NASA TECHNICAL NOTE

NASA TN D-6132

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NASA TN D-6132

# REACTION TIMES OF SUBJECTS IN TESTS WITH DISPLAY-CONTROL CONFIGURATIONS TYPICAL OF THOSE USED IN CONTINUOUS TRACKING TASKS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1971

1. Report No.
NASA TN D-6132

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
REACTION TIMES OF SUBJECTS IN TESTS WITH DISPLAY-CONTROL CONFIGURATIONS TYPICAL OF THOSE USED IN CONTINUOUS TRACKING TASKS

5. Report Date
February 1971

6. Performing Organization Code

7. Author(s)
Walter W. Hankins III and Patrick A. Gainer

8. Performing Organization Report No.
L-7034

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Va. 23365

10. Work Unit No.
127-51-17-07

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Reaction times of human subjects to different displays have been measured. Statistical analyses were made of the effects of intersubject variability, direction of display motion, display differences, learning and fatigue, and rates of display indicator motion. Subjects using the same display-control configuration exhibited significantly different response times. Reaction times were found to differ significantly with displays and display indicator rates.

17. Key Words (Suggested by Author(s))
Reaction times
Displays
Human performance

18. Distribution Statement
Unclassified – Unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
25

22. Price*
$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

# REACTION TIMES OF SUBJECTS IN TESTS WITH DISPLAY-CONTROL CONFIGURATIONS TYPICAL OF THOSE USED IN CONTINUOUS TRACKING TASKS

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## SUMMARY

Reaction times of subjects to different displays have been measured to assess the influence of different display characteristics on response times. The significance of response time differences was determined statistically. Subjects were two pilots and two nonpilots. Total reaction times were broken down into two components, the time required for the stimulus to reach the subject's threshold of recognition and the time remaining until the subject responds. Subjects using the same display-control configuration exhibited significantly different response times. Reaction times were found to differ significantly with displays. Response times varied significantly with display indicator rates, since these rates determined the time to reach stimulus thresholds.

## INTRODUCTION

Pilots are required to respond to information displayed by various instrumentation in order to maintain proper and safe control of aircraft and spacecraft. It is assumed that a pilot's proficiency in continuous tracking is inversely related to the length of his stimulus-response time. Since this generalization applies to any human monitor-controller, it is important to discover the controllable factors which determine his reaction time and minimize it with this knowledge. This report will attempt to show that the characteristics of the display through which the pilot receives information have a significant effect on the pilot's reaction time. It will also explore the effects of some other variables on reaction times in tests which involved display-control configurations typical of those the pilot might actually encounter.

Reference 1 presents a historical review of reaction-time investigations. Of particular interest in these investigations is the high degree of variability in reaction times measured under a fixed set of conditions as well as the number of factors which influence reaction times. Such variability was characteristic of the work reported herein.

Reference 2 contains measurements of pilot reaction times under actual flight conditions. Such factors as motion cues and out-of-the-window visual cues, neither of which were present in the experiments reported herein, probably influenced response times.

The primary objective of this work was to determine whether a subject exhibited significantly different reaction times to different display-control configurations. Subordinate objectives were (1) to assess the significance of possible differences among the reaction times of different subjects using the same display-control configuration, (2) to study the effect of changes in the rate of display movement on reaction times, (3) to assess the effects of learning and fatigue in the experiments conducted, and (4) to study the effects on reaction times of the direction in which the display indicator moves and of the information given the subject to enable him to predict this direction of motion.

## SYMBOLS

| | |
|---|---|
| N | sample size |
| T | statistical quantity for measuring degree of significance between two samples |
| $t_r$ | elapsed time between sensing of stimulus and reaction, seconds |
| $t_t$ | total reaction time, seconds |
| $\dot{\delta}$ | displacement rate of display indicator, centimeters per second |
| $\delta_T$ | threshold for detection of displacement of display indicator, centimeters |
| $\sigma$ | standard deviation, $\sqrt{\frac{\sum (\text{Sample value - Sample mean})^2}{\text{Sample size}}}$ |

## ABBREVIATIONS

| | |
|---|---|
| CW | clockwise |
| CCW | counterclockwise |
| L | left |
| R | right |

| | |
|---|---|
| $P_L$ | pitch line |
| $P_S$ | pitch spot |
| $R_{RL}$ | roll rotating line |
| $R_{SL}$ | roll split line |
| $Y_S$ | yaw spot |

## APPARATUS AND TESTS

A matrix of 45 tests per subject was formulated to measure reaction times. Four subjects were used. Two subjects were NASA test pilots and the other two were engineers, one of whom had had extensive experience as a test subject in human-factors experiments. Figures 1 and 2 show the general display-control arrangement used in making the reaction-time tests. Figure 2 is a block diagram of the equipment and its functions. In each test, one of five displays was generated on the cathode-ray oscilloscope shown. The oscilloscope screen, which was 8 cm high and 10 cm wide, was viewed from a distance of about 76 cm. Subjects reacted to the displays through the side-arm controller at their right. Fore and aft motions of the controller corresponded to pitch inputs; side-to-side motions corresponded to yaw or roll inputs, depending upon the display.

Figure 3 shows the displays used. The spot display (top left) was used to display both pitch and yaw disturbances. The spot was normally at rest in the center of the screen. If the spot moved up or down, a pitch disturbance was indicated and the subject responded with an appropriate fore or aft motion of the control stick. Similarly, horizontal motion of the spot indicated yaw and required appropriate side-to-side motions of the control stick. The line display (upper right) indicated pitch by vertical displacement of the horizontal line from center. The split line (lower left) indicated roll by the vertical separation of the two horizontal lines, the roll direction being determined by which line went up and which went down. The rotating line (lower right) indicated roll by its clockwise or counterclockwise rotation from an initial horizontal position. Roll motions required appropriate side-to-side inputs of the control stick.

Nine runs were made for each display (pitch and yaw spot counted as separate displays). Each run consisted of 50 repetitions of the same test. From these 50 repetitions, the mean, variance, and standard error of the mean were computed. Each set of nine runs was divided into three subsets consisting of three runs each. In the first subset the subject was told that the display would always move in a given direction throughout that subset and he was allowed to choose his response direction commensurate with the axis displayed. The three runs in the subset varied only in the rate of display movement. These rates were in order presented: 1 cm/sec, 5 cm/sec, and 10 cm/sec. With the split line, these rates refer to the rates of vertical separation of the vertically moving horizontal lines; with the rotating line, the rates refer to the rates of change of the vertical distance between the horizontal reference line and the tip of the rotating line. In the second subset the display and control directions were opposite those in the first subset. In the third subset the display direction was pseudorandom with the proper control direction corresponding to those used in the first two subsets.

Data were taken in sets of nine runs per set with short rest periods allowed between runs as desired by the subject. Subjects were allowed as much practice time as they desired before a run began, these times varying from 0 to perhaps as much as 3 minutes. The subject's task was merely to watch the display and react in the proper direction as quickly as possible when the display moved from its zero position. The time from initiation of the display movement until the subject reacted in the proper direction was recorded as his reaction time. Delays in measuring equipment added about 5 msec to the reaction times, which were measured to the nearest 0.1 msec. Deflections of the 7.14-cm-long control stick of $3^{\circ}$ to $7^{\circ}$ were required to trigger measuring equipment. Aft required $4^{\circ}$; fore, $3^{\circ}$; right, $7^{\circ}$; and left, $3^{\circ}$.

## RESULTS

Table I shows the average reaction time, its standard deviation from average, and the standard error of the mean for each subject for each of the 45 runs. Subjects B and H are engineers and Y and S are test pilots. The remainder of this report will analyze and interpret the data of table I with emphasis on the objectives posed in the Introduction.

### Effects of Display Rate

As might be expected reaction times tend to become shorter as display rates become faster. This can be seen in table I and is illustrated by figure 4, which is a plot of average reaction time versus display rate for subject Y. Table II shows the results of applying T tests for unpaired variates (see refs. 3 and 4) to determine whether display-rate differences produce significantly different reaction times. A plus is entered in the T column if the higher display rate corresponds to the shorter reaction time. This occurs in 90 percent of the tests. A "Yes" inserted beside the T value indicates significance at the 95-percent or greater confidence level and was determined using 98 degrees of freedom. Tests of significance were applied only to the comparisons 1 cm/sec versus 5 cm/sec and 5 cm/sec versus 10 cm/sec. These tests showed a greater number of significant differences occurring on the 1 cm/sec versus 5 cm/sec comparisons.

It would seem likely that the subject is responding to some threshold displacement of the stimulus. The time required for the stimulus to reach the threshold value will depend on the display rate and be directly responsible for a fixed portion of the reaction time. The value of this threshold was not determined directly. In order to demonstrate the effect of a threshold, assume that the threshold is a displacement of 1 millimeter. At 1 cm/sec, 0.1 sec would have been required for the threshold to be reached, and thus 0.1 sec would have been added to the reaction time. At 10 cm/sec the time to reach the threshold would have been 0.01 sec. Although it seems likely that the threshold effect is the dominant factor, it also seems possible that a very rapidly moving display would through its rapidity give the subject incentive to react more quickly. Rapidly moving displays soon reach their limits unattended. Subjects likely associate display limits with catastrophic events; thus, high display rates increase the urgency of taking action. There obviously is a limit to which display rate can produce incentive and faster reactions.

## Equation for Total Reaction Time in Terms of Its Hypothesized Components

From the previous discussion it is reasonable to assume that a threshold of stimulus to elicit reaction times does exist and that it may be characterized in terms of displacement of the display indicator from its initial position. The contribution of this threshold to the total reaction time varies inversely with stimulus movement rate, and the remaining portion of the reaction time is assumed to be constant for a given subject and display-control configuration.

Designating the threshold stimulus displacement as $\delta_T$, the elapsed time between sensing of stimulus and reaction as $t_r$, the total reaction time as $t_t$, and the rate of indicator displacement as $\dot{\delta}$, it is hypothesized that

$$t_t = \frac{1}{\dot{\delta}}(\delta_T) + t_r \tag{1}$$

The data of table I consist of 15 sets of three runs, each set varying only in display rate. A least-squares fit of equation (1) was made to each of these sets of three runs and 15 values each of $\delta_T$ and $t_r$ per subject were obtained. Rate is thus eliminated as a variable. Since each run consists of 50 sample points, 150 points were used in computing each three-point curve. An example plot is shown in figure 5. Table III gives the computed values of $t_r$, standard error of $t_r$, $\delta_T$, standard error of $\delta_T$, and the standard error of fit of the whole equation for each set of three runs.

A survey of table III reveals that $\delta_T$ varies from some slightly negative value to slightly more than 0.161 centimeter. From the physical meaning that has been attached to $\delta_T$, obviously it cannot ever be negative. Thus, for the purposes of physical interpretation its lower limit is zero. It should also be noted from table III that the standard error $\left(=\frac{\sigma}{\sqrt{N}}\right)$ of $\delta_T$ is generally large with respect to $\delta_T$. In most cases it is at least 10 percent of $\delta_T$, and in more than half, it is 20 percent or more. A reasonable conclusion then is that the threshold of response is a displacement of about 1 or 2 millimeters. Since $\delta_T$ is a small value with large errors in its determination, it will not be used for comparing experimental conditions in the remainder of this report.

The values of $t_r$ derived from fitting equation (1) to the data are the best available estimates of the time intervals between detection of stimulus and response. These values, rather than the values of $t_t$ presented in table I, will be considered to be the actual reaction times of the subjects. The values of $t_r$ will be analyzed for intersubject variability, display differences, and direction of display indicator motion by the T test for paired variates.

### Intersubject Variability

In order to determine whether the reaction times of different subjects performing the same task were significantly different, the values of $t_r$ for each of the subjects were compared with those for each other subject by means of the T test for paired variates. (See the appendix.) There were 15 pairs of $t_r$ values for each pair of subjects. The differences between these paired $t_r$ values were treated as random variables and T values for the significance of the differences between the $t_r$ values were computed from

$$T = \frac{\bar{d}}{\sqrt{\frac{\sum(d_i - \bar{d})^2}{N(N - 1)}}} \qquad (i = 1, 2, \ldots, 15) \qquad (2)$$

where

$N - 1 = 14$ (degrees of freedom)

$N = 15$ (sample size)

and $\bar{d}$ is the mean value of the differences of a set of paired $t_r$ values. The paired differences $d_i$ are defined so that $d_1$ is the first paired difference of the $t_r$ values of subjects 1 and 2, $d_2$ is the second paired difference, and so forth. These computations resulted in six T values shown in the matrix of figure 6. From figure 6 it can be seen that in four of the six comparisons, significant differences exist at the 99-percent confidence level, and thus the existence of considerable intersubject variability is indicated. The greatest statistical significance occurs when either of the test pilot subjects is compared with either of the other subjects.

## Display Differences

In order to study the differences in reaction times of the same subject to different displays, those runs were used in which subjects had no prior knowledge of the direction in which display indicators would move.

To obtain an overall index for the display comparisons, equation (2) for paired variates was again used. The $T$ values thus computed are shown in the matrix of figure 7. These $T$ values show that significant differences at the 95-percent confidence level occur only in comparisons involving yaw spot. The comparison between yaw spot and roll rotating line does not show a significant difference at the 95-percent confidence level but does at the 90-percent level. Note that for both of the roll displays and the yaw display the response motion of the side-arm controller was the same. It might also be pointed out that in all cases the values of $t_r$ for yaw spot (used in these comparisons) were smaller than those for the other displays. Moreover, each display movement except yaw spot involves some vertical motion. These facts tend to indicate that when both display movement and response are horizontal, reaction times are shorter than when display movement is vertical. It is interesting to note that the difference between the rotating-line display, which involves both horizontal and vertical motion, and the yaw-spot display is significant at a lower confidence level.

## Direction of Display Indicator Motion

Also of interest in the experiments being reported upon were the possible effects the direction of the display indicator motion might have on the reaction times of the subjects. To study such effects, $t_r$ values were again compared by using the $T$ test of equation (2) for paired variates.

These display directions were characterized as + direction, - direction, and unpredictable direction. The following directions were chosen as positive: pitch spot – up; yaw spot – right; roll rotating line – counterclockwise; roll split line – right side up, left side down; and pitch line – up. To compare the positive and negative directions for a given display, the differences between corresponding $t_r$ values for its positive and negative directions were treated as a random variable across subjects. The $T$ values were then computed from equation (2). These values are shown in table IV. No significant differences at the 95-percent confidence level were found. However, significant differences at the 90-percent level are indicated for pitch line and yaw spot. Although this report does not consider differences to be significant at confidence levels below 95 percent, it does consider differences at the 90-percent level to be noteworthy. Those of table IV could have resulted from zero misalinement of the display indicator or from greater muscular difficulty in moving the side-arm controller in one direction than in the other. From table III, it can be seen that the $t_r$ values for the unpredictable directions are much greater than those for the predictable directions. This is expected since subjects must make an extra decision when the display direction is unpredictable; that is, they must decide in which direction to respond.

It is concluded that differences in the reaction times for opposite display directions are not statistically significant, but that differences in reaction times for predictable directions and unpredictable directions are significantly different.

### Effects of Learning and Fatigue on Reaction Times

In order to study the effects of learning and fatigue during a run, each run of each subject was divided into halves and the mean and variance of the reaction times of each half were computed. The T test was used to determine whether the two halves were significantly different. The number of cases showing significance on the T test varied from 4 to 8 out of 45 runs (10 percent total). The means seem to be about as likely to be higher on the first half of the run as on the second half, but the variances with the exception of subject Y are generally greater on the second half of the run. No correlation was found between reaction time and the order in which the run was made in the series of nine. No evidence was found in the data presented to indicate that either learning or fatigue had an important influence.

## SUMMARY OF RESULTS

From a study of the reaction times of subjects to different displays, the following results were found:

1. There were significant differences in reaction times of different subjects to the same display-control configuration.

2. Higher display rates educe shorter reaction times. The differences in reaction times become less significant as the display rates become higher.

3. There is no evidence to indicate that either learning or fatigue had a significant influence on the data presented.

4. For a given display, reaction times for opposite display indicator motion are not significantly different.

5. Reaction times are shorter when the direction of display motion is predictable than when it is not.

6. Some displays produce considerably shorter and more consistent reaction times than do others, with a horizontally moving dot eliciting shorter reaction times than a vertically moving dot, a vertically moving line, a rotating line, or a split-line display. There are indications that horizontal display motion produces shorter reaction times than does vertical motion.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., December 4, 1970.

## APPENDIX

## PAIRED-VARIATES TEST

When a set of pairs of experiments is available with each pair having common values of all parameters but one, the difference between the outcomes of each pair of experiments may be considered to be, on the average, due to the different values of that one parameter. An estimate of the signficance of the effect of that one parameter on the experimental outcome may then be made by comparing each experiment in which the parameter has one particular value with each corresponding experiment in which the parameter has another particular value. If the differences between the outcomes of the ith pair are denoted by $\Delta_i$, and $n$ such pairs are considered, the $\Delta_i$ values can be treated as a sample of size $n$ of a random variable with an estimated mean value

$$m_\Delta = \frac{\sum_1^n \Delta_i}{n}$$

and estimated variance

$$S_\Delta^2 = \sum_1^n \left(\Delta_i - m_\Delta\right)^2 \frac{1}{n - 1}$$

The standard error of estimate of the mean $m_\Delta$ is equal to $S_\Delta / \sqrt{n}$. It is desired to test whether it is safe to say that the true value of $m_\Delta$, if enough samples were available, would turn out to be zero. Then it is desired to know with what probability a sample of size $n$ could have a sample mean of $m_\Delta$ (when the sample is drawn from an infinite population with zero mean and standard deviation $\sigma_\Delta = S_\Delta$). "Student's" $t$ distribution for $n - 1$ degrees of freedom is used for this test. The ratio of $m_\Delta$ to its standard error of estimate is compared with the $t$ distribution to find the desired probability, as in other forms of $T$ test.

The paired-variates test is more sensitive to small, consistent differences in outcome than is the usual test for significance of the difference between sample means. The usual test works under the assumption that the two samples to be compared are independent, not correlated in any way. In that case, the standard error of the mean difference between the two samples can be computed from the standard error of estimate of the mean of each sample. If the two samples happen to differ by a constant (so that all $\Delta_i$ values are equal), then the assumption of independence is not justifiable. In such a case, the paired-variates test would give extremely low confidence to the hypothesis that a difference does not exist. On the other hand, if there is no correlation between the samples, the paired-variates test ought to give the same confidence to the null hypothesis that is given by the test for unpaired variates.

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TABLE I.- MEAN VALUES, STANDARD DEVIATIONS, AND STANDARD ERRORS OF REACTION TIMES

(a) Subjects B and H

| Run | Display | Axis | Direction | State | Display rate, cm/sec | Subject B | | | Subject H | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Average total reaction time, $t_t$, msec | $\sigma$, msec | Standard error, msec | Average total reaction time, $t_t$, msec | $\sigma$, msec | Standard error, msec |
| 1 | Dot | Pitch | Up | Known | 1 | 324.6 | 73.6 | 10.4 | 252.1 | 62.4 | 8.8 |
| 2 | | | | | 5 | 257.1 | 67.4 | 9.5 | 231.7 | 16.5 | 2.3 |
| 3 | | | | | 10 | 240.9 | 46.4 | 6.6 | 223.9 | 25.9 | 3.7 |
| 4 | | | Down | Known | 1 | 356.7 | 55.2 | 7.8 | 330.3 | 70.7 | 10.0 |
| 5 | | | | | 5 | 306.2 | 71.3 | 10.1 | 267.6 | 38.0 | 5.4 |
| 6 | | | | | 10 | 281.0 | 50.3 | 7.1 | 250.1 | 46.6 | 6.6 |
| 7 | | | Up or down | Unknown | 1 | 467.4 | 130.8 | 18.5 | 433.5 | 79.8 | 11.3 |
| 8 | | | | | 5 | 344.5 | 63.7 | 9.0 | 402.9 | 110.9 | 15.7 |
| 9 | | | | | 10 | 363.8 | 77.1 | 10.9 | 340.6 | 101.4 | 14.3 |
| 10 | | Yaw | Right | Known | 1 | 251.6 | 61.8 | 8.7 | 294.7 | 90.3 | 12.8 |
| 11 | | | | | 5 | 236.6 | 29.8 | 4.2 | 250.7 | 30.6 | 4.3 |
| 12 | | | | | 10 | 224.1 | 31.9 | 4.5 | 227.5 | 52.0 | 7.4 |
| 13 | | | Left | Known | 1 | 297.6 | 49.9 | 7.1 | 332.9 | 78.5 | 11.1 |
| 14 | | | | | 5 | 272.6 | 66.1 | 9.4 | 246.7 | 27.9 | 3.9 |
| 15 | | | | | 10 | 233.2 | 25.6 | 3.6 | 245.8 | 24.9 | 3.5 |
| 16 | | | L or R | Unknown | 1 | 369.0 | 44.1 | 6.2 | 370.5 | 57.6 | 8.1 |
| 17 | | | | | 5 | 320.2 | 41.5 | 5.9 | 312.4 | 61.3 | 8.7 |
| 18 | | | | | 10 | 285.6 | 35.3 | 5.0 | 318.8 | 71.1 | 10.0 |
| 19 | Line | Pitch | Up | Known | 1 | 290.9 | 36.5 | 5.2 | 267.4 | 63.0 | 8.9 |
| 20 | | | | | 5 | 256.3 | 42.6 | 6.0 | 242.3 | 22.5 | 3.2 |
| 21 | | | | | 10 | 249.8 | 47.3 | 6.7 | 237.7 | 43.8 | 6.2 |
| 22 | | | Down | Known | 1 | 305.8 | 48.6 | 6.9 | 326.8 | 64.9 | 9.2 |
| 23 | | | | | 5 | 271.6 | 41.6 | 5.9 | 269.6 | 39.9 | 5.6 |
| 24 | | | | | 10 | 244.7 | 31.6 | 4.5 | 247.3 | 23.9 | 3.4 |
| 25 | | | Up or down | Unknown | 1 | 409.6 | 68.8 | 9.7 | 422.6 | 84.9 | 12.0 |
| 26 | | | | | 5 | 349.5 | 55.2 | 7.8 | 357.3 | 119.0 | 16.8 |
| 27 | | | | | 10 | 327.1 | 48.5 | 6.9 | 358.9 | 79.8 | 11.3 |
| 28 | Rotating line | Roll | CCW | Known | 1 | 333.7 | 41.6 | 5.9 | 302.4 | 30.0 | 4.2 |
| 29 | | | | | 5 | 273.5 | 36.2 | 5.1 | 288.2 | 30.0 | 4.2 |
| 30 | | | | | 10 | 229.8 | 22.2 | 3.1 | 314.4 | 32.6 | 4.6 |
| 31 | | | CW | Known | 1 | 300.2 | 50.0 | 7.1 | 285.2 | 34.1 | 4.8 |
| 32 | | | | | 5 | 260.6 | 32.6 | 4.6 | 269.8 | 66.6 | 9.4 |
| 33 | | | | | 10 | 237.3 | 28.7 | 4.1 | 254.5 | 27.1 | 3.8 |
| 34 | | | CCW or CW | Unknown | 1 | 428.6 | 85.9 | 12.2 | 388.4 | 68.9 | 9.7 |
| 35 | | | | | 5 | 341.1 | 64.8 | 9.2 | 332.9 | 57.2 | 8.1 |
| 36 | | | | | 10 | 323.8 | 39.9 | 5.6 | 330.6 | 58.7 | 8.3 |
| 37 | Split line | Roll | R up, L down | Known | 1 | 299.8 | 33.4 | 4.7 | 325.3 | 32.5 | 4.6 |
| 38 | | | | | 5 | 250.2 | 32.5 | 4.6 | 281.3 | 27.4 | 3.9 |
| 39 | | | | | 10 | 233.6 | 22.9 | 3.2 | 275.0 | 29.8 | 4.2 |
| 40 | | | L up, R down | Known | 1 | 278.9 | 40.2 | 5.7 | 290.3 | 44.8 | 6.3 |
| 41 | | | | | 5 | 247.4 | 29.3 | 4.1 | 261.6 | 33.2 | 4.7 |
| 42 | | | | | 10 | 238.4 | 31.7 | 4.5 | 238.0 | 18.4 | 2.6 |
| 43 | | | Either | Unknown | 1 | 432.1 | 99.6 | 14.1 | 435.4 | 98.8 | 14.0 |
| 44 | | | | | 5 | 394.5 | 131.1 | 18.5 | 383.9 | 104.7 | 14.8 |
| 45 | | | | | 10 | 347.2 | 104.9 | 14.8 | 401.4 | 117.1 | 16.6 |

TABLE I.- MEAN VALUES, STANDARD DEVIATIONS, AND STANDARD ERRORS OF REACTION TIMES – Concluded

(b) Subjects S and Y

| Run | Display | Axis | Direction | State | Display rate, cm/sec | Subject S |  |  | Subject Y |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Average total reaction time, $t_t$, msec | $\sigma$, msec | Standard error, msec | Average total reaction time, $t_t$, msec | $\sigma$, msec | Standard error, msec |
| 1 | Dot | Pitch | Up | Known | 1 | 345.9 | 76.0 | 10.7 | 373.7 | 93.8 | 13.3 |
| 2 |  |  |  |  | 5 | 306.4 | 73.7 | 10.4 | 312.4 | 97.3 | 11.2 |
| 3 |  |  |  |  | 10 | 246.3 | 43.5 | 6.2 | 294.4 | 42.9 | 6.1 |
| 4 |  |  | Down | Known | 1 | 302.9 | 90.3 | 12.8 | 374.9 | 91.8 | 13.0 |
| 5 |  |  |  |  | 5 | 250.5 | 39.3 | 5.6 | 295.3 | 60.9 | 8.6 |
| 6 |  |  |  |  | 10 | 254.7 | 50.3 | 7.1 | 267.7 | 33.2 | 4.7 |
| 7 |  |  | Up or down | Unknown | 1 | 451.8 | 36.4 | 5.1 | 438.6 | 90.8 | 12.8 |
| 8 |  |  |  |  | 5 | 397.7 | 103.6 | 14.6 | 394.8 | 97.7 | 13.8 |
| 9 |  |  |  |  | 10 | 355.0 | 86.0 | 12.2 | 366.7 | 71.4 | 10.1 |
| 10 |  | Yaw | Right | Known | 1 | 350.7 | 54.9 | 7.8 | 328.6 | 83.1 | 11.7 |
| 11 |  |  |  |  | 5 | 283.9 | 36.4 | 5.2 | 268.3 | 70.7 | 10.0 |
| 12 |  |  |  |  | 10 | 300.6 | 37.3 | 5.3 | 274.4 | 44.5 | 6.3 |
| 13 |  |  | Left | Known | 1 | 417.5 | 115.0 | 16.3 | 339.1 | 60.8 | 8.6 |
| 14 |  |  |  |  | 5 | 324.6 | 65.7 | 9.3 | 298.6 | 80.8 | 11.4 |
| 15 |  |  |  |  | 10 | 290.1 | 47.0 | 6.6 | 267.8 | 65.4 | 9.2 |
| 16 |  |  | L or R | Unknown | 1 | 383.9 | 55.8 | 8.0 | 455.8 | 145.5 | 20.6 |
| 17 |  |  |  |  | 5 | 337.2 | 63.6 | 9.0 | 385.6 | 75.7 | 10.7 |
| 18 |  |  |  |  | 10 | 328.3 | 53.6 | 7.6 | 328.5 | 100.7 | 14.2 |
| 19 | Line | Pitch | Up | Known | 1 | 316.5 | 93.0 | 13.1 | 374.6 | 65.6 | 9.3 |
| 20 |  |  |  |  | 5 | 270.5 | 62.5 | 8.8 | 282.6 | 82.7 | 11.7 |
| 21 |  |  |  |  | 10 | 282.2 | 66.8 | 9.4 | 267.1 | 81.6 | 11.5 |
| 22 |  |  | Down | Known | 1 | 401.3 | 97.0 | 13.7 | 342.0 | 114.3 | 16.2 |
| 23 |  |  |  |  | 5 | 331.4 | 52.6 | 7.4 | 302.5 | 109.1 | 15.4 |
| 24 |  |  |  |  | 10 | 294.3 | 38.3 | 5.4 | 267.8 | 93.9 | 13.3 |
| 25 |  |  | Up or down | Unknown | 1 | 475.6 | 110.2 | 15.6 | 443.2 | 133.3 | 18.9 |
| 26 |  |  |  |  | 5 | 433.5 | 37.3 | 5.3 | 394.3 | 138.1 | 19.5 |
| 27 |  |  |  |  | 10 | 384.2 | 94.8 | 13.4 | 359.6 | 83.3 | 11.8 |
| 28 | Rotating line | Roll | CCW | Known | 1 | 322.6 | 85.6 | 12.1 | 344.9 | 98.3 | 13.9 |
| 29 |  |  |  |  | 5 | 284.5 | 81.5 | 11.5 | 275.9 | 68.4 | 9.7 |
| 30 |  |  |  |  | 10 | 302.8 | 69.0 | 9.8 | 254.9 | 50.4 | 7.1 |
| 31 |  |  | CW | Known | 1 | 357.1 | 100.4 | 14.2 | 340.7 | 95.4 | 13.5 |
| 32 |  |  |  |  | 5 | 288.1 | 82.0 | 11.6 | 296.8 | 59.4 | 8.4 |
| 33 |  |  |  |  | 10 | 264.7 | 87.8 | 12.4 | 268.7 | 52.9 | 7.5 |
| 34 |  |  | CCW or CW | Unknown | 1 | 477.1 | 112.1 | 15.8 | 558.0 | 124.6 | 17.6 |
| 35 |  |  |  |  | 5 | 422.0 | 91.4 | 12.9 | 459.3 | 82.8 | 11.7 |
| 36 |  |  |  |  | 10 | 402.4 | 88.7 | 12.5 | 420.2 | 118.4 | 16.7 |
| 37 | Split line | Roll | R up, L down | Known | 1 | 332.7 | 78.8 | 11.1 | 321.0 | 85.6 | 12.1 |
| 38 |  |  |  |  | 5 | 301.0 | 46.0 | 6.5 | 285.8 | 94.5 | 13.4 |
| 39 |  |  |  |  | 10 | 258.9 | 57.0 | 8.1 | 267.4 | 66.1 | 9.3 |
| 40 |  |  | L up, R down | Known | 1 | 322.0 | 85.7 | 12.1 | 377.7 | 117.9 | 16.7 |
| 41 |  |  |  |  | 5 | 308.1 | 77.8 | 11.0 | 305.0 | 31.8 | 4.5 |
| 42 |  |  |  |  | 10 | 289.3 | 61.4 | 8.7 | 294.2 | 54.2 | 7.7 |
| 43 |  |  | Either | Unknown | 1 | 505.2 | 111.4 | 15.8 | 543.2 | 127.3 | 18.0 |
| 44 |  |  |  |  | 5 | 393.3 | 114.5 | 16.2 | 442.8 | 116.0 | 16.4 |
| 45 |  |  |  |  | 10 | 371.2 | 95.8 | 13.5 | 374.3 | 77.3 | 10.9 |

## TABLE II.- T TESTS FOR COMPARING DISPLAY RATES

| 1 cm/sec vs 5 cm/sec runs | 5 cm/sec vs 10 cm/sec runs | Display | Axis | Direction | T values for subject – (*) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Subject B | Subject H | Subject S | Subject Y |
| 1 vs 2 | | Dot | Pitch | Up | 4.73 Yes + | 2.21 Yes + | 2.62 Yes + | 3.50 Yes + |
| | 2 vs 3 | | | | 1.39 No + | 1.76 No + | 4.91 Yes + | 1.40 No + |
| 4 vs 5 | | | | Down | 3.92 Yes + | 9.95 Yes + | 3.73 Yes + | 5.06 Yes + |
| | 5 vs 6 | | | | 2.03 No + | 2.03 No + | 0.47 No - | 2.78 Yes + |
| 7 vs 8 | | | | Unknown | 5.67 Yes + | 1.57 No + | 2.45 Yes + | 2.30 Yes + |
| | 8 vs 9 | | | | 1.36 No + | 2.91 Yes + | 2.22 Yes + | 1.63 No + |
| 10 vs 11 | | | Yaw | Right | 1.53 No + | 3.24 Yes + | 7.09 Yes + | 3.87 Yes + |
| | 11 vs 12 | | | | 2.01 No + | 2.69 Yes + | 2.24 Yes - | 0.51 No - |
| 13 vs 14 | | | | Left | 2.11 Yes + | 7.24 Yes + | 4.91 Yes + | 2.60 Yes + |
| | 14 vs 15 | | | | 3.90 Yes + | 0.16 No + | 2.99 Yes + | 2.08 Yes + |
| 16 vs 17 | | | | Unknown | 5.65 Yes + | 4.83 Yes + | 3.86 Yes + | 3.00 Yes + |
| | 17 vs 18 | | | | 4.44 Yes + | 0.47 No - | 0.75 No + | 3.17 Yes + |
| 19 vs 20 | | Line | Pitch | Up | 20.63 Yes + | 2.62 Yes + | 2.88 Yes + | 6.10 Yes + |
| | 20 vs 21 | | | | 0.72 No + | 0.65 No + | 0.90 No - | 0.93 No + |
| 22 vs 23 | | | | Down | 3.74 Yes + | 5.26 Yes + | 4.43 Yes + | 1.75 No + |
| | 23 vs 24 | | | | 3.61 Yes + | 3.36 Yes + | 3.99 Yes + | 1.69 No + |
| 25 vs 26 | | | | Unknown | 4.77 Yes + | 3.13 Yes + | 1.81 No + | 2.15 Yes + |
| | 26 vs 27 | | | | 2.14 Yes + | 0.08 No - | 2.28 Yes + | 1.07 No + |
| 28 vs 29 | | Rotating line | Roll | CCW | 7.65 Yes + | 2.34 Yes + | 2.26 Yes + | 4.04 Yes + |
| | 29 vs 30 | | | | 7.20 Yes + | 1.70 No - | 1.20 No - | 1.62 No + |
| 31 vs 32 | | | | CW | 4.64 Yes + | 1.44 No + | 3.72 Yes + | 2.75 Yes + |
| | 32 vs 33 | | | | 3.76 Yes + | 1.49 No + | 1.37 No + | 2.51 Yes + |
| 34 vs 35 | | | | Unknown | 5.69 Yes + | 4.34 Yes + | 2.67 Yes + | 4.62 Yes + |
| | 35 vs 36 | | | | 1.60 No + | 0.20 No + | 1.08 No + | 1.90 No + |
| 37 vs 38 | | Split line | Roll | R up, L down | 7.46 Yes + | 7.24 Yes + | 2.43 Yes + | 1.93 No + |
| | 38 vs 39 | | | | 2.92 Yes + | 1.10 No + | 4.02 Yes + | 1.11 No + |
| 40 vs 41 | | | | L up, R down | 4.43 Yes + | 3.61 Yes + | 0.84 No + | 4.17 Yes + |
| | 41 vs 42 | | | | 1.47 No + | 4.36 Yes + | 1.33 No + | 1.20 No + |
| 43 vs 44 | | | | Unknown | 1.60 No + | 2.50 Yes + | 4.90 Yes + | 4.08 Yes + |
| | 44 vs 45 | | | | 1.97 No + | 0.78 No - | 1.04 No + | 3.44 Yes + |

*"Yes" indicates significance at the 95-percent or greater confidence level; "No" indicates lack of such significance. Plus indicates that the higher display rate corresponds to the shorter reaction time; minus indicates that it does not.

## TABLE III.- CONSTANTS AND STANDARD ERRORS OF EQUATION (1)

### (a) Subject B

| Runs fitted | Axis and display | Direction and state | Standard error fit of eq. (1), sec | $\delta_T$, cm | Standard error of $\delta_T$, cm | $t_r$, sec | Standard error of $t_r$, sec |
|---|---|---|---|---|---|---|---|
| 1, 2, 3 | Pitch spot | Up, known | 0.063 | 0.090 | 0.013 | 0.236 | 0.008 |
| 4, 5, 6 | | Down, known | 0.063 | 0.074 | 0.013 | 0.283 | 0.008 |
| 7, 8, 9 | | Unknown | 0.095 | 0.127 | 0.019 | 0.337 | 0.011 |
| 10, 11, 12 | Yaw spot | Right, known | 0.045 | 0.026 | 0.009 | 0.227 | 0.005 |
| 13, 14, 15 | | Left, known | 0.055 | 0.055 | 0.011 | 0.244 | 0.007 |
| 16, 17, 18 | | Unknown | 0.032 | 0.079 | 0.006 | 0.291 | 0.004 |
| 19, 20, 21 | Pitch line | Up, known | 0.045 | 0.043 | 0.009 | 0.247 | 0.005 |
| 22, 23, 24 | | Down, known | 0.045 | 0.057 | 0.009 | 0.250 | 0.005 |
| 25, 26, 27 | | Unknown | 0.063 | 0.084 | 0.013 | 0.326 | 0.008 |
| 28, 29, 30 | Roll rotating line | CCW | 0.032 | 0.100 | 0.006 | 0.236 | 0.004 |
| 31, 32, 33 | | CW | 0.032 | 0.061 | 0.006 | 0.240 | 0.004 |
| 34, 35, 36 | | Unknown | 0.071 | 0.113 | 0.014 | 0.316 | 0.009 |
| 37, 38, 39 | Roll split line | R up, L down | 0.032 | 0.067 | 0.006 | 0.233 | 0.004 |
| 40, 41, 42 | | L up, R down | 0.032 | 0.042 | 0.006 | 0.237 | 0.004 |
| 43, 44, 45 | | Unknown | 0.095 | 0.075 | 0.019 | 0.359 | 0.011 |

TABLE III.- CONSTANTS AND STANDARD ERRORS OF EQUATION (1) – Continued

(b) Subject H

| Runs fitted | Axis and display | Direction and state | Standard error fit of eq. (1), sec | $\delta_T$, cm | Standard error of $\delta_T$, cm | $t_r$, sec | Standard error of $t_r$, sec |
|---|---|---|---|---|---|---|---|
| 1, 2, 3 | Pitch spot | Up, known | 0.045 | 0.028 | 0.009 | 0.224 | 0.005 |
| 4, 5, 6 | | Down, known | 0.055 | 0.084 | 0.011 | 0.247 | 0.007 |
| 7, 8, 9 | | Unknown | 0.095 | 0.077 | 0.019 | 0.360 | 0.011 |
| 10, 11, 12 | Yaw spot | Right, known | 0.063 | 0.066 | 0.013 | 0.230 | 0.008 |
| 13, 14, 15 | | Left, known | 0.055 | 0.099 | 0.011 | 0.232 | 0.007 |
| 16, 17, 18 | | Unknown | 0.063 | 0.060 | 0.013 | 0.308 | 0.008 |
| 19, 20, 21 | Pitch line | Up, known | 0.055 | 0.030 | 0.011 | 0.236 | 0.007 |
| 22, 23, 24 | | Down, known | 0.045 | 0.081 | 0.009 | 0.246 | 0.005 |
| 25, 26, 27 | | Unknown | 0.095 | 0.073 | 0.019 | 0.348 | 0.011 |
| 28, 29, 30 | Roll rotating line | CCW | 0.032 | -0.003 | 0.006 | 0.303 | 0.004 |
| 31, 32, 33 | | CW | 0.045 | 0.027 | 0.009 | 0.258 | 0.005 |
| 34, 35, 36 | | Unknown | 0.063 | 0.064 | 0.013 | 0.323 | 0.008 |
| 37, 38, 39 | Roll split line | R up, L down | 0.032 | 0.054 | 0.006 | 0.270 | 0.004 |
| 40, 41, 42 | | L up, R down | 0.032 | 0.047 | 0.006 | 0.243 | 0.004 |
| 43, 44, 45 | | Unknown | 0.110 | 0.046 | 0.022 | 0.387 | 0.013 |

TABLE III.- CONSTANTS AND STANDARD ERRORS OF EQUATION (1) – Continued

(c) Subject S

| Runs fitted | Axis and display | Direction and state | Standard error fit of eq. (1), sec | $\delta_T$, cm | Standard error of $\delta_T$, cm | $t_r$, sec | Standard error of $t_r$, sec |
|---|---|---|---|---|---|---|---|
| 1, 2, 3 | Pitch spot | Up, known | 0.084 | 0.086 | 0.017 | 0.262 | 0.010 |
| 4, 5, 6 | | Down, known | 0.071 | 0.058 | 0.014 | 0.244 | 0.009 |
| 7, 8, 9 | | Unknown | 0.077 | 0.090 | 0.016 | 0.363 | 0.009 |
| 10, 11, 12 | Yaw spot | Right, known | 0.045 | 0.065 | 0.009 | 0.284 | 0.005 |
| 13, 14, 15 | | Left, known | 0.077 | 0.130 | 0.016 | 0.288 | 0.009 |
| 16, 17, 18 | | Unknown | 0.055 | 0.057 | 0.011 | 0.325 | 0.007 |
| 19, 20, 21 | Pitch line | Up, known | 0.077 | 0.043 | 0.016 | 0.271 | 0.009 |
| 22, 23, 24 | | Down, known | 0.063 | 0.106 | 0.013 | 0.296 | 0.008 |
| 25, 26, 27 | | Unknown | 0.089 | 0.079 | 0.018 | 0.397 | 0.011 |
| 28, 29, 30 | Roll rotating line | CCW | 0.077 | 0.030 | 0.016 | 0.291 | 0.009 |
| 31, 32, 33 | | CW | 0.089 | 0.095 | 0.018 | 0.262 | 0.011 |
| 34, 35, 36 | | Unknown | 0.100 | 0.076 | 0.020 | 0.401 | 0.012 |
| 37, 38, 39 | Roll split line | R up, L down | 0.063 | 0.064 | 0.013 | 0.270 | 0.008 |
| 40, 41, 42 | | L up, R down | 0.077 | 0.029 | 0.016 | 0.294 | 0.009 |
| 43, 44, 45 | | Unknown | 0.105 | 0.144 | 0.021 | 0.361 | 0.013 |

TABLE III.- CONSTANTS AND STANDARD ERRORS OF EQUATION (1) – Concluded

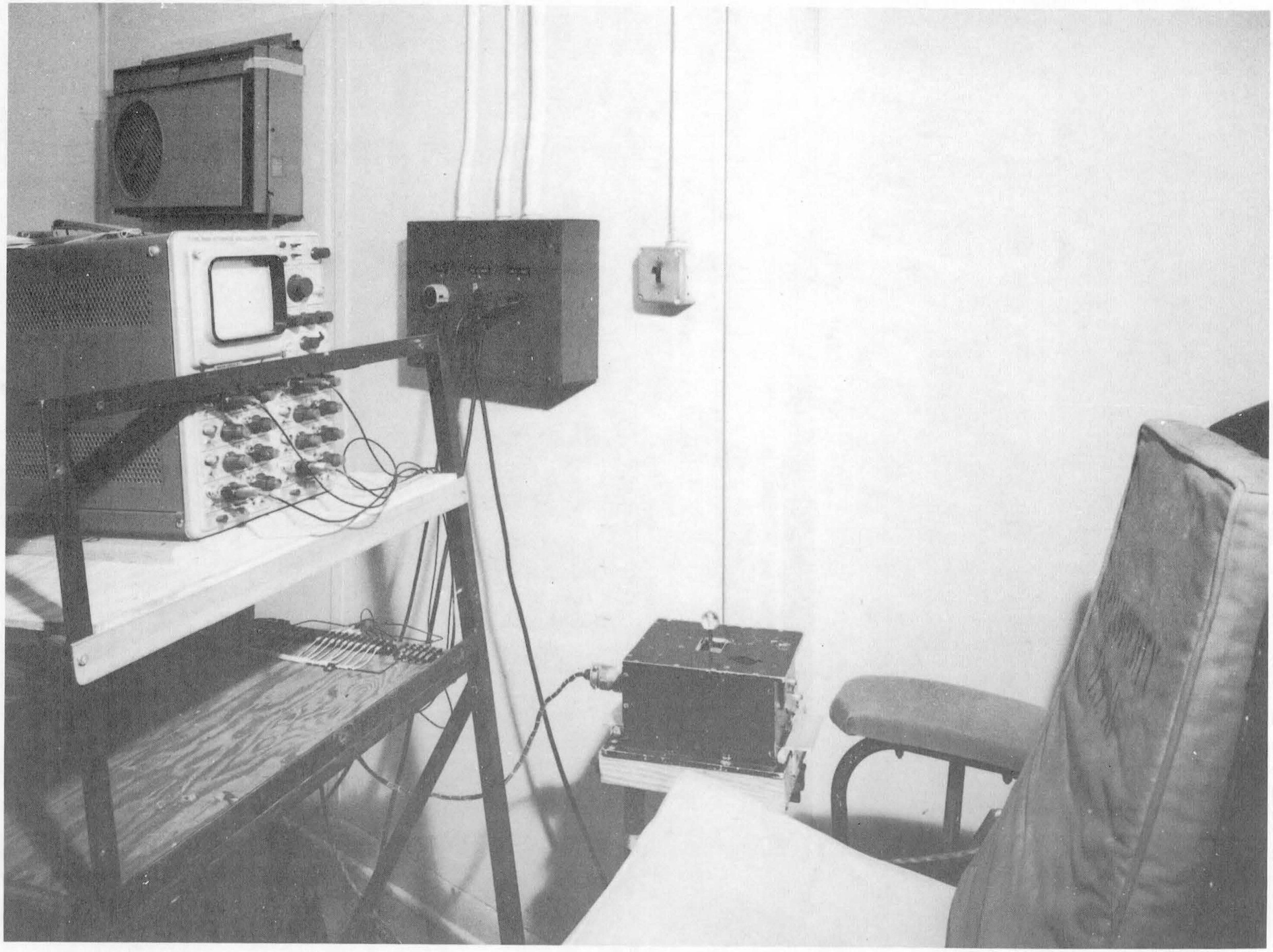
(d) Subject Y

| Runs fitted | Axis and display | Direction and state | Standard error fit of eq. (1), sec | $\delta_T$, cm | Standard error of $\delta_T$, cm | $t_r$, sec | Standard error of $t_r$, sec |
|---|---|---|---|---|---|---|---|
| 1, 2, 3 | Pitch spot | Up, known | 0.105 | 0.083 | 0.021 | 0.291 | 0.013 |
| 4, 5, 6 | | Down, known | 0.095 | 0.110 | 0.019 | 0.265 | 0.011 |
| 7, 8, 9 | | Unknown | 0.122 | 0.069 | 0.025 | 0.371 | 0.015 |
| 10, 11, 12 | Yaw spot | Right, known | 0.095 | 0.065 | 0.019 | 0.262 | 0.011 |
| 13, 14, 15 | | Left, known | 0.100 | 0.067 | 0.020 | 0.273 | 0.012 |
| 16, 17, 18 | | Unknown | 0.158 | 0.119 | 0.032 | 0.339 | 0.019 |
| 19, 20, 21 | Pitch line | Up, known | 0.110 | 0.116 | 0.022 | 0.258 | 0.013 |
| 22, 23, 24 | | Down, known | 0.152 | 0.067 | 0.031 | 0.276 | 0.018 |
| 25, 26, 27 | | Unknown | 0.170 | 0.081 | 0.035 | 0.364 | 0.020 |
| 28, 29, 30 | Roll rotating line | CCW | 0.105 | 0.094 | 0.021 | 0.252 | 0.013 |
| 31, 32, 33 | | CW | 0.095 | 0.068 | 0.019 | 0.273 | 0.011 |
| 34, 35, 36 | | Unknown | 0.155 | 0.140 | 0.031 | 0.419 | 0.019 |
| 37, 38, 39 | Roll split line | R up, L down | 0.114 | 0.052 | 0.023 | 0.269 | 0.014 |
| 40, 41, 42 | | L up, R down | 0.110 | 0.090 | 0.022 | 0.287 | 0.013 |
| 43, 44, 45 | | Unknown | 0.115 | 0.161 | 0.031 | 0.384 | 0.019 |

TABLE IV.- T TESTS FOR COMPARING DISPLAY DIRECTIONS

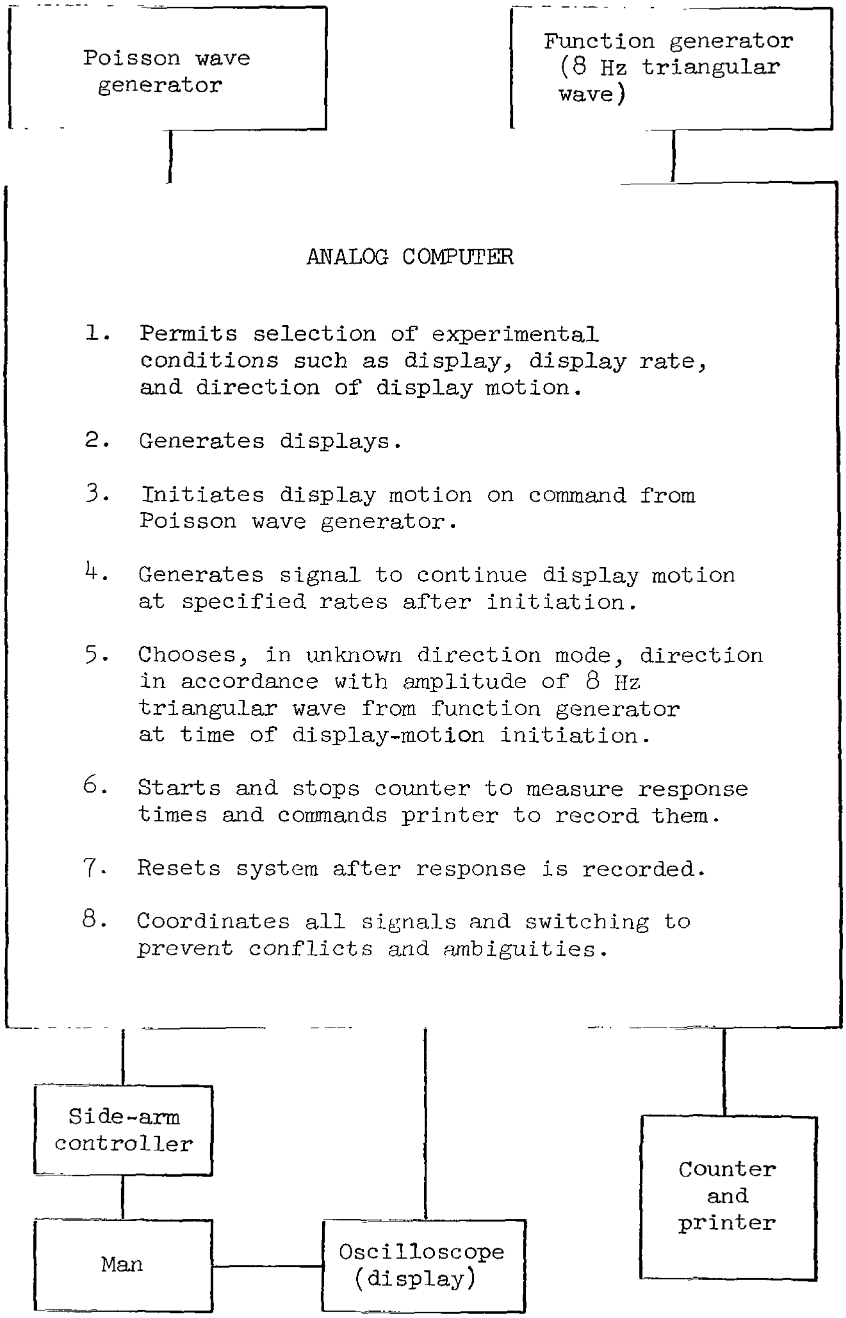
[No T values are significant at the 95-percent confidence level]

| Axis and display | T values from comparisons of opposite display directions | |
|---|---|---|
| Pitch line | 2.93 | Significant at 90 percent |
| Yaw spot | 2.48 | |
| Pitch spot | .377 | |
| Roll rotating line | .813 | |
| Roll split line | .417 | |



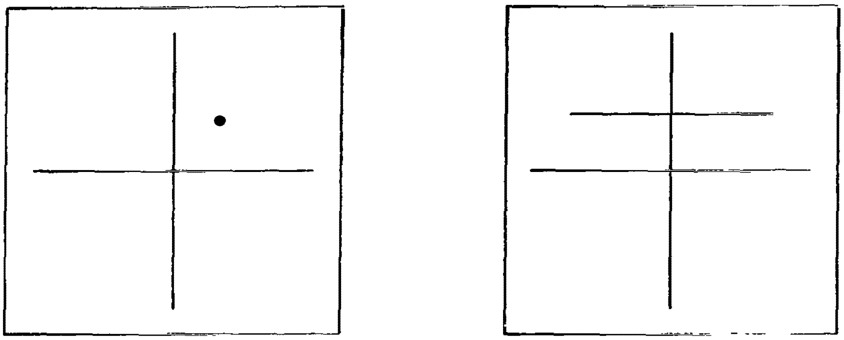
L-68-10 190

Figure 1.- Experimental setup.



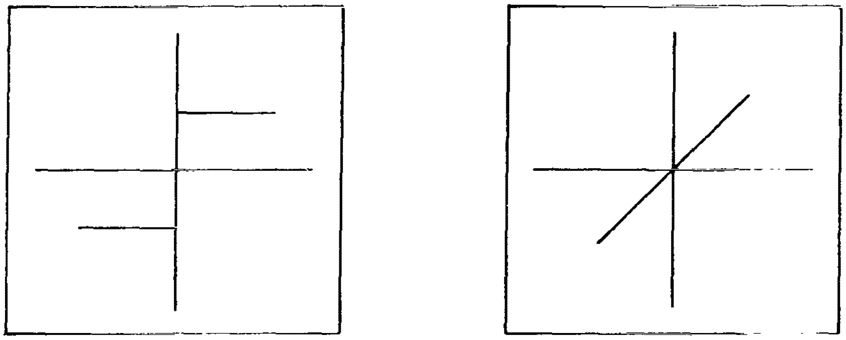
1. Permits selection of experimental conditions such as display, display rate, and direction of display motion.
2. Generates displays.
3. Initiates display motion on command from Poisson wave generator.
4. Generates signal to continue display motion at specified rates after initiation.
5. Chooses, in unknown direction mode, direction in accordance with amplitude of 8 Hz triangular wave from function generator at time of display-motion initiation.
6. Starts and stops counter to measure response times and commands printer to record them.
7. Resets system after response is recorded.
8. Coordinates all signals and switching to prevent conflicts and ambiguities.

Figure 2.- Block diagram of equipment for measuring reaction times.



Spot

Line



Split line

Rotating line

Figure 3.- Displays.

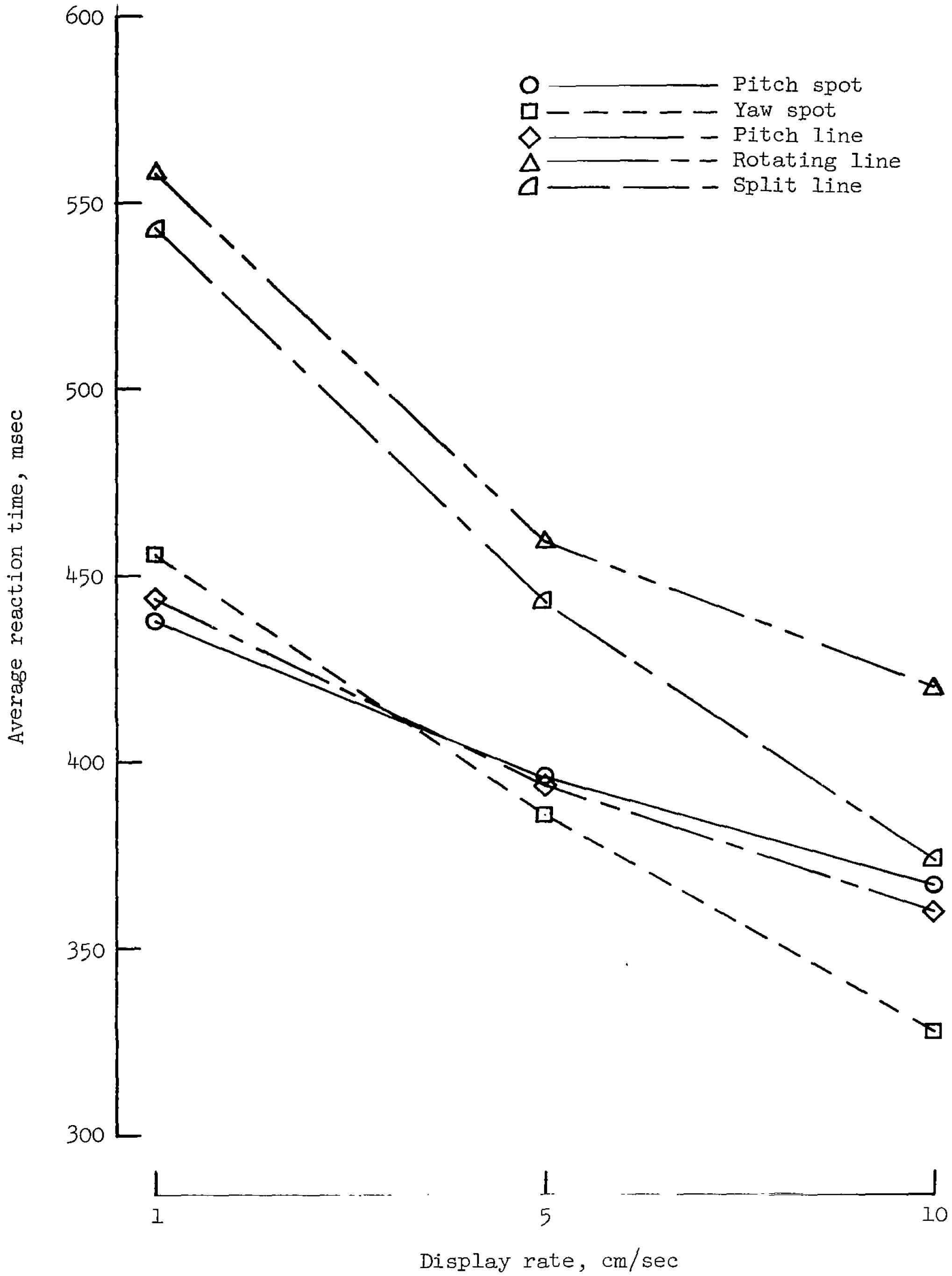


Figure 4.- Typical plot of average reaction time versus display rate.

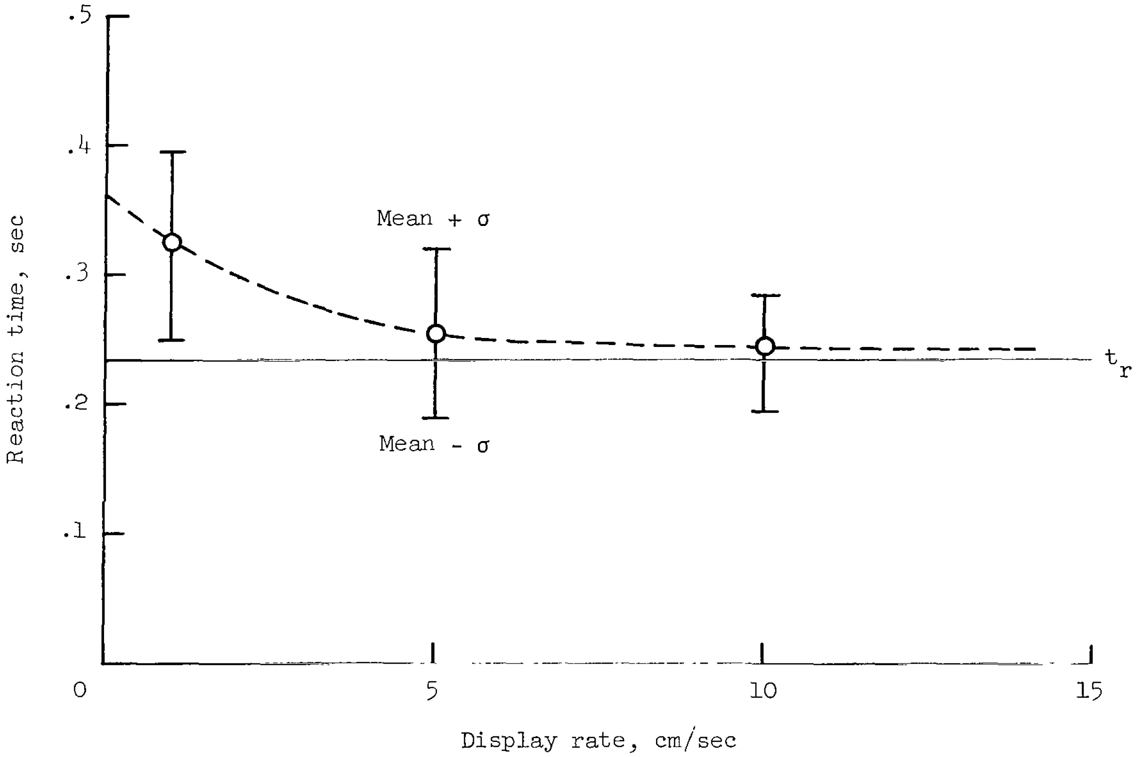


Figure 5.- Plot of $t_t = \frac{1}{\dot{\delta}} \delta_T + t_r$.

Subjects

| Subjects | B | H | S | Y |
|---|---|---|---|---|
| B | — | .436 | 5.30 | 5.21 |
| H |  | — | 3.51 | 3.44 |
| S |  |  | — | .659 |
| Y |  |  |  | — |

For significance at 99%, T ≧ 2.977
95%, T ≧ 2.145
90%, T ≧ 1.761
80%, T ≧ 1.345

Figure 6.- T matrix for comparing subjects.

Displays

| Displays | $P_L$ | $P_S$ | $Y_S$ | $R_{RL}$ | $R_{SL}$ |
|---|---|---|---|---|---|
| $P_L$ | — | .038 | 4.23 | .446 | 1.60 |
| $P_S$ |  | — | 9.41 | .581 | 2.37 |
| $Y_S$ |  |  | — | 2.90 | 5.70 |
| $R_{RL}$ |  |  |  | — | .518 |
| $R_{SL}$ |  |  |  |  | — |

For significance at 99%, T ≧ 5.841
95%, T ≧ 3.182
90%, T ≧ 2.353
80%, T ≧ 1.638

Figure 7.- T matrix for comparing displays.

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