.7 ± .2	18	2.8 ± .2
ALL	61	2.8 ± .6	64	2.8 ± .6	125	2.8 ± .6

Considering the limited number of trials for each subject, the standard deviations were quite low; this argues for an "all-or-nothing" phenomenon, with a near-zero incidence of any partial flashblindness phenomenon. This is another reason for regarding the 0's as being a distinctly separate group of data.

Table 1 also shows that distinct intersubject variations existed in mean FBT, but no significant differences between "easy" and "hard" tasks. Thus, task difficulty did not seem to be a factor in the determination of FBT in these experiments. This observation holds for individual and group means.

Rhesus Monkey Data

Figure 10 illustrates a typical macaque exposure trial in the same format used for human trials (Figs. 5-9). Although the error trace is more irregular than for the human subjects performing the "easy" tasks, it remains generally within the boundary of the target ring. Note that during the F-R interval the error trace does not parallel the forcing function; continuous stick movement was typical of the rhesus subjects, even while presumably flashblinded.

The monkey data also elicited a number of 0's; an example is shown in Figure 11. The incidence of 0's was greater for the rhesus subjects than for the humans. This difference could be attributed to the fact that, even though the decision logic activated the shutter only when the eye position was centered, a finite delay time (approximately 0.1 sec) was inherent in the eye tracker/decision logic/shutter circuit. This delay, coupled with a higher

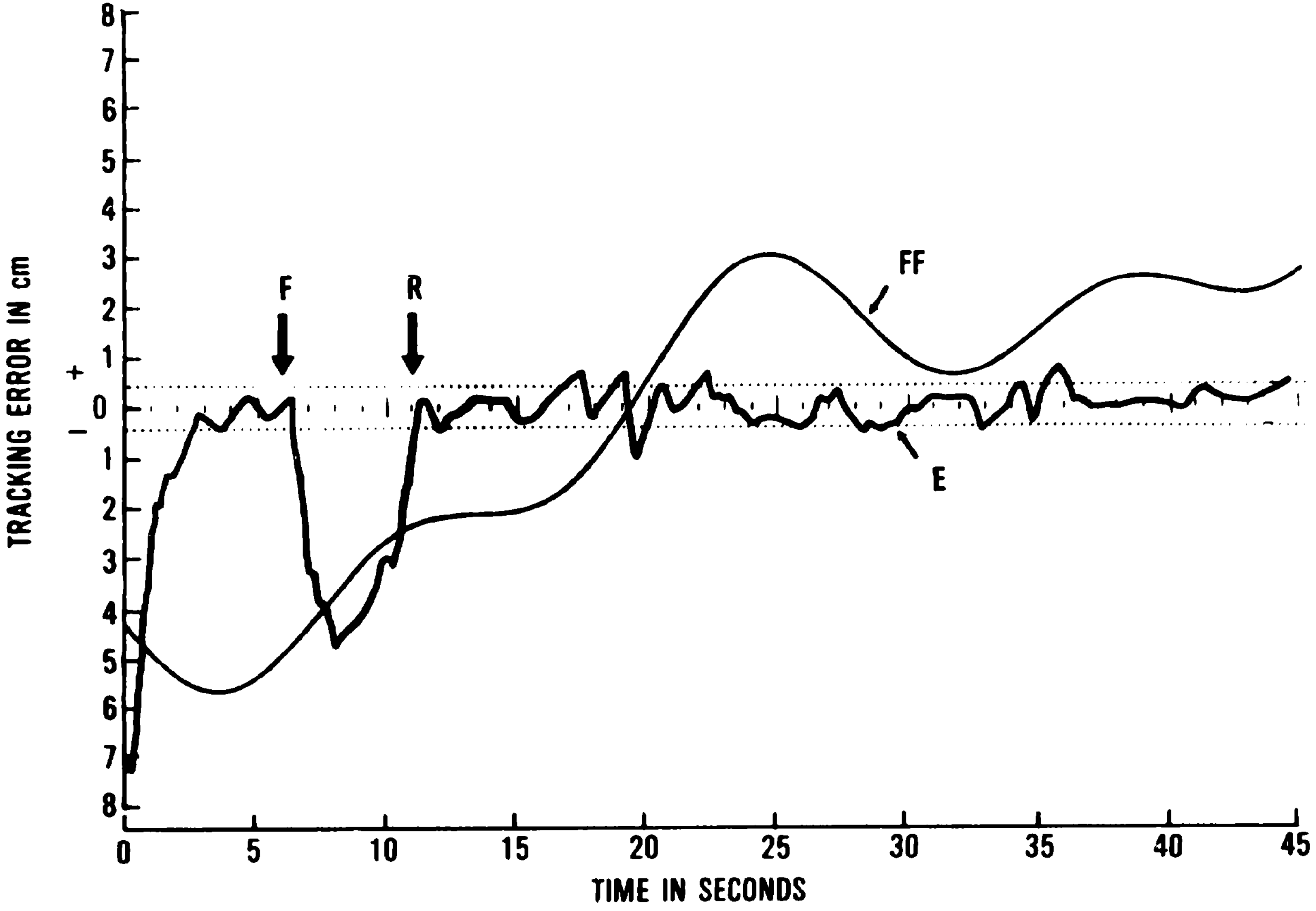

Figure 10. Typical exposure trial of a rhesus monkey subject (M1). The error trace shows that rhesus subjects did not display the same degree of control as did the humans for the "easy" forcing functions.

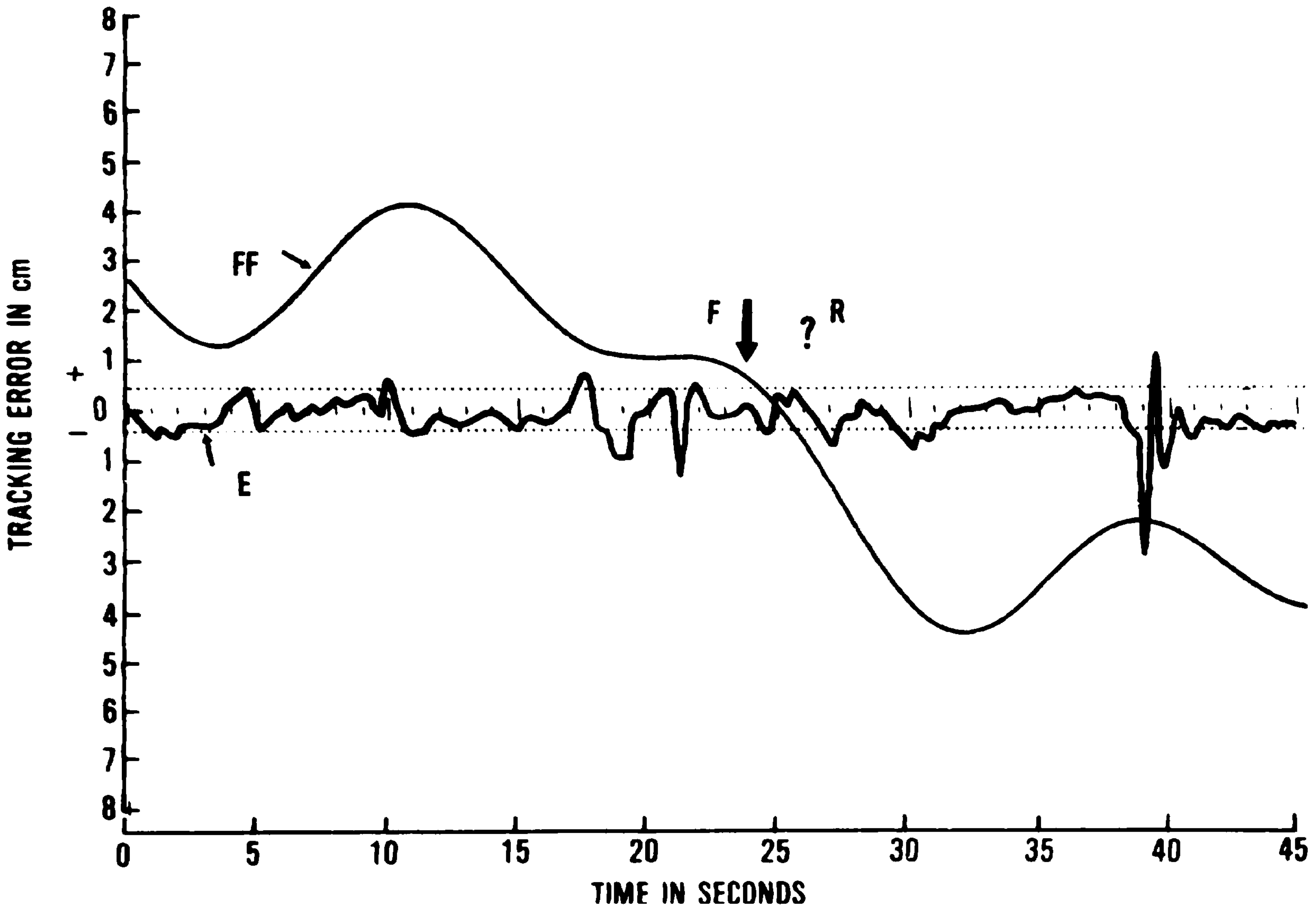

Figure 11. A "0" exposure trial for a rhesus subject (M1). No flashblinding event could be inferred from the error trace.

incidence of random eye movement in the monkey subjects (these were occasionally monitored during tracking with the infrared video camera described in METHODS), could account for the differences in the two groups.

The rhesus monkey exposures also yielded a category of data that was labeled "indeterminate." An example of an indeterminate trial is shown in Figure 12, with shutter activation indicated as usual. This was a "7-sec no-shock" condition, so the reinforcement paradigm was turned off for 7 sec after the flashblinding pulse. The subject, after an initial period of dithering the control stick, appeared to simply "give up" upon discovering that no shock was forthcoming. After the 7-sec interval the paradigm once again came into effect, causing a shock to be presented at S, after which the subject immediately resumed control. There were three trials of this type, all contributed by subject M3. Three other trials were also classed as indeterminate because of sustained high-amplitude dithering after the flash; one of these is shown in Figure 13. All six indeterminate trials were discarded during data reduction.

Initial reduction of data was more difficult for rhesus subjects than for humans. While many trials yielded straightforward FBT's (e.g., Fig. 10), an equal number required careful examination and considered judgment. The general rule for determining the point of visual recovery was that if the subject performed a control movement to bring the cursor into the target ring (or its close vicinity), followed by a second control movement to keep the cursor in the ring or its near vicinity, then recovery was judged to have occurred. This process is illustrated in Figure 14, with the flash occurring at F as usual. At points C1 and C2 the subject moved the cursor into (or close to) the target circle, but those movements were immediately followed by motions away from the target and so were discarded as potential recovery points. At point R the cursor was brought into the ring, followed by control movements with pauses at C3 and C4, both in the near vicinity of the target. Therefore, R was judged to be the recovery point for this trial.

Sometimes the definition of "near vicinity" was subject to a liberal interpretation, as in Figure 15. Here an animal adopts the common strategy of dithering the control stick when (presumably) unable to visualize the display after being flashblinded. For some seconds after F, these motions are ineffectual, being centered 3-4 cm above the target. Then at R the dither pattern appears to move purposefully to become centered about the ring. Therefore, R was judged to be the recovery point even though subsequent dithering moved the cursor 1 to 1.5 cm outside the target.

Of the 97 exposures performed on the three macaque subjects, 23 were 0's, 6 were indeterminate, and 1 was lost. The remaining 67 were assigned FBT's according to the procedures described above. Means and standard deviations, by subject and condition, are given in Table 2.

TABLE 2. RHESUS MONKEY FLASHBLINDNESS RECOVERY TIMES

	Normal Paradigm		7-sec No-Shock		All Tasks	
Subject	# Expos	FBT ± SD	# Expos	FBT ± SD	# Expos	FBT ± SD
M1	14	3.7 ± 1.5	14	4.3 ± .9	28	4.0 ± 1.3
M2	8	2.6 ± .8	11	2.6 ± .9	19	2.6 ± .8
M3	11	2.8 ± .5	9	2.7 ± .4	20	2.7 ± .5
ALL	33	3.1 ± 1.1	34	3.4 ± 1.1	67	3.2 ± 1.1

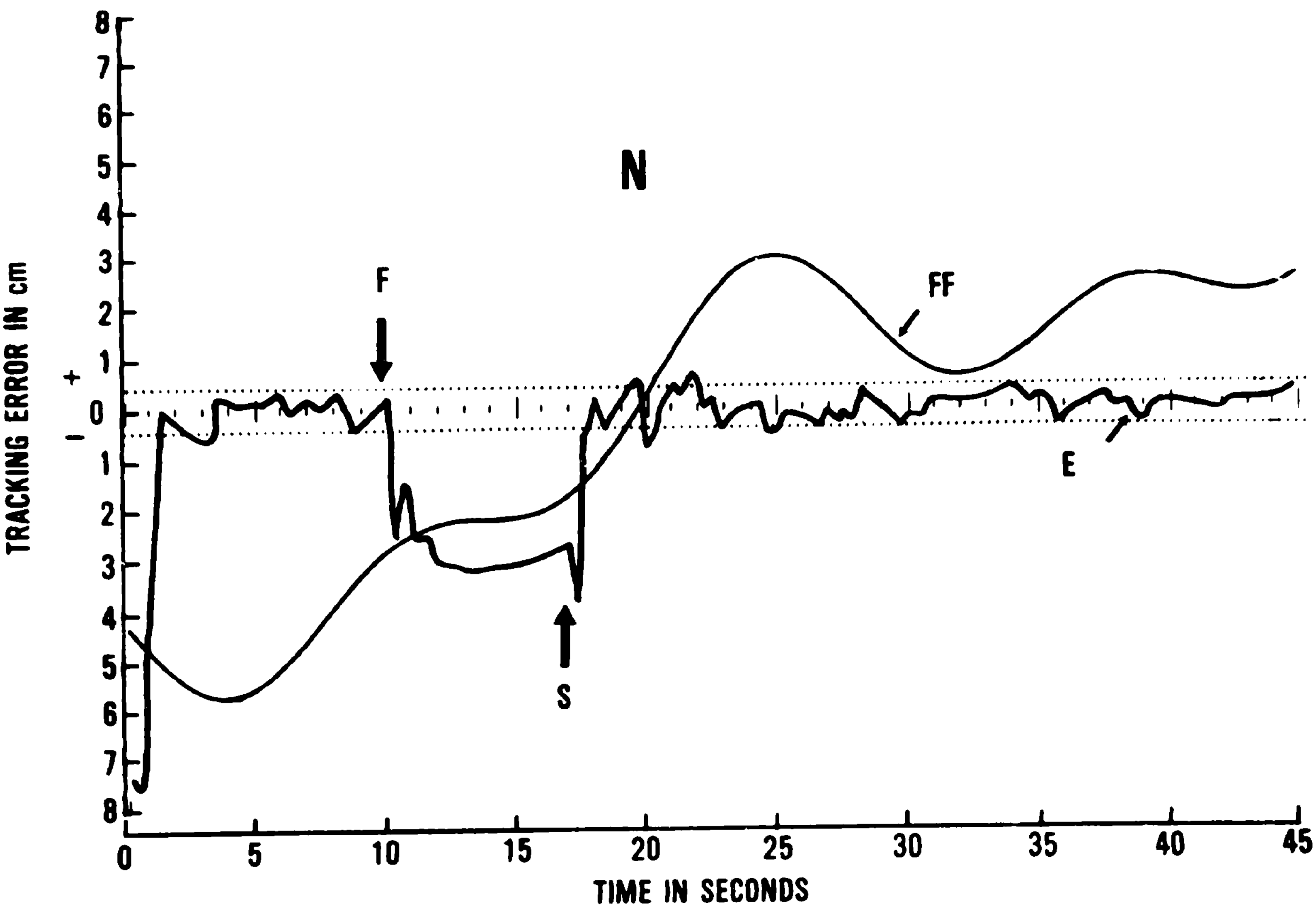

Figure 12. An indeterminate exposure trial of a rhesus subject (M3). This was a "7-sec no-shock" trial in which the subject relinquished control of the stick until the shock paradigm was restored.

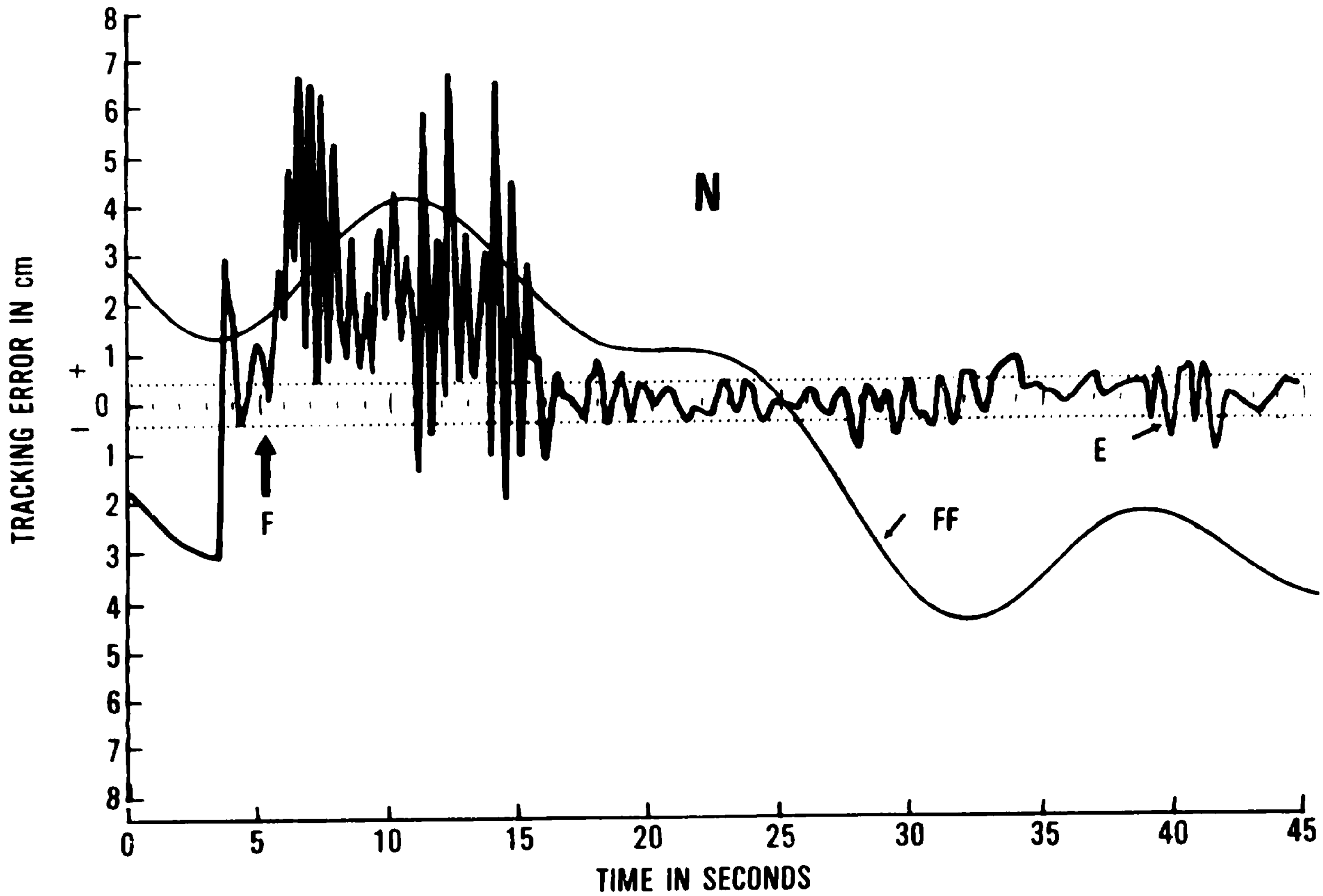

Figure 13. Another type of indeterminate exposure trial with rhesus subject M2. Subject dithered the control stick for approximately 10 sec after the flashblinding pulse and was judged to have recovered visual function before the error trace indicated that control was resumed.

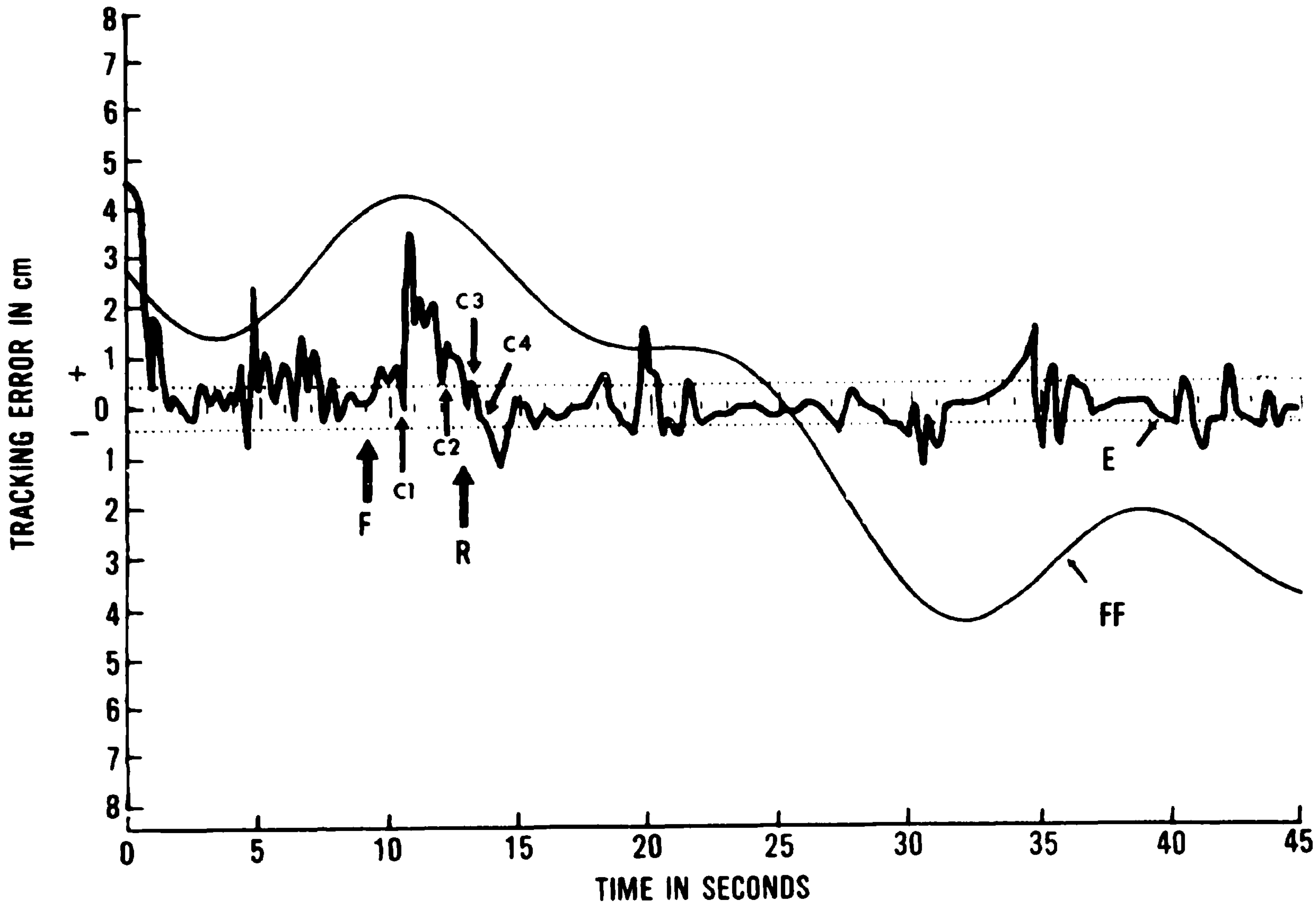

Figure 14. An exposure trial of a rhesus subject (M2), showing the judgment process used to determine R. Points C1 and C2 are discarded as potential recovery points because subsequent stick motions did not maintain the cursor in the near vicinity of the target ring. Point R, on the other hand, was followed by pauses at C3 and C4--both of which were near the ring and demonstrated control logic.

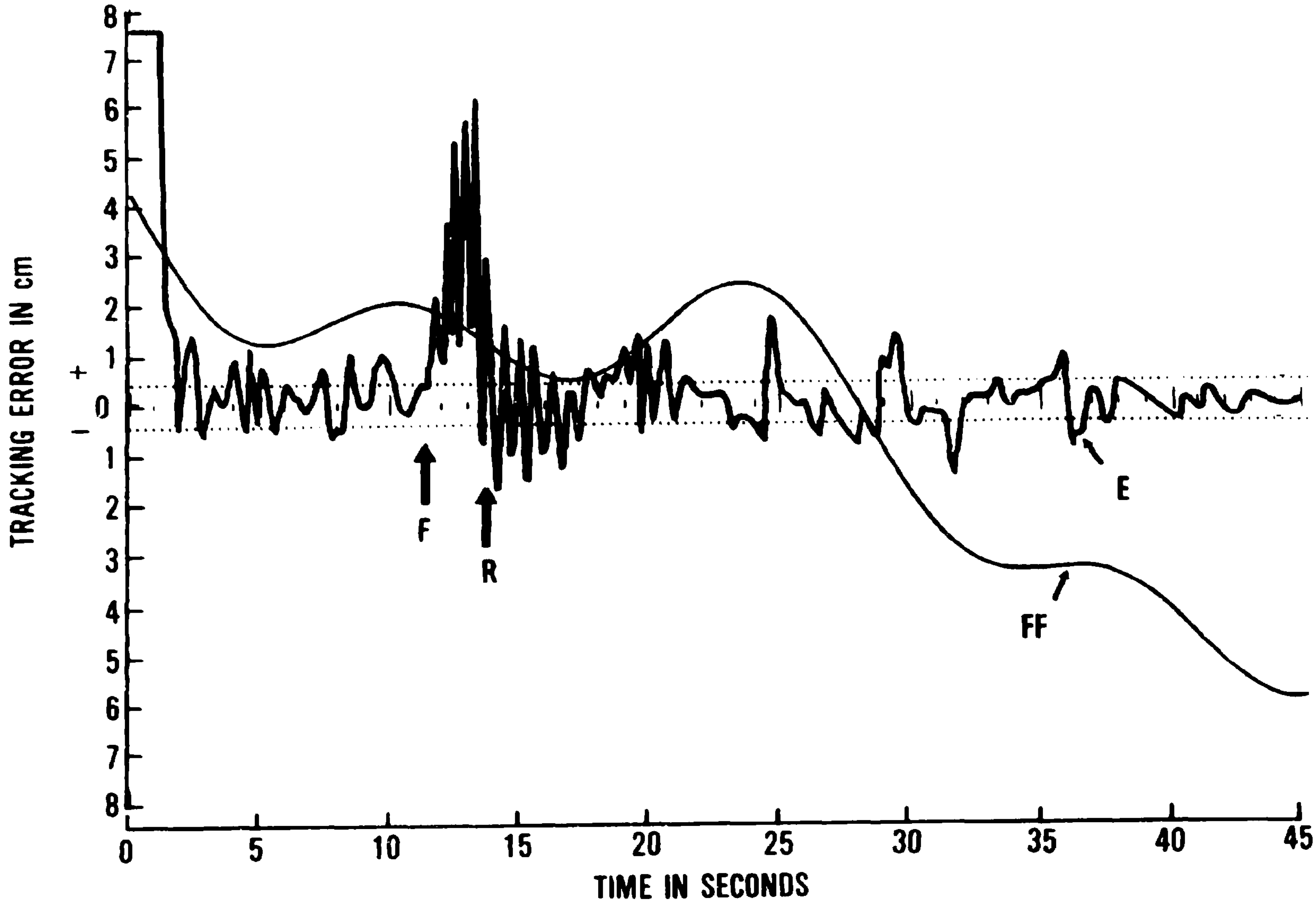

Figure 15. An exposure trial of rhesus subject M2, illustrating a judgment call. Recovery was determined to be at R because of the dramatic and purposeful change in the dither pattern.

The analyses show no significant differences (t-test, $p<.05$) between the "normal" and "7-sec no-shock" conditions for any given subject or for the grouped data.

Human/Rhesus Comparison

Given the dissimilarity in species and training paradigms, the agreement in FBT's is good, with no significant difference between the human and macaque mean FBT's (grouped data: t-test, $p<.05$). The distribution of FBT's for the two species is shown in Figure 16; both sets of data appear to be distributed normally. The major differences are the relatively higher number of 0's in the rhesus data and the presence of an anomalous spike at 5.0-5.9 sec in the distribution of rhesus FBT's. All data points in this spike were contributed by subject M1; most occurred in the "7-sec no-shock" condition.

DISCUSSION

Intersubject variability in human flashblindness recovery has been a common finding (7, 10, 11). The present experiment, even with low flash intensity and relatively short recovery times, demonstrates a similar variability. Individual FBT means for the human subjects ranged from 2.2 to 3.7 sec (see Table 1). However, all subjects seemed to be consistent about their mean FBT's; half had standard deviations of 0.3 sec or less, and only H5 was above 0.5 sec. A similar phenomenon was reported by Severin, who noted that each of his subjects was "dramatically consistent" in reproducing a given recovery time for a given exposure (9). Such findings were not well demonstrated in the macaque subjects of this experiment. Intersubject variability was difficult to show with only three subjects, and standard deviations were approximately twice those of the humans.

Despite some qualitative differences in the data, the human and rhesus mean FBT's were separated by only 0.4 sec (see Tables 1 and 2). Insofar as visual tracking of the target/cursor display was performed photopically, these results appear to support the conclusions of De Valois and Jacobs (3) and Crawford (1), who assert that cone vision mechanisms and spectral sensitivities of macaque and human retinae are essentially identical.

Thus, for tests in which simple flashblindness times are to be determined, the use of rhesus monkey subjects appears to be justified if care is taken in designing the training paradigm; the possibility of presenting nonvisual cues must be eliminated. With the paradigm used for these studies, the "7-sec no-shock" condition was apparently not necessary; it caused the elimination of some data points and possibly raised the mean FBT of subject M1.

Although FBT's of humans and monkeys showed good agreement, the control strategies of the two groups differed considerably. In normal tracking (see Figs. 5-7) the humans tended to exert maximum control over the cursor, attempting to maintain it very close to the center of the target ring.

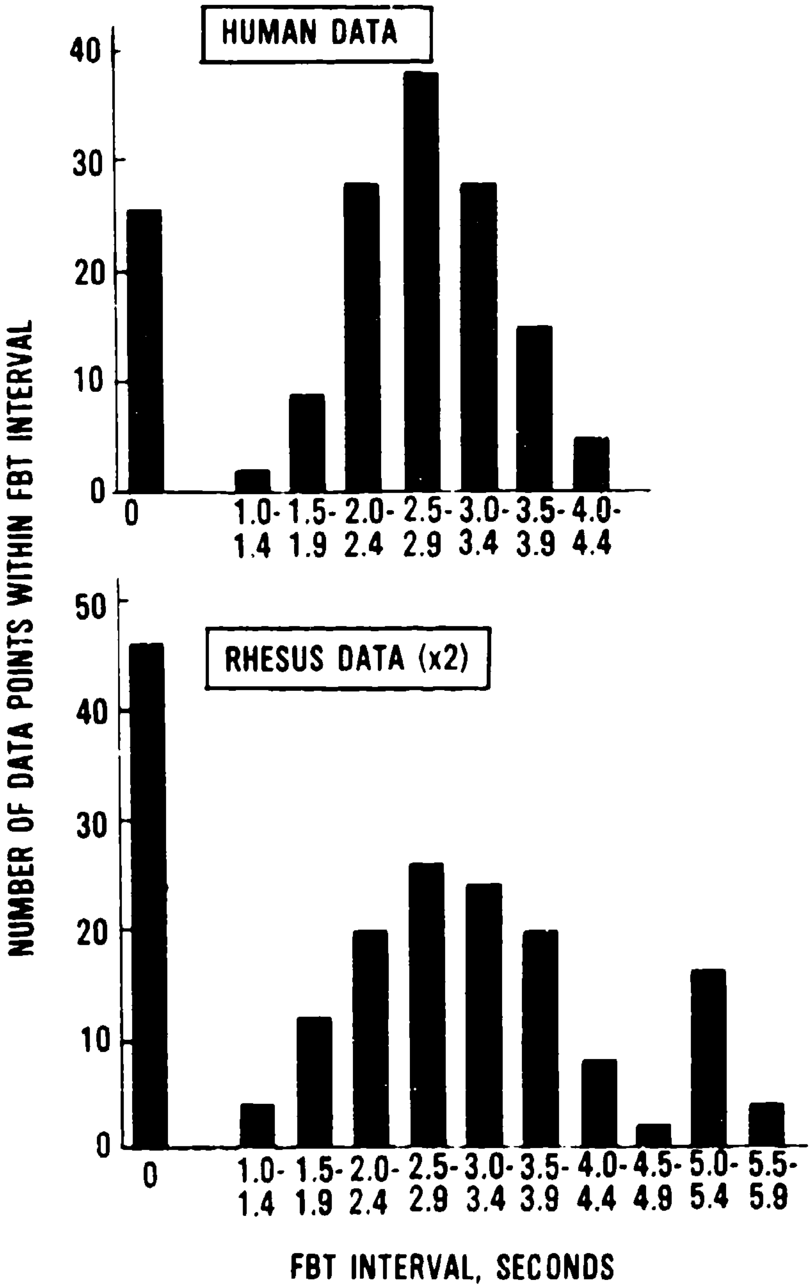

Figure 16. Distribution of flashblindness recovery times for human and rhesus monkey subjects. Note the higher incidence of 0's for the rhesus subjects. All rhesus data above 4.9 sec were contributed by subject M1, who demonstrated a bimodal distribution of FBT's. The number of data points in each FBT interval were doubled for the rhesus monkeys; this was to approximately normalize the two distributions (the rhesus subjects contributed a total of only 90 data points, while the humans had 151).

The monkeys, however, tended to exert much less control throughout most of the trials. They often allowed the cursor to drift near or past the boundaries of the target before using the control stick to move it back toward the center (see Figs. 10-15). During the flashblinding episodes these strategies seemed to reverse; the humans simply held the stick motionless, but the rhesus subjects continued to exert control--and often overcontrolled.

The differences in control strategies would seem to limit the use of rhesus monkeys as human analogues in predicting tracking performance. Especially suspect would be predictions based on modeling rhesus performance in compensatory tracking tasks. Performance measures in which control strategy plays a minor or secondary role in predicting the effects of an insult to the system would be more acceptable.

CONCLUSIONS

Humans and rhesus monkeys exhibited similar recovery times after receiving identical flashblinding treatments during a visual compensatory tracking task. Individual variations occurred among subjects, but the group means showed no statistically significant difference.

Rhesus monkeys should be acceptable as human analogues for this specific performance measure. Performance predictions that depend strongly on method of tracking, however, would not be justified because of species differences in control strategies.

REFERENCES

1. Crawford, M. L. J. Personal communication, from an unpublished manuscript. University of Texas Medical School, Department of Ophthalmology, Houston, Texas, 1980.

2. Davies, J. M., and D. I. Randolph. Panel discussion. In Proceedings of the U.S. Army Natick Laboratories Flash Blindness Symposium, Nov 1967. (AD 697793)

3. De Valois, R. L., and G. H. Jacobs. Primate color vision. Science 162:533-540 (1968).

4. Dickson, A. M. A study of flashblindness recovery. Thesis, Air Force Institute of Technology, 1977.

5. Frisch, G. D., E. S. Beatrice, and R. C. Holsen. Comparative study of argon and ruby retinal damage thresholds. Invest Ophthalmol 10:911-919 (1971).

6. Gibbons, W. D. Retinal burn thresholds for exposure to a frequency-doubled neodymium laser. SAM-TR-73-45, Nov 1973.

7. Parker, J. F. Visual impairment from exposure to high intensity light sources. Biotechnology Incorporated, Report 63-2, Prepared for the Office of Naval Research, May 1963.

8. Richey, E. O. Personal communication. USAF School of Aerospace Medicine, Radiation Sciences Division, Brooks AFB, Texas, 1979.

9. Severin, S. L. Photo stress testing and macular function. In Proceedings of the U.S. Army Natick Laboratories Flash Blindness Symposium, Nov 1967. (AD 697793)

10. Severin, S. L., N. L. Newton, and J. F. Culver. An experimental approach to flash blindness. Aerospace Med 33:1199-1205 (1962).

11. Teresi, J. D. A review of research on flashblindness. USNRDL-TR-68-76, July 1968. (AD 840277)

APPENDIX A. PHOTOMETRIC CALCULATIONS

The calculations in this appendix were done for the human exposures. All quantities except the values calculated for comparison with the ANSI standard hold also for the rhesus monkeys because pupil diameter and eye focal length are not used in calculations involving retinal energy density.

Power and Energy of Exposures

To insure that the experimental setup would create illumination over a large area of the retina, the following steps were taken: (1) An artificial human eye (pupil diameter, 3.5 mm; focal length, 17 mm) was placed where the subject's right eye would be during testing; (2) the light source was turned on and the shutter opened; (3) a frosted reticle was placed 17 mm behind the pupil of the artificial eye; and (4) the field lens in the light path was adjusted so that a 3-mm spot was formed on the reticle. The reticle was then replaced with a United Detector Technology 80X power meter, and the lamp voltage regulator was adjusted to produce a continuous measured output of 0.207 mW (shutter open). The detector head was manufactured to reproduce the absorption characteristics of the human eye.

Since the illuminated retinal area was $\pi \cdot (0.15)^2$, the following calculations apply:

$$\text{Power density} = \frac{0.207 \text{ mW}}{.0707 \text{ cm}^2} \quad \text{at retinal surface}$$

$$= 2.93 \text{ mW/cm}^2$$

$$= 2930 \ \mu\text{W/cm}^2 \quad \text{(retinal)}$$

Since exposure durations were fixed at 0.1 sec by the shutter, the total energy density per exposure was:

$$\text{Exposure energy density} = (2930 \ \mu\text{W/cmx}^2) \cdot (0.1 \text{ sec})$$

$$= 293 \ \mu\text{J/cm}^2 \text{ (retinal)}$$

This quantity may also be expressed in calories by applying the conversion factor of 0.2389 calories per joule:

$$\text{Exposure energy density} = (293 \ \mu\text{J/cm}^2) \cdot (.2389 \text{ cal/J})$$

$$= 70.0 \ \mu\text{cal/cm}^2$$

$$= 7.0 \times 10^{-5} \text{ cal/cm}^2 \quad \text{(retinal)}$$

Comparison with Indirect Ophthalmoscope[1]

The indirect ophthalmoscope illuminates the retina with 0.1 W/cm^2. Comparing this to the power of the source in the present experiments:

Ophthalmoscope: 100,000 $\mu W/cm^2$

These experiments: 2930 $\mu W/cm^2$

$$\text{"Safety factor"} = \frac{100{,}000}{2930} = \underline{\underline{34}}$$

This "safety factor" is extremely conservative. At times the ophthalmoscope might be in continuous use for a minute or more, but the exposures of this experiment are for only 0.1 sec. The total energy deposited on the retina for one 60-sec session with an ophthalmoscope would be 6,000,000 $\mu J/cm^2$, as compared with the 293 $\mu J/cm^2$ per exposure for this experiment--a factor of more than 20,000.

Comparison with Fundus Camera Flash[1]

The highest setting on a Zeiss fundus camera produces a 4-msec flash, depositing 0.1 J/cm^2 on the retina. Thus the comparison:

Fundus camera: 100,000 $\mu J/cm^2$ (retinal)

These experiments: 293 $\mu J/cm^2$ (retinal)

$$\text{"Safety factor"} = \frac{100{,}000}{293} = \underline{\underline{341}}$$

This calculation also is conservative. The fundus camera deposits its total energy in 4 msec, compared to the 100 msec for the present experiments. Therefore, the peak power density produced by the camera is at least 25,000,000 $\mu W/cm^2$, as opposed to the 2930 $\mu W/cm^2$ of these tests. So the peak power generated by the highest setting of the Zeiss camera is at least 8532 times that of the present experiments. Also, the fundus camera requires a high level of preillumination for focusing prior to the picture-taking flash.

ACGIH/ANSI Standard for Extended Laser Sources

The American Congress of Governmental and Industrial Hygienists (ACGIH) and ANSI both use the same maximum permissible exposure (MPE) for viewing extended laser sources or diffusely reflected laser light in the visible

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[1]Energy and power levels for the indirect ophthalmoscope and Zeiss fundus camera were obtained by personal communication with Dr. Frank Delori of the Retina Foundation, Boston, Massachusetts.

(400-700 nm) region. Though the present exposures are only to noncoherent light, a comparison with this quasi-official laser standard is in order. The ACGIH/ANSI limit in the visible region is based on exposure duration and solid angle (in steradians) subtended by the source:

$$\text{MPE (ACGIH/ANSI)} = 10.\sqrt[3]{t}\ \text{J/cm}^2\text{-sr} \quad \text{(corneal)}$$

The solid angle subtended by the light source in these experiments can be calculated in the following manner:

$$\text{Source solid angle} = \frac{\text{Area of retinal spot}}{(\text{Focal length of eye})^2} = \frac{.0707\ \text{cm}^2}{(1.7\ \text{cm})^2}$$

$$= .0245\ \text{sr}$$

Therefore, for the 0.1-sec exposures in the present experiments, the ACGIH/ANSI limiting value would be:

$$\text{MPE (ACGIH/ANSI)} = (10\cdot \sqrt[3]{.1}\ \text{J/cm}^2\text{-sr})\cdot(.0245\ \text{sr})$$

$$= .1135\ \text{J/cm}^2$$

$$= 113{,}500\ \mu\text{J/cm}^2 \quad \text{(corneal)}$$

To find the corneal energy density for the present exposures, assume a transmissivity of 0.8 through the ocular media, and an effective area ratio of $(3.5/3.0)^2 = 1.361$. This figure is derived from the fact tnat the pupil diameter was 3.5 mm in these tests, as compared to the 3.0-mm retinal spot diameter. Therefore,

$$\text{Corneal energy density} = \frac{\text{Retinal energy density}}{(\text{Transmissivity})\cdot(\text{Area ratio})}$$

$$= \frac{293\ \mu\text{J/cm}^2}{(.8)\cdot(1.361)}$$

$$= 269\ \mu\text{J/cm}^2 \quad \text{(corneal)}$$

These experimental exposures and the ACGIH/ANSI standard for extended laser sources or diffuse reflections from laser sources can now be compared:

MPE (ACGIH/ANSI): 113,500 $\mu J/cm^2$ (corneal)

These experiments: 269 $\mu J/cm^2$ (corneal)

$$\text{"Safety factor"} = \frac{113,500}{269} = \underline{\underline{422}}$$

This "safety factor" should theoretically apply only to coherent illumination. A good argument can be made, however, for its relevance to the present experiments with an incandescent source because (1) no real differences between coherent and noncoherent light have been discovered with respect to eye damage vs energy deposition on the retina, and (2) retinal damage thresholds seem to be relatively independent of wavelength in the visible region. Also, the calculated "safety factor" is quite conservative because the ACGIH/ANSI limit is derived assuming a 7-mm pupil diameter. The pupil diameters in the present tests were 3.5 mm, so a working "safety factor" of 4·422 = 1688 was achieved.

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BROOKS CITY-BASE TEXAS

3 September 2003

MEMORANDUM FOR LARRY DOWNING
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FROM: AFIOH/DOBP (STINFO)
2513 Kennedy Circle
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 ADB056770, SAM-TR-81-3, Visual Compensatory Tracking Performance After Exposure to Flashblinding Pulses: I. Comparison of Human and 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
SHERRY Y. MCNEW
AFIOH STINFO Officer

Attachment
Corrected page (DD Form 1473)

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