NASA TECHNICAL NOTE

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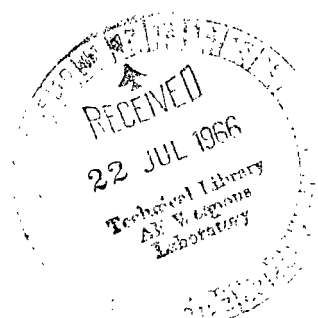
SEXTANT SIGHTING PERFORMANCE IN MEASURING THE ANGLE BETWEEN A STATIONARY SIMULATED STAR AND A STATIONARY BLINKING LIGHT

by Robert J. Randle, Bedford A. Lampkin, and Emmett C. Lampkin

Ames Research Center
Moffett Field, Calif.

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SUMMARY

In space flight, the target vehicle in a rendezvous maneuver might carry a high intensity blinking light as a marker and navigation aid for the chase vehicle. The present study was made to determine the ability of subjects to measure the angle between a simulated star and a blinking point of light of the same magnitude as the star.

The subjects were eight male junior college students with normal visual acuity (Snellen 20/20). Four were pretrained on the task and four were trained using as targets a simulated star and a steady light.

The blinking light was given three levels of frequency (1/2, 1, and 3/2 cps) and three levels of on-time (5, 10, and 20 percent), making possible nine experimental conditions. Two steady stars were used as a control. A Plath micrometer marine sextant was used to measure the angle by star superposition. There was no relative motion between the two targets. The sextant was mounted and did not need to be supported by the subject. The angle was measured with a digital encoder attached to the sextant vernier shaft. Performance decreased at the shorter on-times, in terms of larger variability in measured angle, and at the lower frequencies, in terms of longer sighting time.

INTRODUCTION

Many investigations have been made of the potential accuracy of a sextant and the problems associated with its use in space navigation (refs. 1-4). A navigator might use a sextant in an orbital rendezvous task for measuring the angle between the lines of sight to a known star and an orbiting space vehicle. In order to measure this angle, he would superpose the star and the light on the target vehicle within the field of view of the sextant telescope, and read the angle from the limb and vernier of the sextant.

To assure visual detection, the light on the target vehicle will probably be a blinking light, for the blinking of a light appears to be an excellent aid in detecting a target (refs. 5-8). The effectiveness of a blinking light

as a sextant sighting target, however, has not been determined. The requirements for the two tasks, target detection and sextant angle measurement sighting, may well be incompatible.

The accuracy of a sextant for measuring the angle between a simulated star and a blinking light was assessed in this investigation. The blink rates and on-times of the blinking light were selected to be near optimum (refs. 6-8) for visual detectability. Line of sight angular rates between the blinking light and the star were not included in this laboratory simulation.

The two criteria of performance in the sighting task were (1) the standard deviation of the measured angle and (2) the time required to perform the measurement task. The study was designed specifically to investigate the following:

1. The effect of "on-time" of the blinking light on performance (within a restricted selection of on-times: 5, 10, and 20 percent of the period of the blinking light).

2. The effect of frequency of the blinking light on performance (within a restricted selection of frequencies: 1/2, 1, and 1-1/2 cps).

3. The differences in group performance when one group is trained using two steady lights and the other is trained using a steady light and a blinking light.

4. Sextant sighting performance in measuring the angle between two point sources of light when one of the lights blinks in a regular fashion.

The on-time of the blinking light refers to the percent of the period during which the light was visible. A 5-percent on-time and a 1-cps frequency would mean that the light was on for 0.05 second and off for 0.95 second, the period being 1 second.

Both lights used in the study were collimated point sources which appeared as stars at infinite distance. A shutter mechanism placed in front of one of these provided the blinking light. A high intensity light on a target vehicle at some distance would first appear as a point source, that is, as a "star."

EXPERIMENTAL PROCEDURE

Test Apparatus and the Sighting Task

Figure 1 is an artist's rendition of the testing room and the experimental equipment. Figure 2 shows the sighting station, which consists of a chair for seating the subject and a gimbal-supported sextant. In the foreground is shown the observer's station with the mechanism used to record the measured

values. The sextant was a Plath micrometer marine sextant with a telescope with a magnifying power of 6 and a 30 mm objective lens.

The sextant was mounted on gimbal supports to provide two angular degrees of freedom of motion. The secondary line of sight (index mirror) could be rotated about the mirror axis in the measurement plane, while the entire sextant could be rotated about the primary line of sight in order to osculate the two target images (see fig. 3). The orientation of the primary line of sight was rigidly fixed by the orientation of the gimbal supports. To record the measured angle between the star and blinking light, the subject actuated a pushbutton which caused the output of a digital shaft encoder to be recorded. The encoder (fig. 4) was attached to the sextant vernier control axis so that the encoder shaft reflected the rotational position of the vernier knob. The vernier knob makes one revolution per degree of angle. Since the encoder makes 3600 counts in one revolution, the readout resolution can be 1 second of arc provided there are no slippages or other mechanical anomalies. In an empirical test of the fidelity of the readout associated with an earlier study, experimental subjects were asked to visually set the sextant vernier as precisely as they could at the 0 and 30 minute fiducial lines. For each of these settings the value indicated by the encoder was recorded. The position of the subject's head was rigidly maintained at all times during the settings. All subjects had 20/20 vision. The standard deviation of the encoder readout for both positions was 1.3 seconds of arc and the standard error of sigma for both was 0.05 second of arc. These values are based upon 700 settings distributed among 12 subjects.

The experimenter recorded the time required to complete each series of 16 sightings. This time to complete 16 sightings is the "sighting time" used in the analysis of the results of the study.

The sighting targets (fig. 5) were two collimated point light sources. Each source consisted of a parabolic mirror mounted at the end of a steel tube with a light source located at the mirror's focal point. The light source was a grain-of-wheat lamp enclosed within a metal capsule with a 0.0005-inch hole pointing at the mirror. Both targets simulated third magnitude stars.

The upper collimated target of figure 5 had a shutter mechanism (Neff shutter, ref. 9) attached to the front of the tube. Details of this shutter mechanism may be seen in figure 6. In this figure the shutter aperture is closed and is located in the lower half of the mechanism. The projection in the top half of the mechanism contained a solenoid for activating the shutter which was a disk of metal.
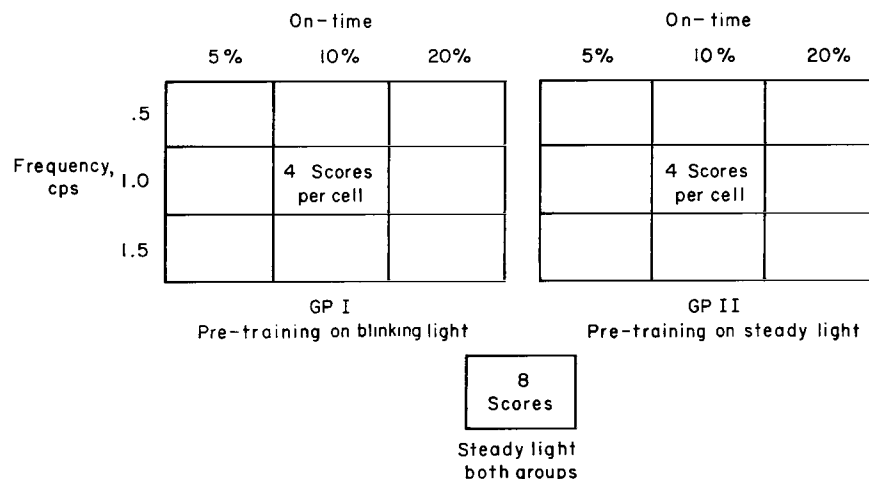
Figure 7 is a photograph of a cathode ray tube face with two electronic traces that show the interruption characteristics of the blinking light target. The characteristics shown are for a blink rate of 1.5 cps and a 20-percent on-time. In this figure, time is represented on the horizontal scale with each major division representing 0.1 second of time. The raised portion of the lower trace indicates the period of voltage application to the solenoid; the raised portion of the upper trace indicates the period of excitation of a light sensor due to its having received light through the shutter. It may be

noted that a lag existed between the time the voltage was impressed upon and removed from the shutter solenoid and the time at which the light sensor responded; however, this lag remained constant for all experimental conditions.

The marine sextant is a relatively simple optical device which may be used to measure the angle between the lines of sight to any two points of interest. Its use is described in standard texts on marine navigation (refs. 10 and 11). The angle of interest for the present study is that between a star and a blinking light placed on an orbiting space vehicle, such as the Apollo command and service module. Instead of osculating the target (star, moon, etc.) on the horizon as in marine navigation sightings, the point source (star) is osculated on another point source. The task in this laboratory setting is further modified by the elimination of search, the elimination of the initial gross setting, and the elimination of hand tremor. In short, the task was simplified to the final visual aspects, osculation and fine setting, of the vernier. The reduction of the sighting task to what is felt to be its crucial elements by placing it in a laboratory setting is for purposes of clear delineation and control of independent variables and the measurement of dependent variables.

Experimental Design

A 2 x 3 x 3 factorial design was used (Lindquist Type VI analysis of variance, ref. 12). The factors were two levels of training, three levels of on-time, and three levels of frequency. In addition, a multiple comparison test was made in which the nine conditions of frequency and on-time (training conditions combined) were compared with a control condition (Dunnett's multiple comparisons with a control, ref. 13). The control condition consisted of measuring the angle between a simulated star and a steady light. The analysis of variance applies to study questions (1), (2), and (3) (see Introduction), and to the possible interaction effects of training, on-time, and frequency should such exist. Dunnett's test applies to question (4). Analyses were carried out for both criterion measures - time scores and standard deviations. Diagrammatically, the experiment appeared as follows:

	On-time			On-time		
	5%	10%	20%	5%	10%	20%
.5						
Frequency, cps 1.0		4 Scores per cell			4 Scores per cell	
1.5						

GP I
Pre-training on blinking light

GP II
Pre-training on steady light

8 Scores

Steady light
both groups

The primary dependent variable was the standard deviation about the mean of the subject's sighted angles. Each subject took 16 sightings under each of the 10 experimental conditions. For each of these 10 conditions a mean and standard deviation were computed. The standard deviation was used as the subject's score for a particular condition. The true angle between the simulated star and the blinking light was not known any more accurately than the subject measured it with the sextant. Therefore, it was not possible to score each subject according to the discrepancy between his mean sighted angle and the actual angle. The standard deviation is a valid measure of the consistency with which the subject made his sightings, so it is an indicant of the reliability of the sightings.

Time scores were also recorded for each subject in each of the 9 conditions and the control condition. Speed was not stressed; the subjects were told to take all the time they needed but to continue uninterruptedly through the 16 sightings. Though the standard deviations of the sighted angles were posted daily for the subjects to see how they were performing, the time scores were not revealed. This was done to emphasize the importance of accuracy and to de-emphasize speed.

Subject Selection and Preparation

Eight male subjects were selected from the students at a local junior college on the basis of vision tests using the Bausch and Lomb Orthorater (ref. 14). Only those individuals who achieved a 20/20 Snellen equivalent score were accepted. None had had prior experience with this task.

The training given the subjects was for the purpose of differentiating the two groups in terms of prior experience with either a blinking light or a steady light. The use of the marine sextant requires some training (ref. 2) conventionally; however, in this study the sextant was mounted so that its operation was simplified. Thus initial performance was not expected to improve substantially with increasing experience.

The subjects were randomly divided into two groups of 4 subjects each. Both groups had an equal number of training sessions. All trained for 8 days, 3 conditions per day, 16 sightings per condition. The training of the two groups differed, however, in that Group I used the blinking light and Group II used the steady light. Group I trained on all the 9 conditions of frequency and on-time represented by the experiment which followed. Since there was a total of 24 sessions (15 during the first week, 9 during the second), each condition was sampled at least twice; those sampled 3 times were randomly selected from the 9 conditions.

During the 5-day test period all subjects sighted under the 10 conditions. Each subject sighted 2 conditions per day with the order of presentation of the conditions randomly determined. Again, 16 sightings were taken under each condition. The subjects rested about 30 minutes between each condition.

RESULTS AND DISCUSSION

Training

Figure 8 shows the mean standard deviation ($\bar{\sigma}$) chronologically for each group through the 8 days of training and the 5 days of the experiment. Group I, which trained on the blinking light, was poorer than Group II during the training sessions, but equalled or excelled Group II during the testing sessions. As shown below in the analysis of variance, training made no significant difference between the two groups in sighting performance for the conditions of the test.

Test Results

Two sets of test scores (days 9-13) were available for the statistical evaluation of the results. One was the standard deviation (σ) for each subject under each condition, and the other was a time score for each subject under each condition. Identical analyses were carried out for both σ and time scores as follows:

1. An analysis of variance (Lindquist Type VI, ref. 12) was performed to evaluate the main and possible interaction effects of frequency, on-time, and subject pretraining; this involved 18 experimental combinations.

2. The control (steady light) condition was compared with the 9 blinking light conditions (Dunnett's multiple test for comparison with a control). Since the same group performed in each of the conditions, the variance estimate used here for Dunnett's test was calculated from the interaction term in the basic treatments by subject's design (refs. 12 and 13).

These analyses correspond to the study questions outlined in the Introduction. The first refers to questions 1, 2, and 3, the second refers to question 4. For the statistical analyses in this study 0.05 is taken as the confidence level required for significant effects.

Figure 9 and table I support the following statements:

1. Performance appeared best for the 20 percent on-time but on-time did not have a statistically significant effect.

2. Frequency appeared to have no regular effect upon performance.

3. The differences in training caused no difference in performance of the two groups.

4. None of the simple interaction terms are significant (OF, OT, FT, table I). The triple interaction term OFT is significant, which means that training interacted differently with on-time than it did with frequency. This result appears to be of dubious practical significance.

Figure 10 shows the results of the multiple comparisons test for the mean standard deviations. Conditions 3, 6, and 9 do not differ from the control; all other do (at $p \leq 0.05$ level). This indicates that performance for the 20-percent on-time conditions, for all values of frequency, did not differ from the normal or steady light condition. Performance for all other combinations of frequency and on-time was, however, poorer. If on-time can be controlled, it ought not be below 20 percent and an even higher value might be advisable.

Generally, it may be stated that on-time is critical where reliability of performance (standard deviation) is important. Frequency, however, is important when the time taken to acquire a set of sightings is important. The next analysis is based on these sighting times.

The time scores taken during the test were subjected to the same two analyses as the standard deviations: the analysis of variance and the multiple comparisons test. The results may be stated as follows (see fig. 11 and table II):

1. The on-time of the light did not affect sighting time.

2. Performance evaluated in terms of "time to sight" is sensitive to frequency changes. It is best (least time) for the higher frequencies and deteriorates practically monotonically with decreasing frequency.

3. Training makes no difference in time to complete a sighting.

4. None of the interaction terms are significant.

Figure 12 shows the results of the multiple comparisons test for the mean time scores. Those points which are underscored (all conditions except 1, 2, and 3) are not significantly different from the control condition (condition 10, the steady light). Performance under the 1/2 cps condition, at all three on-times, is significantly poorer than under the control condition. There was considerably more variability in the data for sighting time than in the data for the standard deviation.

Figure 13 shows the mean angle sighted by condition for all 8 subjects. There is no apparent difference and an analysis of variance (using the mean angle as the criterion variable) confirmed this.

Both the standard deviations and the sighting time scores were from skewed distributions. Both scores were appropriately transformed to normalize the shapes of the distributions, but the analyses of variance carried out using these transformed scores did not differ from those for the original scores.

It is not yet known what standard deviations or sighting times will be required for success in specific missions. In the present tests, the largest decrement noted for the mean standard deviation is between the steady condition (control) and condition 2 (1/2 cps and 10-percent on-time). This is about 0.1 minute or 6 seconds of arc (fig. 10). Is this important for accurate navigation? This study cannot answer that question. It can only conclude, with a confidence reflected by the associated probability figures, that the effects noted are associated with the experimental conditions which did not incorporate relative movement between the star and blinking light.

RÉSUMÉ

Results of this study regarding the vernier adjustment for the angle between a simulated star and a blinking light (no relative motion between the two targets) indicate that:

1. The reliability (consistency, variability) of sighting performance was adversely affected by blinking light on-times below 20 percent of the period.

2. The average time taken to complete a sighting session (16 angle measurements) increased considerably as the frequency of the blinking light decreased from 1 to 1/2 cps.

3. The mean measured angle was essentially constant for all experimental conditions.

4. Caution should be exercised in selecting a target for a sighting task when a steady light cannot be used, since performance always appeared poorer with the blinking light.

Ames Research Center
    National Aeronautics and Space Administration
        Moffett Field, Calif., Mar. 29, 1966

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TABLE I.- ANALYSIS OF VARIANCE BASED UPON STANDARD DEVIATION

Source of variance	Degrees of freedom	Sum of squares	Mean square	F ratio	Probability
Between subjects	7	0.155	0.022		
T (training)	1	.016	.016	0.696	Not significant
e between	6	.139	.023		
Within subjects	64	.375	.006		
O (on-time)	2	.031	.016	2.29	Not significant
F (frequency)	2	.001	.001	.167	
OF	4	.008	.002	.400	
OT	2	.003	.002	.286	
FT	2	.009	.005	.833	
OFT	4	.059	.015	3.00	< 0.05
e (within)	48	.264	.006		
e 1 (W)	12	.082	.007		
e 2 (W)	12	.071	.006		
e 3 (W)	24	.110	.005		

TABLE II.- ANALYSIS OF VARIANCE BASED UPON TIME SCORES

Source of variance	Degrees of freedom	Sum of squares	Mean square	F ratio	Probability
Between subjects	7	475.87	67.98		
T (training)	1	13.01	13.01	0.16	Not significant
e between	6	462.86	77.14		
Within subjects	64	447.17	6.98		
O (on-time)	2	15.44	7.72	1.53	Not significant
F (frequency)	2	139.66	69.83	17.03	< 0.001
OF	4	32.75	8.18	2.63	Not significant
OT	4	28.06	14.03	2.78	↓
FT	2	24.63	12.31	3.00	
OFT	4	22.34	5.58	1.80	↓
e (within)	48	184.29	3.83		
e 1 (W)	12	60.48	5.04		
e 2 (W)	12	49.28	4.10		
e 3 (W)	24	74.53	3.10		
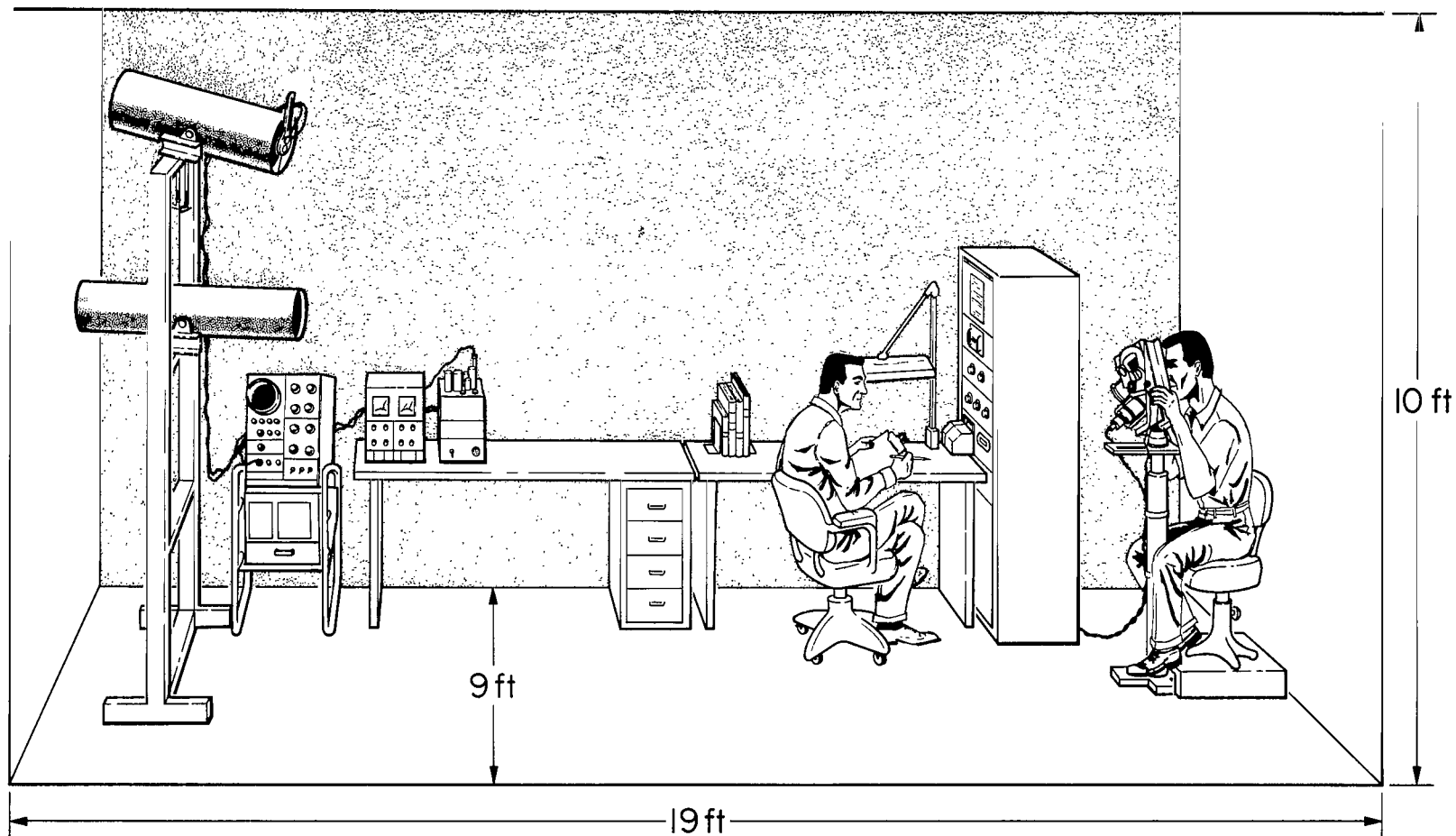
Figure 1.- Sketch of equipment location for the investigation.
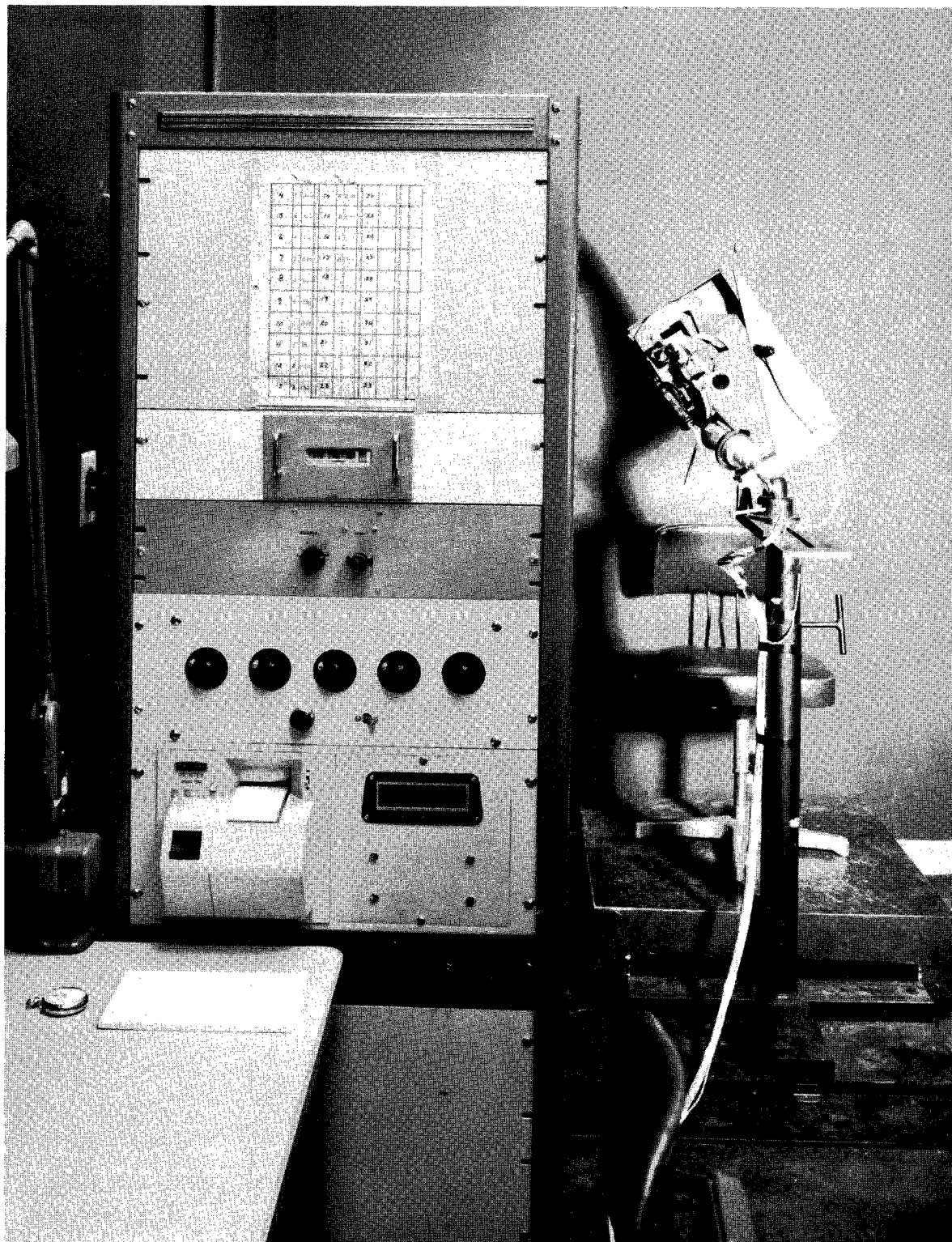
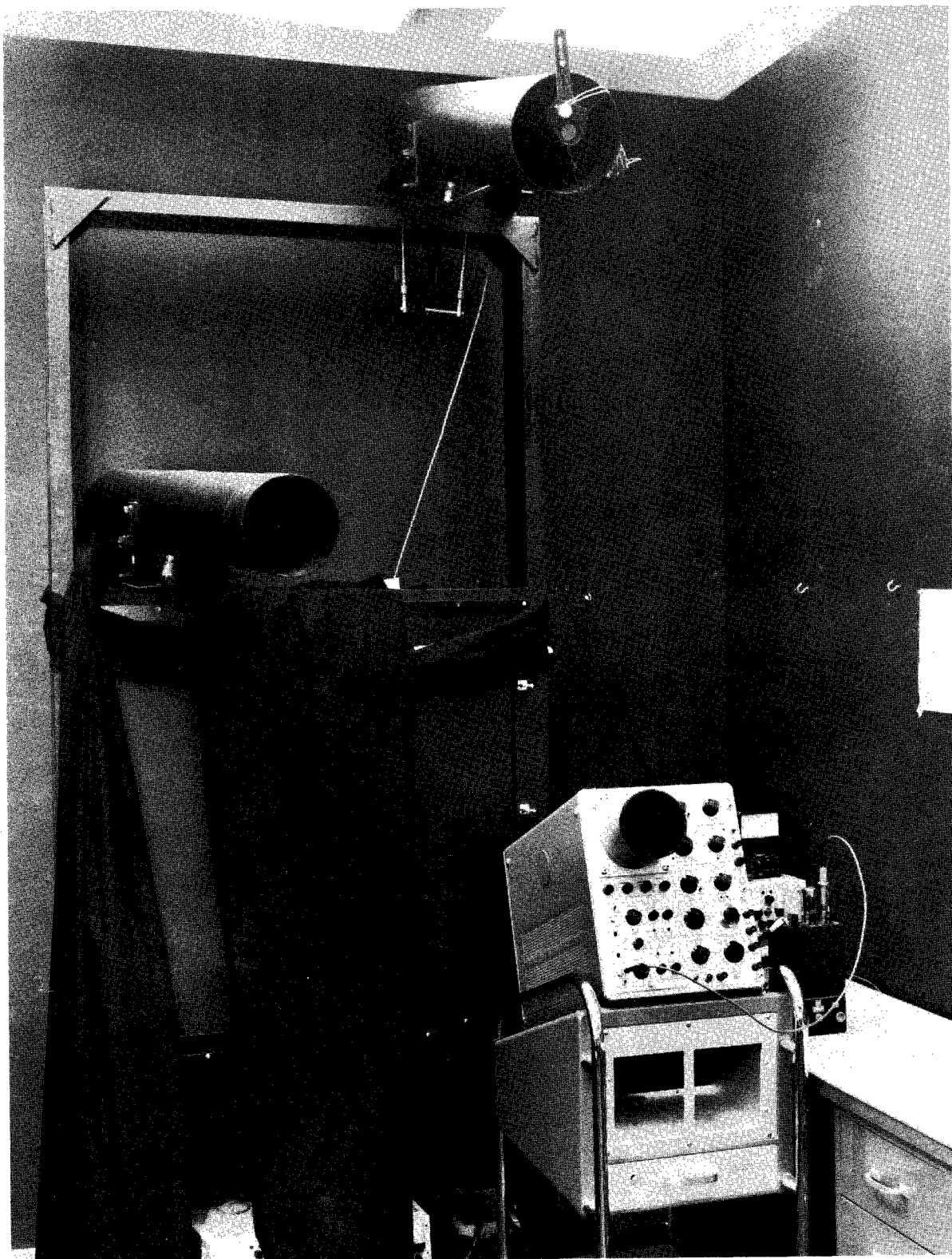Figure 2.- Photograph of the sighting station (background) and experimenter's station (foreground).
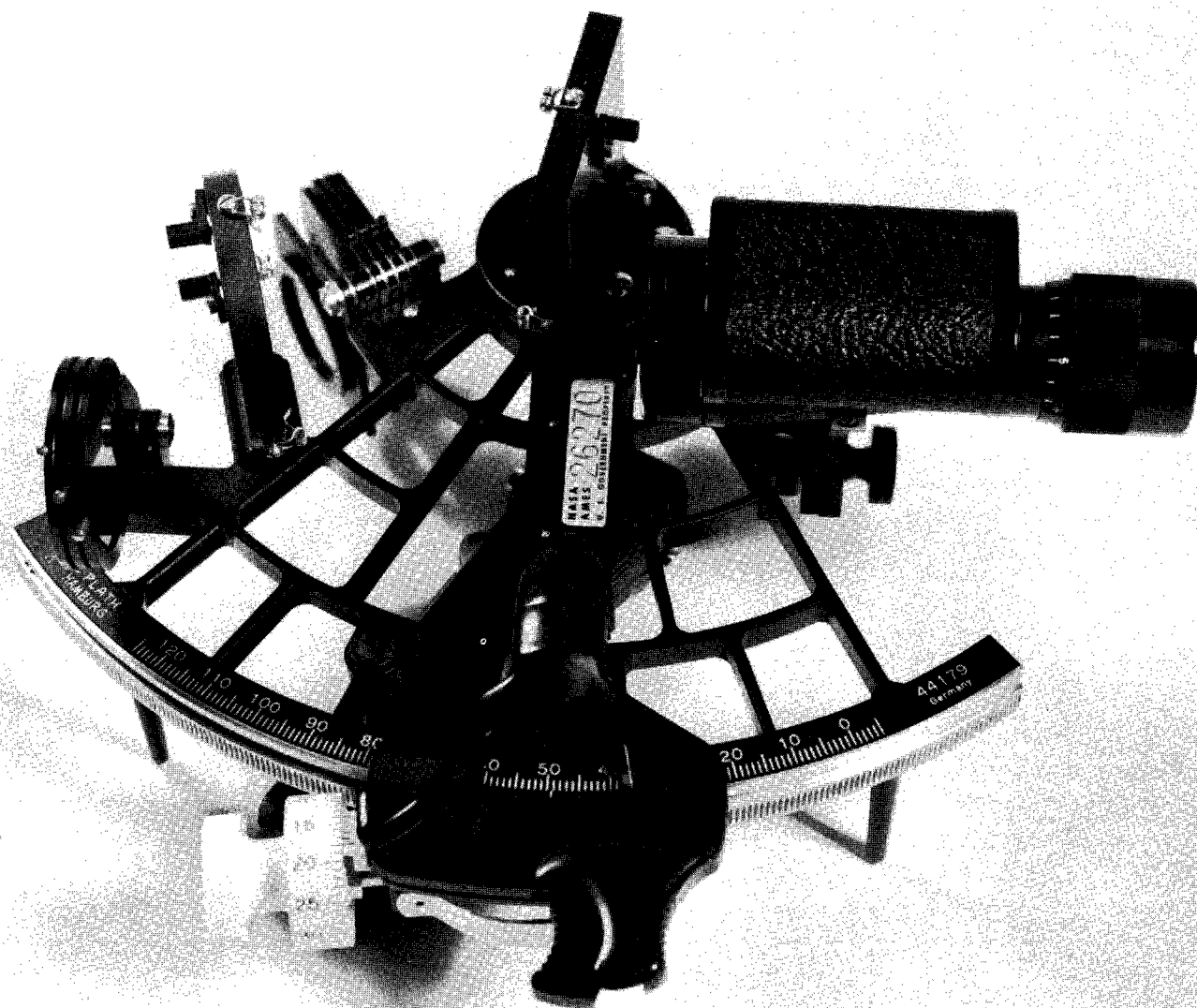
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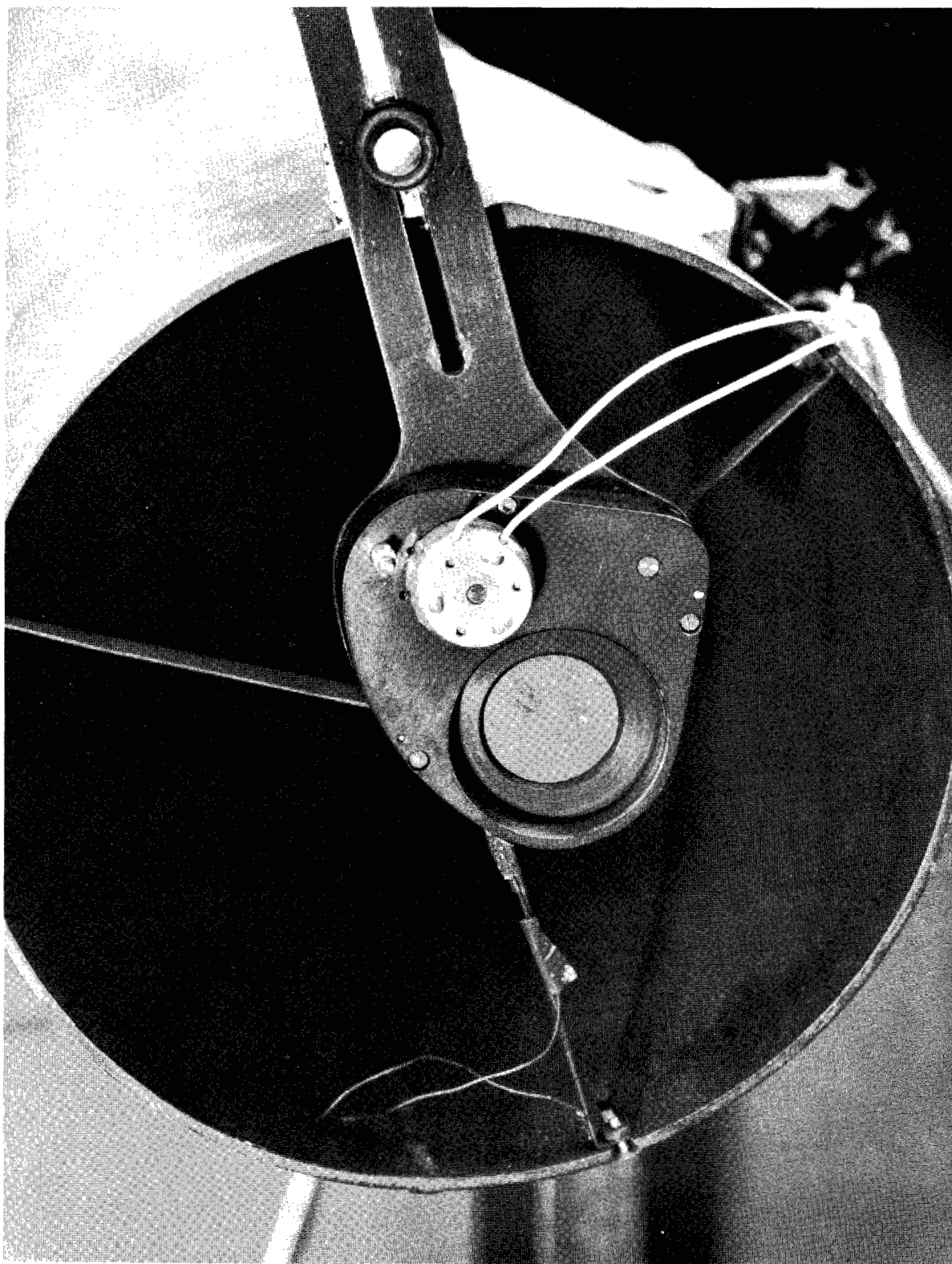Figure 3.- Photograph of the Plath marine sextant removed from the gimbal mounting and shaft encoder.
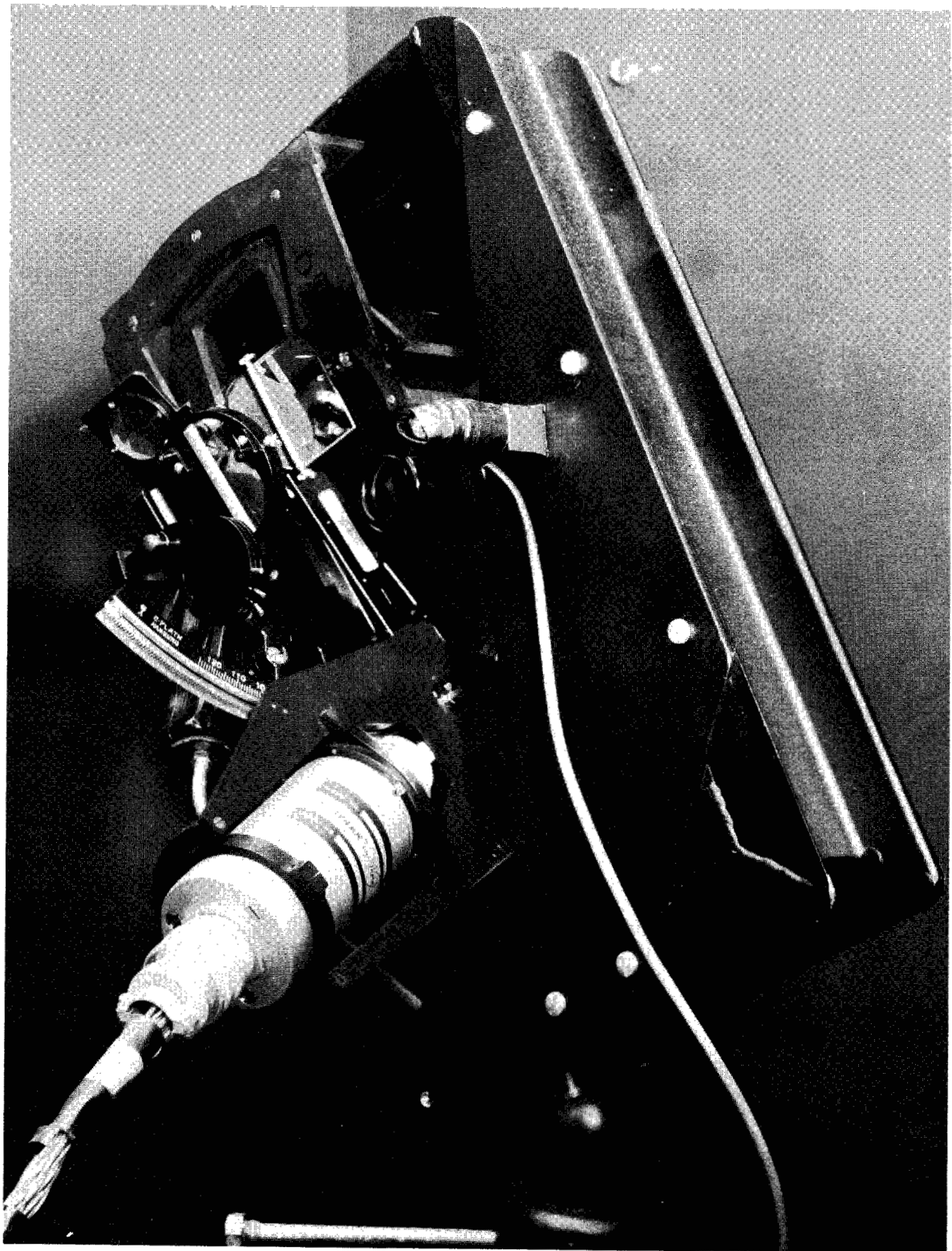
A-34697

Figure 4.- Photograph of the Plath marine sextant attached to the gimbal
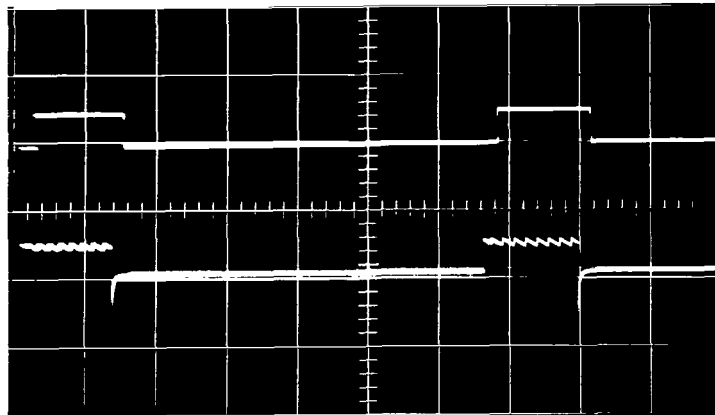mounting with the shaft encoder attached to the vernier shaft.

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A-34694

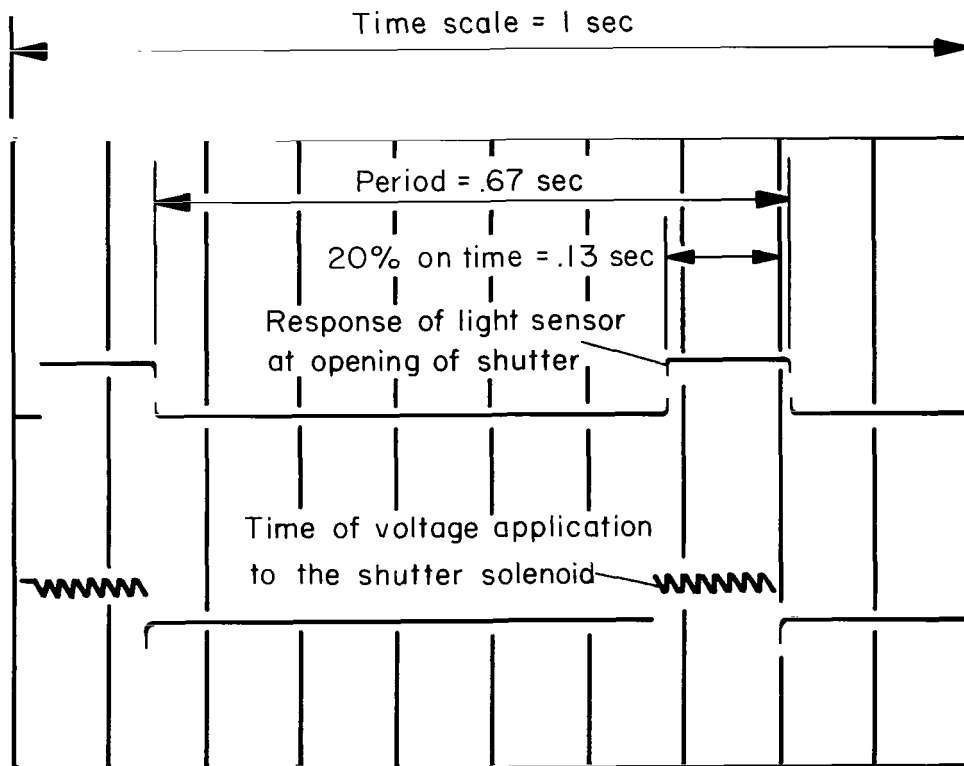Figure 5.- Photograph of the simulated star and blinking light apparatus.

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A-34695

Figure 6.- Photograph of the shutter device attached to the face of the collimating mechanism.

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(a) Photograph of waveforms

Time scale = 1 sec

Period = .67 sec

20% on time = .13 sec

Response of light sensor
at opening of shutter

Time of voltage application
to the shutter solenoid

(b) Diagram of waveforms

Figure 7.- Waveforms displayed on a cathode ray tube of the voltage
application to the shutter solenoid and the response of a light sensor
to the blinking light; frequency = 1.5 cps, on time = 20 percent.
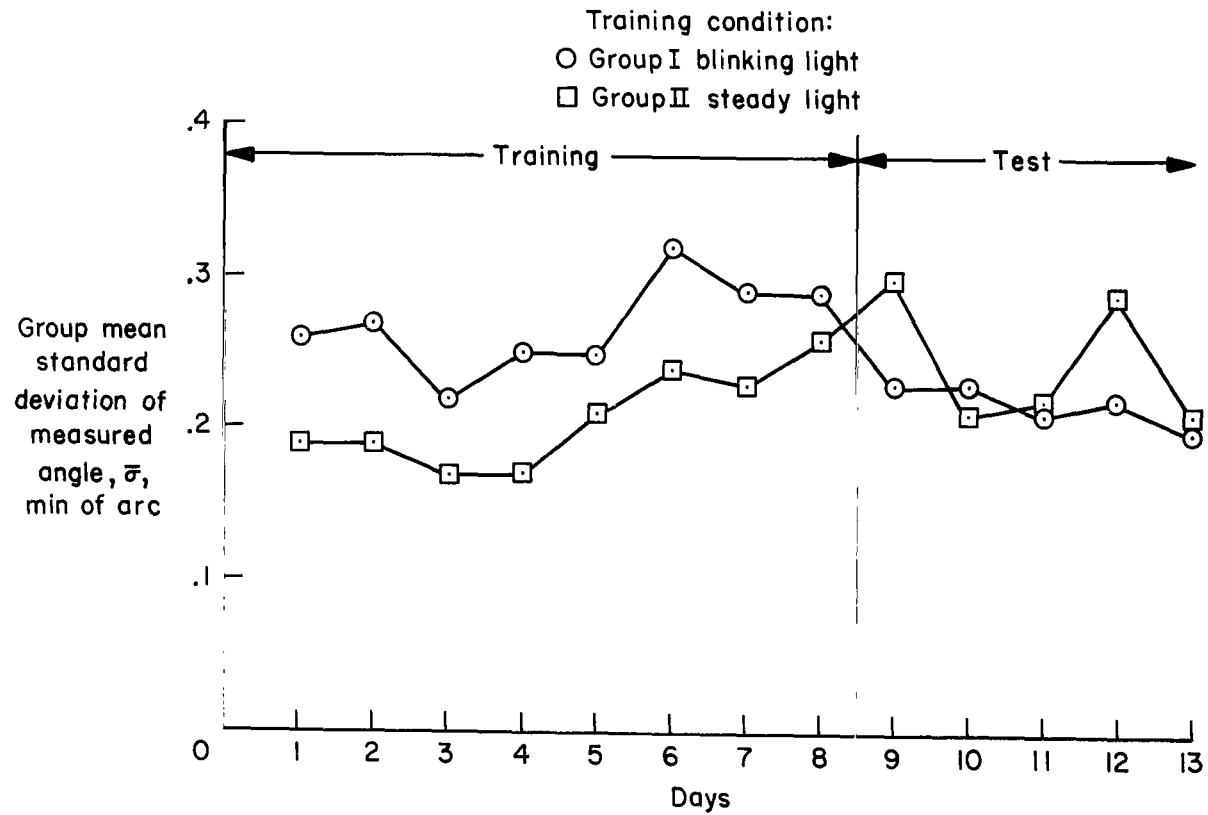
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Training condition:
O Group I blinking light
□ Group II steady light

Figure 8.- Daily group mean standard deviation of measured angle for Groups I and II.

On-time
percent of period
○ 5
□ 10
◇ 20
— —Score with
steady light

(a) Group I scores

(b) Group II scores

(c) Average scores
of groups I and II

Group mean standard deviation of measured angle $\bar{\sigma}$, min of arc

Blink frequency, cps
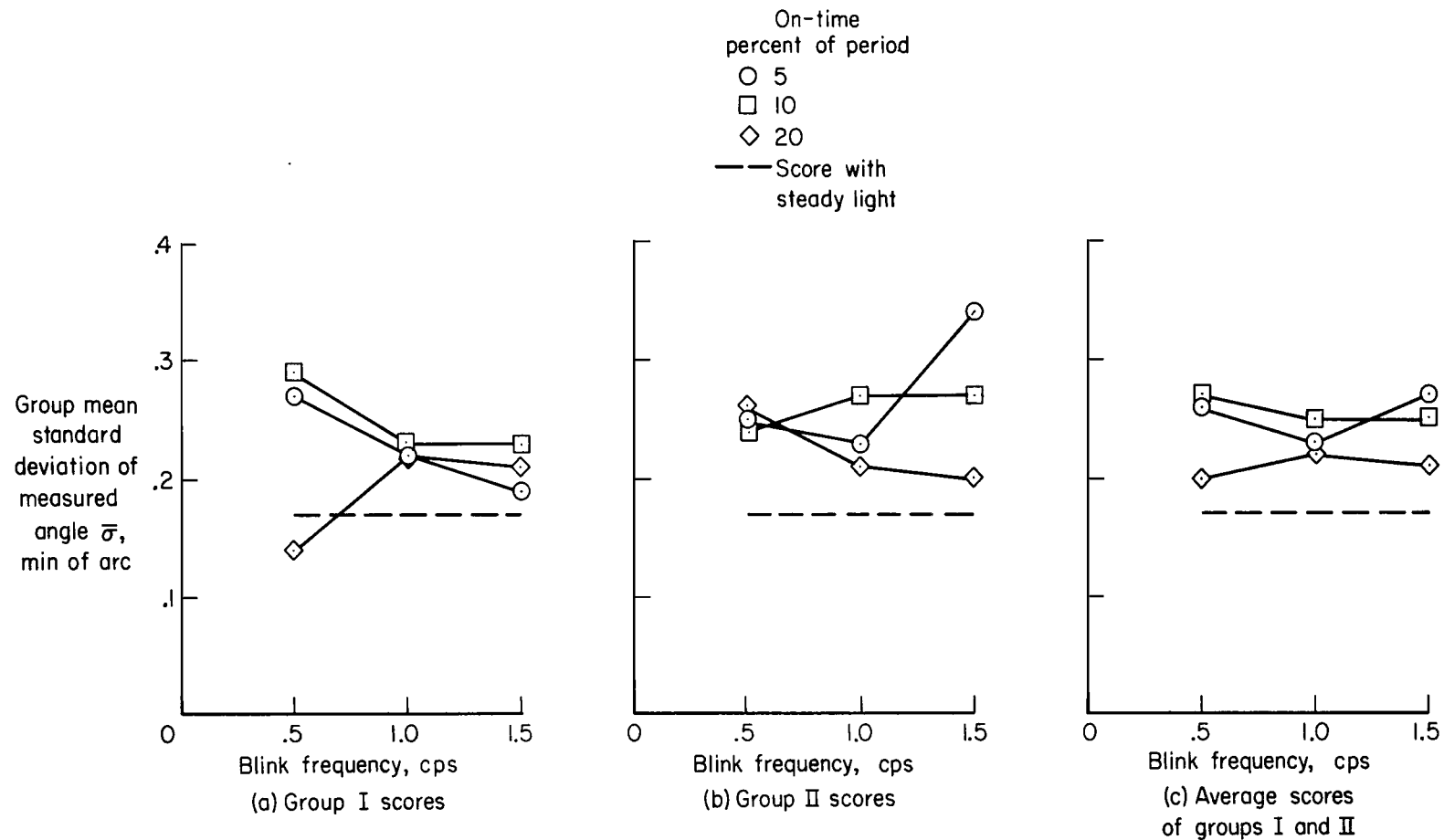
Figure 9.- Group mean standard deviation of measured angle for all 10 conditions.
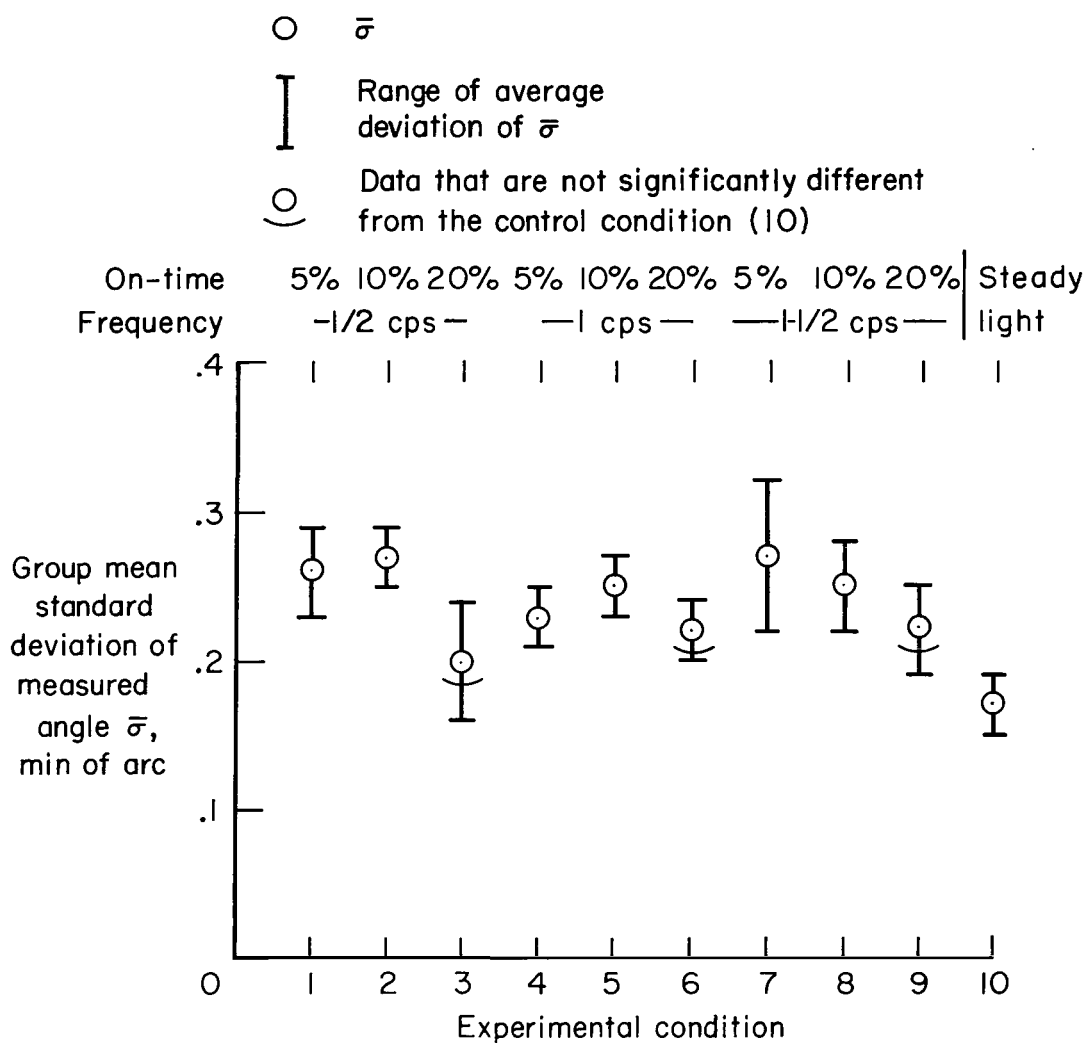
Figure 10.- The variation of the group mean standard deviation of measured angle with the experimental conditions.
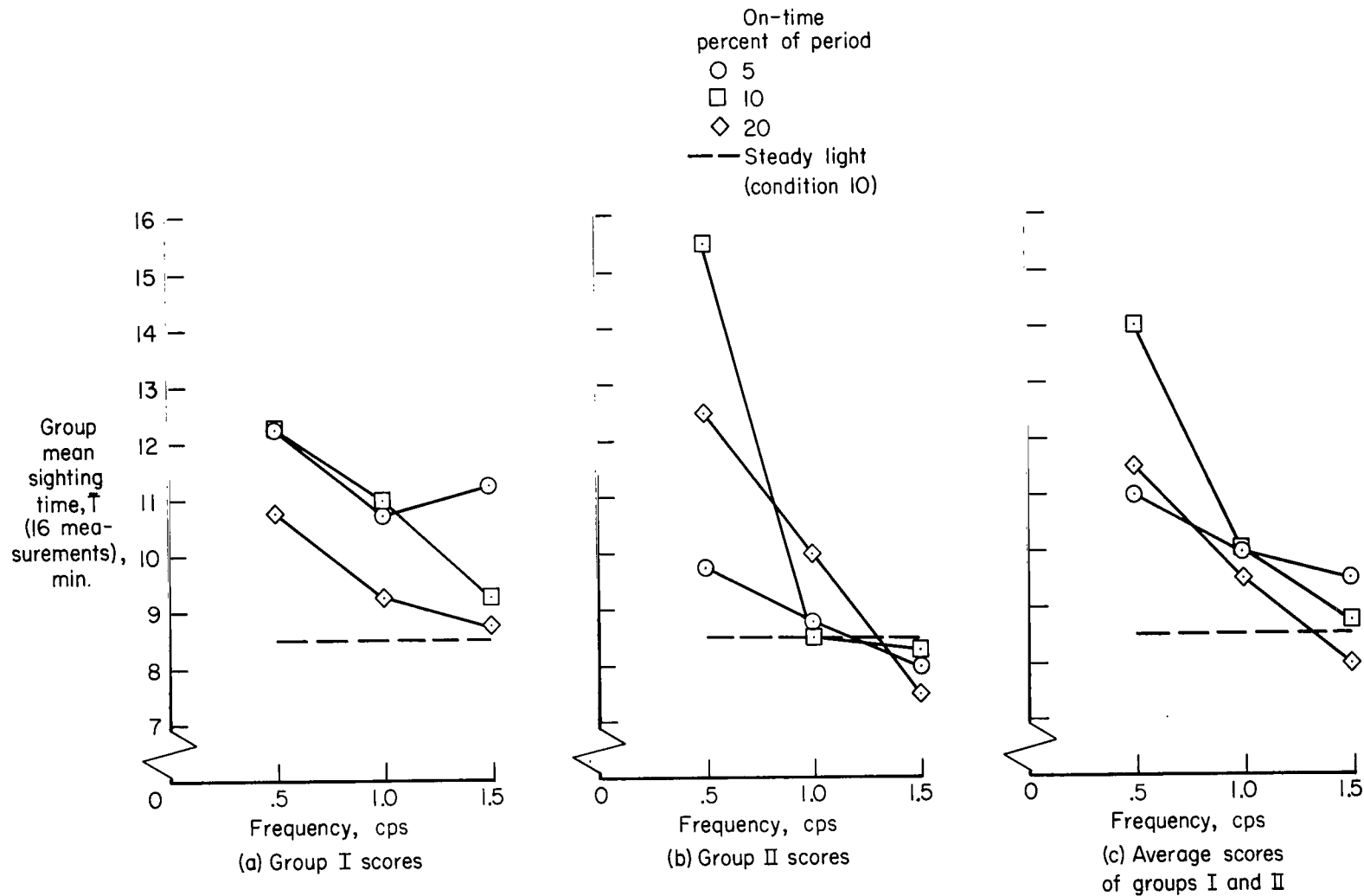
Figure 11.- The group mean sighting time to complete sixteen measurements for all experimental conditions.
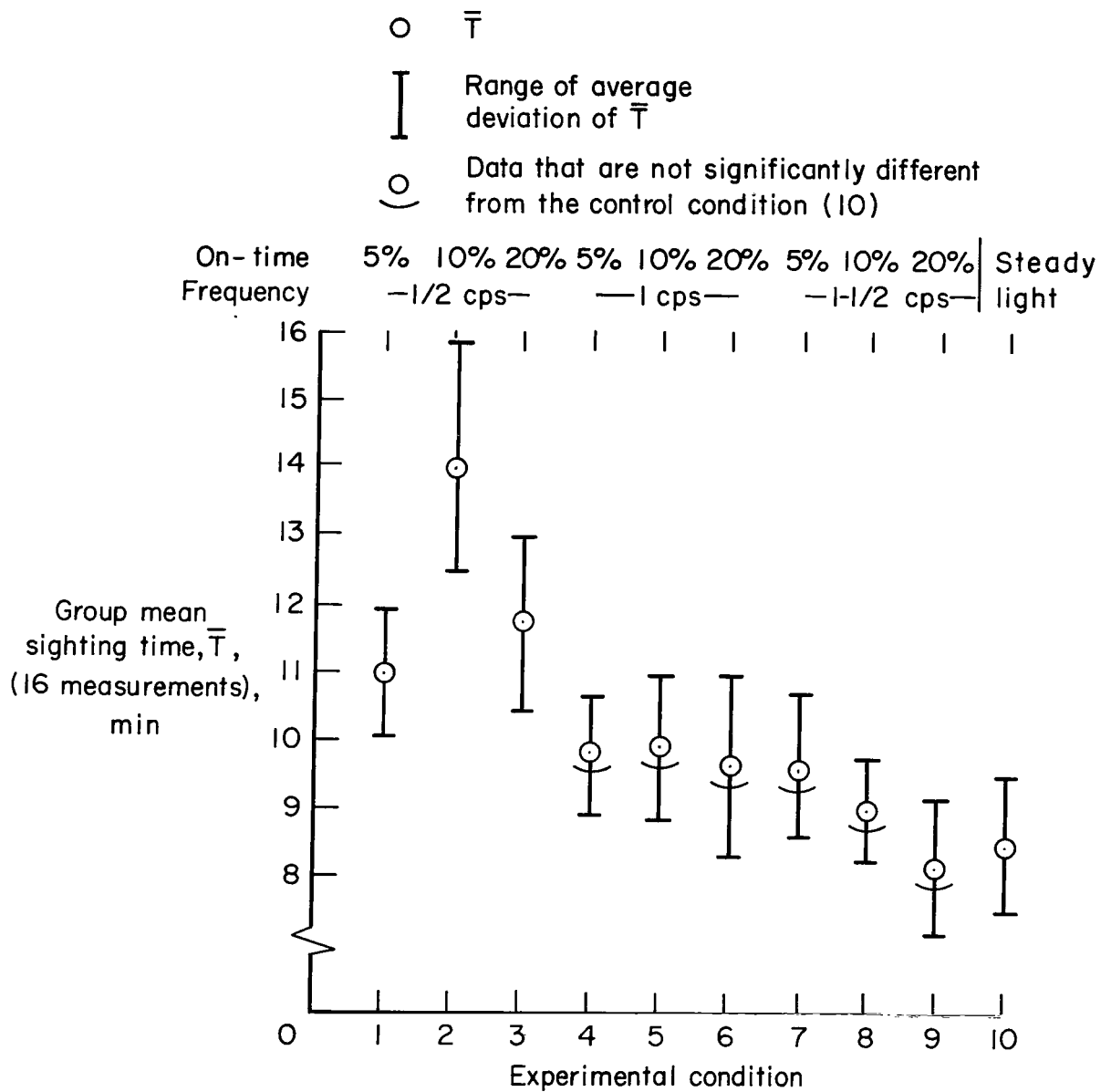
Figure 12.- The group mean time to perform 16 measurements for each of 10 experimental conditions.
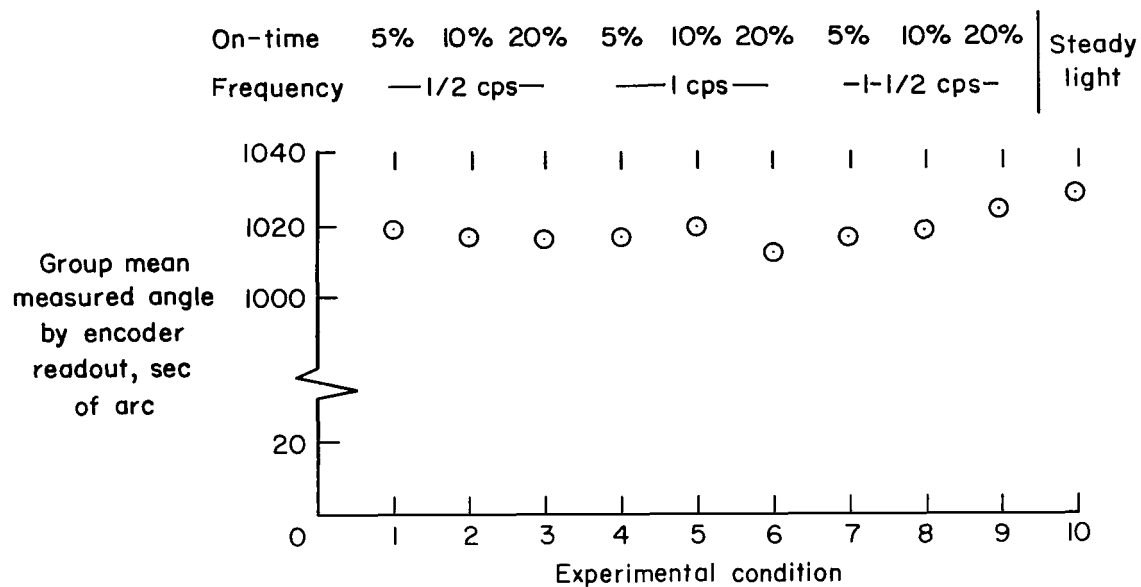
Figure 13.- The group mean measured angle by encoder readout at each of the
10 experimental conditions.

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