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TRACKING PERFORMANCE WITH A VISCOUS-DAMPED MOUNT UNDER SIMULATED CONDITIONS OF VARIED AMBIENT LIGHT LEVELS AND TARGET VELOCITIES

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DIVISION OF BIORHEOLOGY

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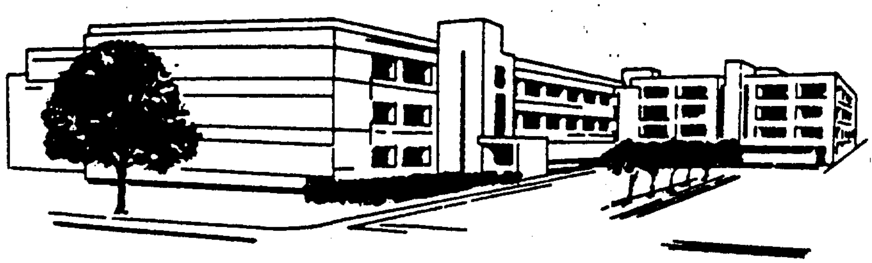

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Human Subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 70-25 on use of volunteers in research.

John U. Marshall 22 Jan 80
(Date)

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During three training sessions 12 U.S. Army male volunteers used a laboratory constructed laser designator to track a 1/35th scale model tank. The model traversed a fixed course located 5 m from the pivot point of the designator. The optics and mechanical response of the designator was adjusted to simulate an engagement of 2 km. Each of three training sessions was comprised of 15 trials (all trials lasted 10-12 sec) at 5.0 mrad/sec velocity and 15 at 7.5 mrad/sec. During 3 subsequent experimental sessions, the designator

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20. ABSTRACT (Cont)

operators tracked targets at velocities of 2.5, 5.0, and 7.5 mrad/sec under bright and low ambient lighting conditions. Analysis of root mean square (RMS) error tracking scores during the experimental sessions showed significant performance decrements related to decreased ambient light levels and increased target velocities. Under the low light conditions significantly improved RMS error scores across the three experimental sessions were found for the 7.5 mrad/sec velocity condition. This was interpreted as reflecting a change in tracking proficiency as operators switched from the use of a specific aiming point to center of mass tracking. Comparison of RMS error scores with time-on-target scores suggested that RMS measurements were more sensitive to subtle performance changes.

ABSTRACT

During three training sessions 12 U.S. Army male volunteers used a laboratory constructed laser designator to track a 1/35th scale model tank. The model traversed a fixed course located 5 m from the pivot point of the designator. The optics and mechanical response of the designator was adjusted to simulate an engagement of 2 km. Each of three training sessions was comprised of 15 trials (all trials lasted 10-12 sec) at 5.0 mrad/sec velocity and 15 at 7.5 mrad/sec. During 3 subsequent experimental sessions, the designator operators tracked targets at velocities of 2.5, 5.0, and 7.5 mrad/sec under bright and low ambient lighting conditions. Analysis of root mean square (RMS) error tracking scores during the experimental sessions showed significant performance decrements related to decreased ambient light levels and increased target velocities. Under the low light conditions significantly improved RMS error scores across the three experimental sessions were found for the 7.5 mrad/sec velocity condition. This was interpreted as reflecting a change in tracking proficiency as operators switched from the use of a specific aiming point to center of mass tracking. Comparison of RMS error scores with time-on-target scores suggested that RMS measurements were more sensitive to subtle performance changes.

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PREFACE

We wish to express our appreciation to the various support elements within LAIR and to COL John E. Canham who made this project possible. Also, to Mr. Charles LeFeat for construction of the laser designator and to SSG Robert Jones for construction of the terrain area. Appreciation is also offered to Mr. Robert Patterson, Mr. Michael Helbig, SP5 Gregory Muller, and SP4 Jerry Molchany for their assistance in the collection and analysis of the tracking data. Finally, to Dr. John P. Hannon for his timely suggestions throughout the development and conduct of the experiment.

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INTRODUCTION

Several of the new weapon systems that will soon be widely deployed by the military require the use of laser rangefinder-designators. The operational environment in which these laser rangefinder-designators will be used include surface-to-surface, surface-to-air, and air-to-surface engagements with both direct and indirect fire weapons. In a typical engagement, once the approximate position of the target has been determined, a laser-seeking missile or artillery round is fired at the target. During the last several seconds of flight, as long as the laser beam remains on the target, the projectile will be directed to the target.

It is generally agreed that natural (weather, terrain, etc.) and man-made (smokes, obscurants, weapons effects) environmental factors will influence the operating characteristics of laser designator devices. The same variables in combination with target variables, target initiated countermeasures, and subjective variables (fatigue, stress, etc.) will also affect the operator of the designator. Since the U.S. Army is presently developing an extensive program to train laser-designator operators, additional information regarding biomedical factors that are related to environmental changes which may serve to degrade or improve their performance is needed. Consideration of the critical interaction of soldier/environmental factors must serve as the basis for the development of this training doctrine.

A field simulation which utilizes a desert terrain model, scale model targets, and a viscous-damped, laser-designator has been developed within our laboratory (1). The use of such a simulation should enable investigators to provide biomedical information for the designers of training programs for laser-designator operators. Considerable time, money, and effort can be saved if specific information can be obtained in the laboratory which corresponds accurately to data obtained from field experiments.

The purpose of this report is to evaluate the effects of two environmental factors (i.e., target velocity and ambient light level) on tracking proficiency. Specifically, it is hypothesized that as the velocity increases from 2.5 to 7.5 mrad/sec and the ambient light level diminishes from bright to low-light, tracking performance will deteriorate. The combined effect of these two factors on tracking performance were evaluated.

METHODS

Subjects. The participants were 12 U. S. Army volunteers, 11 enlisted men and 1 officer, that were selected from a group of 18 volunteers. All volunteers received an extensive eye examination and visual function evaluation to determine acceptability. Four of the original group of 18 volunteers were not selected to participate in the experiment because of vision deficiencies that were found during the preliminary eye examinations. The remaining 14 individuals were within normal limits and emmetropic, which indicated no additional external refractive correction was required. However, 2 of the 14 did not complete the experiment and their data were not used in the subsequent analyses. The ages of the participants ranged from 22 to 38 years. None of the volunteers had received prior training using a viscous-mounted laser-designator type tracking device. For their participation in this experiment, these soldiers received no monetary reward but were told that they would receive the results of their eye examination.

The BLASER Simulator. For a complete description of the BLASER simulator see O'Mara et al, 1979 (1). In the present experiment the body of an Athearn HO model train engine was removed from the engine and frame, and replaced with a Leopard A4 1/35 plastic scale model tank chassis. This target was mounted on a train track positioned in an arc 5 meters from the laser designator mount. Power to the track was provided by three model train transformers through a multiposition switch that allowed for rapid change among the three velocities that were used. The velocities were 2.5, 5.0, and 7.5 mrad/sec (at the simulated 2000 m engagement distance these velocities were approximately equal to 11.2, 22.4, and 33.6 mph).

A light emitting diode, that was used as a reference point for the error detection system, was affixed to the rigidly mounted gun barrel and wires were run through a resistor to a 9V battery that was mounted inside the tank turret. A 2.5 cm^2 target, a black dot on a white background which subtended a visual angle of 5.0 mrad, was attached to the side of the tank at the center of the tank (front to rear) and at the level of the turret ring. A television camera located within the designator was used to monitor the target during each trial. The video signal from the camera was processed electronically and a continuous record of the horizontal and vertical aiming errors was derived during each trial. A microcomputer was used for data acquisition and to derive summary statistics at the end of each trial.

The laser-designator cover was modified to allow a 2.5 neutral density filter to be inserted just ahead of the monocular eye piece. With this modification the amount of light reaching the operator was reduced with no change in light intensity to the coaxially mounted television camera (Sanyo, Model No. VC 1600X) and video monitor (Sanyo, Model No. VM 4209). The terrain luminance measurements were obtained by use of a Spectra Minispot Photometer. The average luminance, measured from the position of the designator objective lens, was 170 lm/m^2sr. The luminance reaching the eye was attenuated by the designator optics, which had a luminous transmittance of 10%. Low terrain luminance conditions were simulated by inserting a 2.5 OD neutral density attenuator in the designator optics. The apparent terrain luminance was thereby reduced to 0.54 lm/m^2sr. No light from the terrain passed into the bunker other than through the designator optics. The bunker was dimly illuminated by a rheostatically controlled incandescent bulb which was turned off during the low-light tracking trials. The designator was mounted on an O'Connor Engineering model 50 fluid head, viscous-damped (500,000 centistoke viscosity rating) traversing unit.

Procedure. When each soldier was asked to participate in the experiment the nature of the research and all of the procedures were carefully explained. They were then asked to sign a volunteer consent statement which acknowledged that all tests and possible health hazards had been explained to them. An eye examination was then given which included the Armed Forces Visual Acuity Test, Farnsworth Munsell 100-hue Color Vision Test, a dark adaptation test (2), undilated funduscopic examination, and a visual history. The color vision, acuity, and funduscopic examination were repeated after the experimental phase of the project. No test of oculomotor function was performed. According to current plans, evaluation of these data will be included in a subsequent report.

Each volunteer was given 30 training trials/day under the bright-light condition for 3 days (sessions 1, 2, and 3). During these sessions, 15 of the trials were run at 5.0 mrad/sec and 15 at 7.5 mrad/sec velocity (Table 1).

Following the 90 training trials, 90 experimental trials were run (30 trials/day) that included 10 trials at each of three velocities (2.5, 5.0, and 7.5 mrad/sec). Each group of 10 trials were again divided such that 5 trials were performed under the bright-light condition and 5 under the low-light condition. The 15 trials under each light condition were combined, but the two light conditions were separated by a 10-minute rest period between trials 15 and 16. The light/dark ordering was intended to be completely counterbalanced; however, 2 of the volunteers had to withdraw from the study for personal reasons thereby reducing the number of participants to 12. Lacking their data, during sesson 4 (the first experimental session), 5 of the participants received the dark trials first and 7 received their light trials first. During the next two sessions, the order of the light/low-light conditions for each group was reversed from the previous day. The experimental sessions (i.e., 4, 5, and 6) were always completed during the same 5-day work-week.

At the beginning of each session, each participant was seated in the bunker, on sand bags which were adjusted for individual heights. If the first 15 trials were dark trials, they were allowed to relax and the bunker light was turned off for 10 minutes to allow for partial dark adaptation to the semi-darkened room. The 10-minute period was considered sufficient and allowed for acceptable sensitivity at that dark adaptation level. Following this, or if no dark adaptation was required (i.e., during the bright-light trials), they were given the command "ready," and they would center the crosshairs on the target. Next, they were given the command "go" and the tank would begin an immediate right-to-left or left-to-right movement across the terrain. The total time of the track ranged from 10 to 12 seconds. Each trial was followed by a minimum delay of one minute, during which time the processing system summarized the data, printed the summary information, and the complete data set was recorded with a General Electric Model No. 3-5121B cassette tape recorder. Following this, the next trial would begin in the opposite direction.

<u>Statistical Design and Analysis</u>. The experiment was planned as a 2 (light level) X 3 (velocity) X 3 (sessions) factorial design with all factors considered as repeated measures factors. While the entire 10-second period of tracking data was recorded on a cassette tape, only the period from 4 to 8 seconds of each trial was used for the subsequent analyses. This was unknown to the participants. The delayed sampling was necessary to allow tracking performance to stabilize following the start of target movement. During the 4-second period, performance was sampled at a rate of 50 Hz, yielding 200 data points for each trial. For each trial, a percent time-on-target score (TOT) and the average and root mean square (RMS) error scores for horizontal and vertical axes was recorded. The quantitatively superior RMS error scores were emphasized as the primary criteria of tracking proficiency. The relatively less sensitive TOT scores were mainly used to provide trial-by-trial feedback to the tracker. The formula used to compute the RMS error for the horizontal axis was:

$$\text{RMS error} = \sqrt{\frac{\Sigma (X_i)^2}{n}}$$

where: $X_i = X - X_o$

n = Sample size

X = Average location of crosshairs during the trial

X_o = Position of the crosshairs for each sample point

Separate analyses of variance (ANOVA) were computed for the analysis of the learning curve of the performance scores, including both RMS error and TOT scores, across all six sessions. For the evaluation of speed and light effects, horizontal RMS error and TOT scores for sessions 4, 5, and 6 (i.e., the experimental sessions) were also analyzed with separate ANOVA. The ANOVA were performed using Biomedical Computer Programs BMD-P2V for multifactorial mixed designs (3). The specific post hoc comparisons of significant findings were made using Newman-Keuls Tests (4). The 0.05 level was used for determining significances.

RESULTS

As noted above, 5 individuals received their low-light trials first during session 4 with the remaining 7 receiving the opposite order. Comparison of the $\overline{X}$ RMS error scores and TOT scores of the two groups during sessions 4, 5, and 6 for each light condition and speed was made using t-tests for independent samples (5). The performance of the group of 5 soldiers was found to be significantly better than the group of 7 soldiers when tracking targets at 7.5 mrad/sec under low-light conditions in session 4 and again during the bright-light 7.5 mrad/sec trials of session 5. However, the superior performances of the group of 5 soldiers occurred during the first 15 trials without regard to light condition. These findings suggest that apparently some other factor related to performance (e.g., individual differences in ability) was likely to be responsible for these differences. Therefore, subsequent evaluation of the tracking data were made without regard to light presentation order.

The effects of training on performance (Figure 1) across the three training sessions (1, 2, and 3) and the three experimental sessions (4, 5, and 6), were shown by an ANOVA computed for scores obtained during the bright-light condition only. The scores were the within session means ($\bar{X}$) of the 5.0 mrad/sec and the 7.5 mrad/sec velocity trials. The results of the ANOVA of the RMS error scores for the 5.0 and 7.5 mrad velocities are summarized in Tables 2 and 3, respectively. For both velocities significant repeated measure effects were found. The post hoc comparisons showed, in general, a statistically significant improvement in performance when sessions 1 and 2 were compared with 3, 4, 5, and 6. However, with both velocities, despite the slight observable trend for continued improvement, no statistically significant differences were found when comparing the sessions subsequent to session 3. The results for TOT were highly similar.

Horizontal RMS Error Scores. The group $\bar{X}$ horizontal RMS error scores obtained during sessions 4, 5, and 6 are presented in Figure 2, and the ANOVA of these data are summarized in Table 4. The results of this ANOVA indicated that the effects of ambient light level, angular velocity sessions, and the interaction of angular velocity with light level were all significant. The post hoc comparisons of the differences between the bright-light and low-light conditions, at all velocities, during each session were significant. When specific comparisons of the velocity conditions were made, all 2.5 to 7.5 mrad/sec comparisons were found to be significant. Additionally, 5 of the 6 2.5 to 5.0 mrad/sec and 5.0 to 7.5 mrad/sec comparisons under the low-light condition were significant. However, under the bright-light conditions only 2 of these 6 comparisons were significant. Finally, the significant three-way interaction between sessions, light level, and target velocity can likely be attributed to changes in performance under the low-light conditions when tracking at the 2.5 and 7.5 mrad/sec velocities during these 3 sessions. This effect is seen in Figure 3, which shows the $\bar{X}$ scores for each velocity for the 3 sessions under bright-light and low-light conditions. The difference in horizontal RMS error between the bright-light and low-light condition was approximately .05 mrad at the 2.5 mrad/sec velocity, but increased to approximately .09 mrad for the 5.0 and 7.5 mrad/sec velocity conditions. The post hoc comparisons of these data, however, indicated that ambient light levels produced significant effects only for the 7.5 mrad/sec target velocity.

TOT Error Scores. Table 5 presents the summary of the ANOVA for the TOT scores for sessions 4, 5, and 6. These data are visually depicted in Figure 4. The results of this ANOVA showed that only the main effects of light and velocity were significant. The post hoc comparisons between the bright-light and low-light conditions, as with the RMS error scores, were all significant. However, only 3 of 18 post hoc tests of the velocity effects were significant. These significant comparisons were found during session 5, where the 2.5 mrad/sec trials under the bright-light condition were different from the 5.0 and 7.5 mrad/sec velocities under the same light condition. It was also found that during session 5, the 2.5 mrad/sec scores under the low-light condition were siginficantly different from the 7.5 mrad/sec scores under that same light condition.

DISCUSSION

Based on the findings, several points merit further elaboration. Evaluation of the learning curves obtained under the 5.0 and 7.5 mrad/sec velocity bright-light conditions showed that improvements in performance after 90 trials (total training time of 15 minutes) were not statistically significant. However, as seen in Figure 1, the RMS error scores for the 5.0 mrad/sec velocity tended to show a small improvement through session 6. This suggests that an additional session(s) was needed to determine if the group scores at the 5.0 mrad/sec velocity were truly at an asymptotic level.

The ANOVA of the RMS horizontal error scores revealed significant effects for light level, angular velocity, sessions, and the interaction of light level and velocity. The increased error scores as velocity increased were not unexpected and corresponded well with other work that measured error rates at comparable velocities for volunteers tracking with optical systems and with several viscous-damped mounts (6). In addition to the significant main effects of ambient light level (i.e., performance under reduced light levels yielded significant performance decrements), the significant interaction of light level with angular velocity indicated that not only did error scores increase as velocity increased from 2.5 to 7.5 mrad/sec, but that this effect was even greater for 5.0 and 7.5 mrad/sec velocities under the low-light condition. The added difficulty of tracking under reduced illumination and the partial adaptation noted for the 7.5 mrad/sec velocity across the three experimental sessions emphasize the need to provide laser-designator operators with training under reduced illumination conditions.

Time-on-target scores reflected a similar learning function as RMS error scores (i.e., the scores improved from session 1 to 2), but comparisons among subsequent sessions yielded nonsignificant findings. Additionally, specific comparisons of effects of the 3 velocities as a function of lighting conditions showed, as did RMS comparisons, consistently poorer performances under the low-light condition. However, the percent time-on-target scores were not as sensitive to target velocity effects as the corresponding RMS scores. Also, the significant improvement in RMS horizontal error scores during sessions 4, 5, and 6 for the fast, low-light trials was not found for the TOT scores.

The relative lack of sensitivity of TOT scores was not unexpected. In the present study the boundaries used to define "hits" or "misses" were approximately the same as the target aiming patch attached to the tank. As our trackers became more proficient, they were able to keep the crosshairs inside of the boundaries of the target attached to the side of the tank. Any further reduction in aiming errors were not determined by the TOT computations. The TOT scores would likely have shown a more gradual, but continued improvement, and reflected greater sensitivity had smaller error boundaries been used. Since targets will vary in size and shape, direct comparison of TOT scores may be misleading. This and other limitations of TOT scores have been previously described (7,8).

CONCLUSIONS

The results of this study using the BLASER simulator corresponded well with earlier work using laser tracking devices. Specifically, (1) As velocity increased, RMS error scores correspondingly increased; (2) As ambient light levels decreased, RMS error scores again increased and were attributed to shifting from aiming at a specific aiming point under the bright-light to aiming center-of-mass under low-light conditions; (3) At higher velocities, operator tracking proficiency may partially recover as he acquires experience while tracking under low illumination conditions; (4) RMS error scores were more sensitive to changes in target velocity and ambient light level.

RECOMMENDATIONS

Additional research should be conducted to determine at what point continued reduction of ambient light level will increase tracking error such that the projectile will miss the intended target. At that point the laser-designator operator should be instructed to switch to night tracking techniques. Information concerning the ability of the soldier to track with night vision aids is also needed.

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LEGENDS OF FIGURES

APPENDIX A

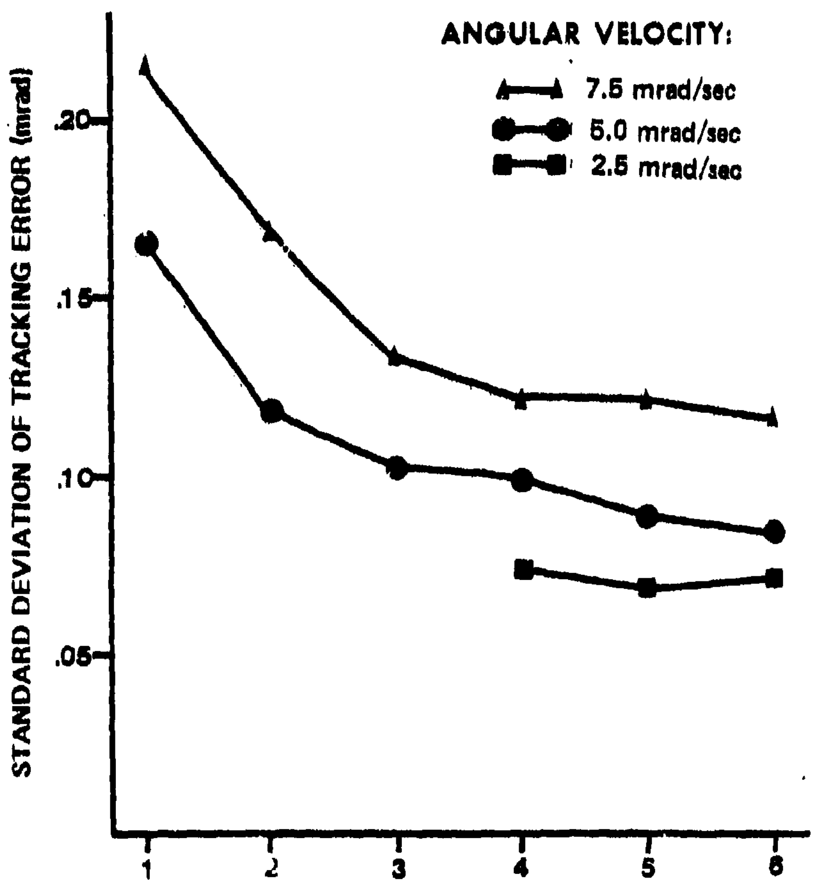

Figure 1. Horizontal error as a function of training and target velocity.

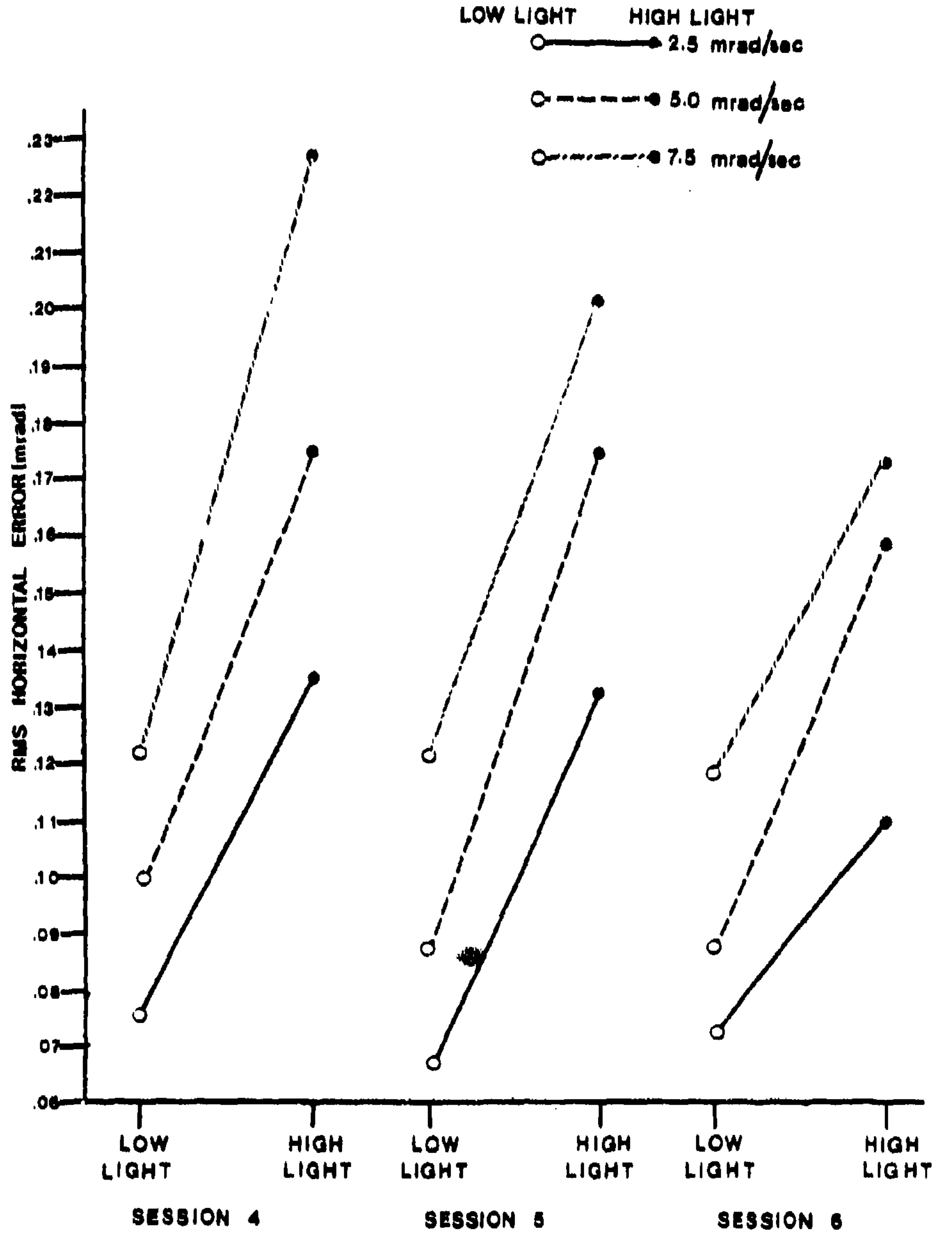

Figure 2. RMS horizontal error scores for high-light and low-light trials at target velocities of 2.5, 5.0, and 7.5 mrad/sec.

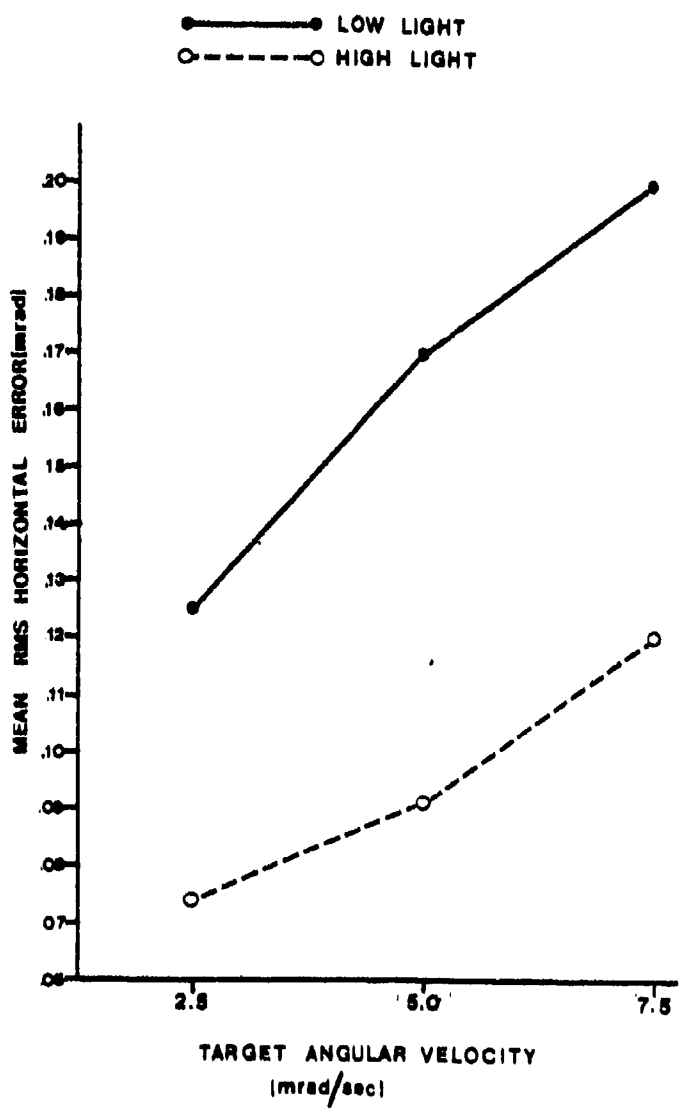

Figure 3. Mean RMS horizontal error scores for the 2.5, 5.0, and 7.5 mrad/sec velocities under high-light and low-light conditions.

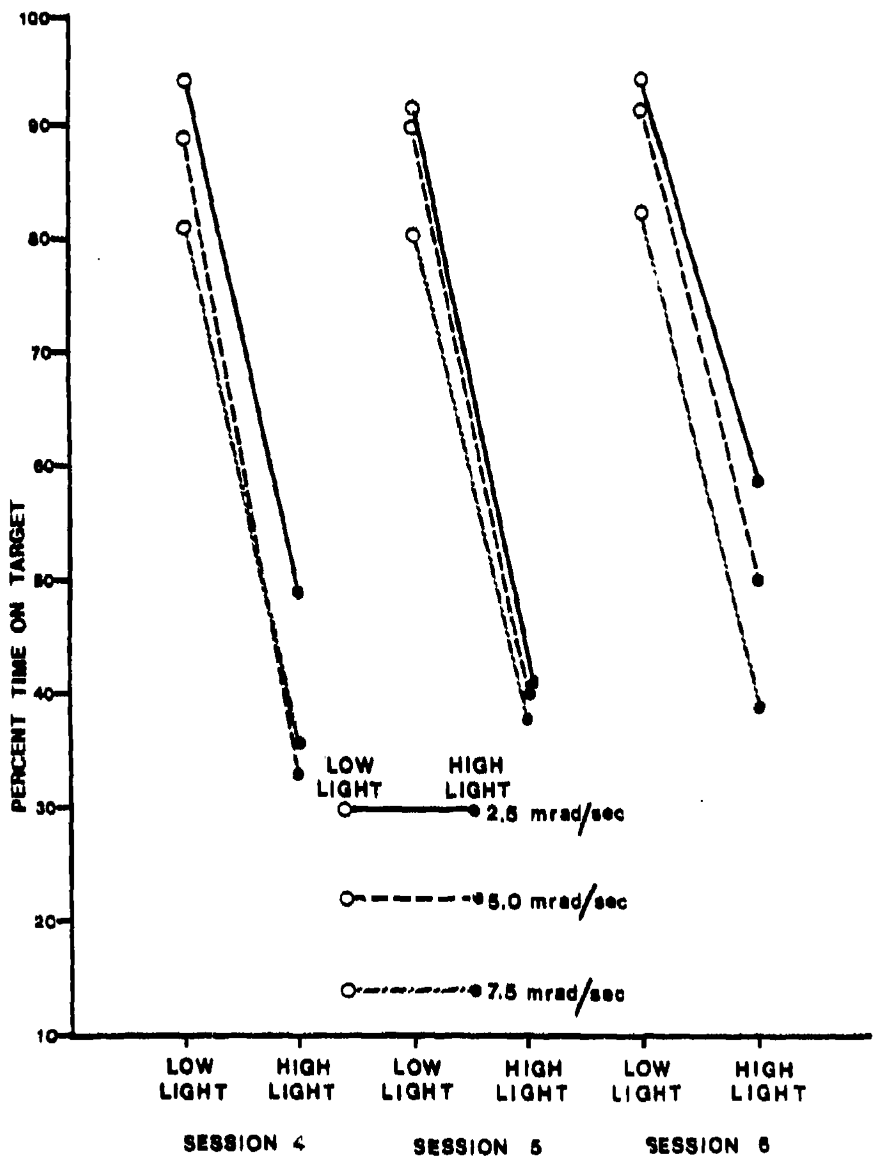

Figure 4. Percent time-on-target scores for high-light and low-light trials at target velocities of 2.5, 5.0, and 7.5 mrad/sec.

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APPENDIX B

TABLE 1

Training and Experimental Session Schedules

Light Level	Angular Velocity	Sessions 1	2	3	4	5	6
Bright Light	2.5				5	5	5
	5.0	15	15	15	5	5	5
	7.5	15	15	15	5	5	5
Low Light	2.5				5	5	5
	5.0				5	5	5
	7.5				5	5	5
Total Trials		30	30	30	30	30	30

TABLE 2

Summary of Analysis of Variance
for RMS Horizontal Error Scores at 5.0 mrad/sec Velocity*

Source	Degrees of Freedom	Mean Square	F†
Sessions	5	.01076	17.25860
Error	55	.00062	

*The analysis was performed using Biomedical Computer Programs BMD-P2V

†Only significant F values are presented

TABLE 3

Summary of Analysis of Variance
for RMS Horizontal Error Scores at 7.5 mrad/sec Velocity*

Source	Degrees of Freedom	Mean Square	F†
Sessions	5	.01803	16.50165
Error	55	.00109	

*The analysis was performed using Biomedical Computer Programs BMD-P2V

†Only significant F values are presented

TABLE 4

Summary of Analysis of Variance* of RMS Horizontal Error Scores for Sessions, Light Level, and Velocity Treatment Effects

Source	Degrees of Freedom	Mean Square	F†
Sessions	2	.00593	4.18
Error	22	.00142	
Velocity	2	.06514	82.60
Error	22	.00079	
Sessions x Velocity	4	.00029	
Error	44	.00055	
Light	1	.25834	154.80
Error	11	.00167	
Sessions x Light	2	.00250	
Error	22	.00097	
Velocity x Light	2	.00339	6.31
Error	22	.00054	
Sessions x Velocity x Light	4	.00062	
Error	44	.00061	

*The analysis was performed using Biomedical Computer Programs BMD-P2V

†Only significant F values are presented

TABLE 5

Summary of Analysis of Variance* of Percent Time-on-Target Scores for Light Level and Target Velocity Treatment Effects

Source	Degrees of Freedom	Mean Square	F†
Sessions	2	905.81	
Error	22	526.93	
Velocity	2	2528.26	24.10
Error	22	104.89	
Sessions x Velocity	4	194.21	
Error	44	85.74	
Light	1	113,391.67	334.08
Error	11	339.41	
Sessions x Light	2	358.22	
Error	22	424.00	
Velocity x Light	2	97.38	
Error	22	99.21	
Sessions x Velocity x Light	4	115.37	
Error	44	89.55	

*The analysis was performed using Biomedical Computer Programs BMD-P2V

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