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REFERENCE NUMBER			16325	

TITLE Design of instrument dials for maximum legibility: I. Development of methodology and some preliminary results

AUTHOR(S) Kappauf, William E. DATE

ORIG. AGENCY Air Materiel Command, Hq. O.A. NO. TSEAA-694-1L

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TSEAA-8/PMF/je

MEMORANDUM REPORT ON

Date: 20 Oct 47

SUBJECT: Design of Instrument Dials for Maximum Legibility: I. Development of Methodology and Some Preliminary Results.

SECTION: Aero Medical Laboratory

SERIAL NO.: TSEAA-694-11

Expenditure Order No. 694-15
Contract No. W33-038-ac-14480

ATI No. 16325

A. **PURPOSE:**

1. Research on the problem of instrument dial legibility is necessary for several reasons. It is desirable that instruments be designed so that readings can be made as precisely and rapidly as possible. It is also desirable that standards outlining the design characteristics necessary to meet stated requirements of reading precision be established. The purpose of the present report is to describe the development of experimental procedures for systematic experimentation upon the many variables affecting dial reading, and to report some preliminary results.

B. **FACTUAL DATA:**

2. A report has been prepared by Princeton University covering development of methodology for legibility studies and a preliminary investigation of dial reading. This work is being carried on under Contract No. W33-038-ac-14480.

3. The preliminary experiment was undertaken with four objectives in mind:

a. To develop a standardized test situation for the study of dial readings.

b. To obtain a rough measure of the range of error and time scores in dial reading.

c. To explore methods of analyzing the effects of any given variable in relation to other variables.

d. To obtain an indication of the effects of attitude and practice of the individuals employed as subjects in the tests.

4. Panels of 12 instrument dials were exposed and experimental subjects were required to read them in a prescribed sequence and call out the indicated values. Both time and error scores were recorded. Three dial designs, each in three sizes, were employed in the experiment. The designs differed only in the number of sub-divisions. Scale divisions at every unit, at every fifth unit, or at every tenth unit were employed. Two sets of instructions were used. One set emphasized both speed and accuracy, while another emphasized extreme accuracy. Six individuals served as subjects.

5. The entire experiment was repeated on the same subjects after a period of one month as a check on the reliability of the procedure. A detailed description of rationale, experimental procedures and results is given in Appendix I.

C. **CONCLUSIONS:**

6. The following conclusions are drawn:

a. Errors are less frequent for the larger and more finely graduated dials, and for reading instructions that emphasize accuracy.

b. Speed of reading is faster for the larger and more finely graduated dials.

c. Time scores are more difficult to deal with in analyzing the data than are error scores.

d. For the dials and subjects used, there were very few errors greater than one unit, that is, greater than one percent of the full scale. The percent of total readings in error was 10.1. The percent of total readings in error by more than one unit was 1.3.

e. Numeral design may be responsible for large dial reading errors since partially concealed numbers may be confused with others. Army-Navy Aeronautical Design Standard for numerals, AND 10400, permits ready confusion of the numeral 5 with the numeral 6 for the pointers used in the experiment and for dials which place the numeral five at the bottom of the dial.

f. Until more is known about them, practice effects must be recognized as variables of importance. In this experiment they resulted in a drop of twenty to twenty five percent in error scores from test to retest and a change in the importance of some of the interactions.

7. A number of conclusions are drawn concerning methodology in legibility research. These are summarized in the Appendix.

D. **RECOMMENDATIONS:**

8. None.

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20 October 1947

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Engin. Div. MR No. TSEAA-694-1L
20 October 1947

Bendix Aviation Corporation
Eclipse-Pioneer Division
Teterboro, New Jersey
Attn: USAF Representative

Sperry Gyroscope Co., Inc
Great Neck, Long Island, N. Y.
Attn: USAF Representative

APPENDIX I

REPORT NO. 3 from the

Department of Psychology
Princeton University
Princeton, N. J.

A METHODOLOGICAL STUDY OF DIAL READING

Prepared for the

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Engineering Division
Air Materiel Command
Wright Field
Dayton, Ohio

Prepared by William E. Kappauf
William E. Kappauf

William M. Smith
William M. Smith

Charles W. Bray
Charles W. Bray

Contract # W 33-038 ac 14480

August 1947

A METHODOLOGICAL STUDY OF DIAL READING

In a large number of situations, including that of the aircraft cockpit, it is necessary that circular scales be read with the greatest possible accuracy and speed. Yet the conditions that lead to optimal human performance in dial reading have received only a minimum of psychological attention. This paper is the first in a series that will describe systematic experimentation upon some of the many variables affecting dial reading.

Dial reading is a complex perceptual process which may be affected by a host of variables. These include: 1) the characteristics of the scale, e.g. its size, number of graduations, numerical value of scale intervals, contrast of markings to background, etc., 2) similar characteristics of the pointer, 3) the characteristics of the general situation, e. g. the illumination, whether one or many dials are being read, the interrelation of dial to dial, requirements for speed and accuracy, etc., and 4) the characteristics of the reader. If it could be assumed that these variables acted singly and additively on dial reading, research planning would not be difficult. The likelihood is, however, that some of the variables interact. Under these conditions, only a series of carefully planned experimental studies can estimate the significance of each of the possible variables and produce the basic information required for the rational design of dial faces.

As an introduction to such a series of studies, a preliminary investigation has been completed. This preliminary experiment was undertaken with four objectives in mind: 1) to develop a standardized test situation for the study of dial reading, 2) to obtain a rough measure of the range of error and time scores in dial reading, 3) to explore methods of analyzing the effects of any given variable in relation to other variables, and 4) to obtain an indication of the effects of attitude and practice. The experiment and this report are thus primarily methodological. They are not intended to yield definitive information on dial design.

GENERAL QUESTIONS OF EXPERIMENTAL PROCEDURE

The results of three previous studies may be used in the planning of new research on dial design. These are the studies of Loucks (2) (3) (4) (5), Vernon (7), and Williams (8), which show that there are considerable differences in the accuracy with which different dials or scales are read. The frequency of error, varying in part, of course, as a function of the criterion of error, ranges from less than one percent of readings under some conditions up to eighty or ninety percent of readings under other conditions. The character and relation of numbers, the frequency and spacing of graduations, the general "cleanliness" or simplicity of the dials, the amount and the character of the illumination, the characteristics of other scales in the series, all appear to have some effect. It is also clear that subjects differ considerably from one another and that practice has a marked effect. The experiments were not designed to give convincing evidence of the possible interaction of variables.

Not only do the experiments of Loucks, Vernon, and Williams provide useful information about dial reading performance, but they represent trials of particular experimental procedures. Their remarks or results relating to methodology can be of assistance in supplementing the usual criteria of convenience or purpose which any new experimenter in the field might use in choosing his method. In developing a procedure for new research in dial design, there are at least five questions on which decisions must be made:

1) How will the experiment take cognizance of subject-to-subject differences? This may be done by comparing the average performance of one group of subjects in the test situation with that of other groups of subjects in other test situations. (Williams used groups of twenty in this way.) Or the same group may be observed in two or more situations, group average scores again being compared. (This was the procedure of Loucks and Vernon.) Or, lastly, each subject may be tested in a sufficient number of trials to get a reliable measure of his performance in each experimental situation. As we see it, the first two procedures are satisfactory only when looking for general effects. The last procedure usually makes it necessary to use a smaller number of subjects, but, since it recognizes the possibility of subject differences and interactions, it deserves attention until

subject effects are well known.

2) What will be the procedure for presenting the dials and evaluating the performance? Alternative procedures here are: (a) using a tachistoscopic presentation and scoring errors only (Loucks and Vernon), (b) exposing dials singly, timing readings and scoring for errors (as Williams did with admittedly crude results), (c) presenting a bank of dials to be read in immediate succession and determining errors and total time (as Vernon did in the second half of her experiment), and (d) presenting the dial reading task as part of a more general task (as the job of flying a plane) and scoring for errors and time. Method (d) is fundamental to the final validation of dial designs, but for initial studies it is time consuming and inefficient in terms of the number of readings obtained per interval of research time. For speed in assembling data and for more sensitive time measurements, method (c) seems to offer the best possibilities.

Avoided by method (c) is the necessarily speeded attitude of the subject in a tachistoscopic experiment. The natural situation in dial reading is for most readings to be paced by the subject himself. Even when readings do have to be hurried in accordance with the demands of the task, the dial reader is usually free to check himself by a second glance if he feels it important to do so.

3) How will the "true" dial setting be established? The limits of

error or variability of the "true" setting which can be tolerated are a function of the purpose of the experiment and the precision of the reading which is to be required. If high reading precision is required or if the purpose of the study is to examine variables which might affect precision only at strict limits, then the settings used for each presentation must be accurately known. Because one of our objectives is to establish the limits of reading precision, we rejected the following two methods: (a) setting the dials manually for each trial (which requires a recorded check of each setting) and (b) setting the dials by means of an automatic control system (which is subject to a variable error). In preference we chose the method of using previously prepared photographs, each photograph composed of a set of twelve similar dials. These keep the task constant from subject to subject and can easily be checked for accuracy of setting.

4) What particular dial settings will be used? Will settings at every unit be used on every comparison for every subject? Or, will a selected but identical group of settings be used on every comparison dial for every subject? Or, will it be adequate to use a selected group of settings chosen by some randomizing method and thus not the same for every comparison dial? The first alternative may be exhausting. The second, we thought, might become obvious to the subjects in the experiment (e.g. that the reading 22 recurs but never 23). We

therefore chose to use a restricted randomizing scheme and selected a different set of sixty readings for any one dial design. As it turns out, this procedure may be all right for the study of general effects, but for the analysis of specific sources of error it may be unsatisfactory (see page 34 below).

5) Will the material be presented to single subjects or to groups? To this time, research has favored individual test procedures rather than group testing. Individual testing permits simpler methods of timing performance.

After consideration of the problems described above, the following experiment was planned to permit a preliminary study of all major effects, interaction effects, and any effects attributable to practice, fatigue, or warm-up. At the risk of overemphasizing the limited data obtained, the discussion below has been expanded to give a thorough treatment of methods and problems of analysis.

APPARATUS

A simple two-compartment structure provided the basic experimental situation. This structure is shown in Figure 1. In the top half of the figure is the subject's compartment. The subject was seated in a chair of adjustable height with his forehead against a solid head-rest. In the forward wall of the compartment and on the subject's horizontal line of regard was a circular hole in which a sample dial could be exposed by the experimenter. Directly below the sample dial was an aperture, eleven by fourteen inches in size, within which the experimenter exposed the stimulus dials. These were on cards showing twelve dials each. The top edge of this aperture was fifteen degrees below the horizontal line of sight. Within the aperture the stimulus card was tipped so that it would be perpendicular to the depressed line of sight. The center of the card was 30 inches from the subject's eyes.* The stimulus cards were moved into viewing position by the experimenter by means of a sliding carrier (see lower half of Figure 1).

The sample dial was illuminated by one of the three light sources shown in the figure. The light sources consisted of Mazda lamps in cans. The sample dial was so illuminated that the white markings were 5 foot lamberts on a background of .6 foot lamberts. For the stimulus dials these values were 6 and .6 foot lamberts respectively. Brightness measurements were made with the Macbeth Illuminometer.

A master switch on the experimenter's table controlled the illumination of the dials. In one position of the switch only the sample dial was illuminated; in the other position the illumination of the sample dial was off and the illumination of the stimulus dials was on. The change in lighting marked the beginning and end of the reading of a stimulus card.

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*For future work this has been modified to 28 inches to be in accordance with the new standards for visual research (6).

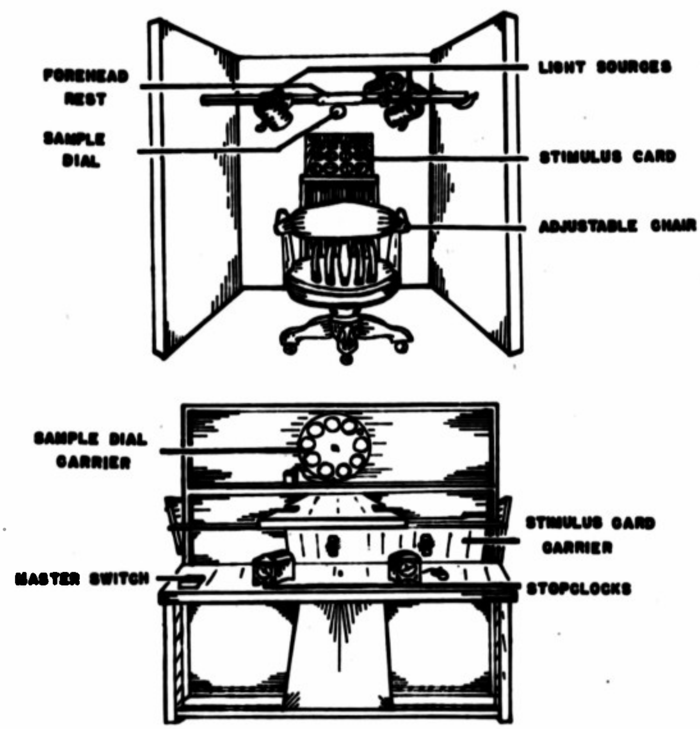

Figure 1. The experimental situation: above, subject's compartment; below, experimenter's compartment, which is on the reverse side of the rear wall of the subject's compartment.

The lighting switch also controlled two stopclocks for timing the readings. These were Standard Electric Timers, S-10, which time intervals up to one thousand seconds in steps of one tenth of a second.

Stimulus Materials

Three dial designs, each in three sizes, were employed in the experiment. The designs are shown in Figure 2. As shown in the figure, the designs differed only in the number of subdivisions. The dial at the upper left in Figure 2, hereafter called the 100 x 10 dial, read to one hundred units over the full scale in numbered steps of ten units each. It illustrates the smallest size, 0.7 inches scale diameter, i.e. diameter of the inner one of the two bounding circles. The dial at the upper right, 100 x 5, read to one hundred units in steps of five units, every tenth unit being numbered. It illustrates the 1.4 inch size. The dial below, 100 x 1, was subdivided to the unit with every tenth unit being numbered. It illustrates the largest size, 2.8 inches in diameter. The dimensions of markings are shown for the 2.8 inch dial. For the smaller dials all dimensions were reduced proportionately as the diameter was reduced. Number dimensions were chosen in accordance with Army-Navy Aeronautical Design Standard, AND10400, and other line dimensions were taken as a rough average of line dimensions in a variety of dials inspected by us.

The three dial designs were originally prepared as master drawings, twenty inches in diameter. The master drawings were reproduced photo-

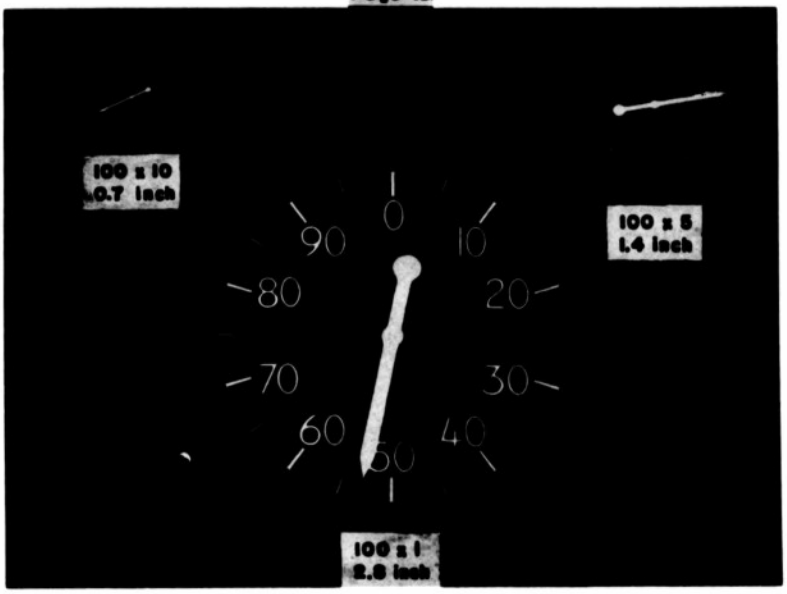

Figure 2. Dial designs and sizes used in the experiment. Each of the three designs shown were used in all three sizes indicated. The dimensions, in inches, given below are for the 2.8 inch dial. For the 1.4 inch and 0.7 inch dials all dimensions are respectively one half and one fourth as large.

		Length	Width
Major Graduations		0.215	0.046
Intermediate Graduations		0.135	0.025
Fine Graduations		0.081	0.012
Pointer:	Overall	0.641	0.040
	Center to Tip	0.412	0.040
	Beginning of Taper to Tip	0.087	———
Numerals:	Height 0.266		
	Width 0.032		

graphically in a number of seven-inch copies. For each dial design in turn, twelve copies were furnished with movable pointers and mounted on a large panel in three horizontal rows of four dials each, the dial centers being 9 inches apart in the horizontal dimension and 9.5 inches apart in the vertical dimension. When the pointers of each of the twelve dials had been set to prearranged values, the bank of dials was photographed on a four-by-five inch negative. Photographic enlargement of each negative to the three appropriate sizes provided the material for the stimulus cards. The photographs were mounted on Presdwood boards, 11 x 14 inches in size. A completed stimulus card for the dials of intermediate size is shown in Figure 3.

Since the same type of errors may be expected to appear in setting dials as in reading them, great care was exercised to insure accuracy of setting. It was decided that the dials should always be set as nearly as possible to an exact unit, i.e. never intentionally at fractional values. While this decision entailed a relatively "unnatural" stimulus situation, it greatly simplified analysis of results. The accuracy of settings of the 100 x 10 and 100 x 5 dials was increased by the use of a hand scale, marked to the nearest scale unit. The accuracy of setting was checked by projecting the negatives of the stimulus dial photographs up to a size of twenty one inches and reading the settings with the aid of a hand scale graduated to the nearest tenth of a scale unit. The average error of setting proved to be 0.08 scale units, 0.07 scale units, and 0.02 scale units

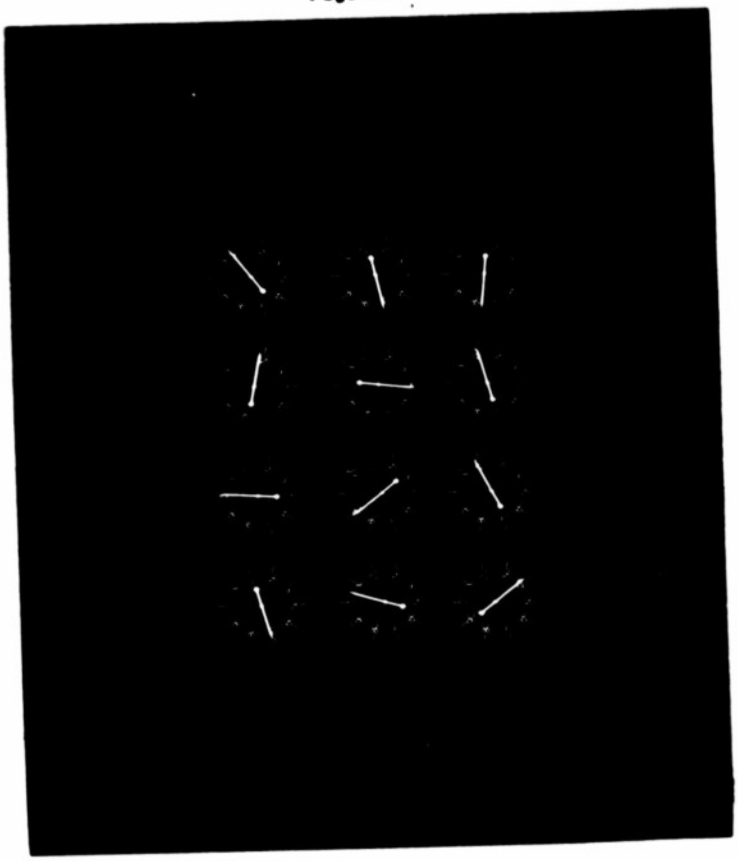

Figure 3. A stimulus card showing the 100 x 5, 1.4 inch diameter dial
(one half natural size)

for the 100 x 10, the 100 x 5, and the 100 x 1 dials respectively. The errors were symmetrically distributed around zero, and, with a single exception, all setting errors were less than 0.2 scale units. For this single exception an error of 0.3 scale units was observed. These data are given in this detail because for similar photographs of other types of dials, intended for reading to the nearest unit, we have found average errors of as much as 0.3 scale units, with many settings in error by 0.5 or more scale units, and sometimes with a strong bias. These observations suggest that the accuracy of the original dial settings should be specified for any experimental study of the precision with which quantitative data can be read from a dial or scale.

A total of forty five stimulus cards was reproduced. Each of the nine kinds of dials (three designs x three sizes) was represented by five cards. Since each card showed twelve settings of one kind of dial, there was a total of sixty settings for each dial design in all the stimulus cards and these settings were repeated for all three sizes of a given dial design. The pointer settings were derived from a table of random numbers following, however, two restrictions: 1) in the series of sixty settings for any dial type no initial or final digit was proposed to appear more than six times, and 2) in the twelve settings on any one card no initial or final digit was proposed to appear more than three times. It will be observed in the discussion below that this procedure was probably inadequate for certain control of the ease or difficulty of the settings appearing on any one card or in the set of five cards for each design. In future experiments additional restrictions will be imposed.

SUBJECTS

Six male subjects, one undergraduate student, three graduate students, and two faculty members, all from the Princeton Department of Psychology, served in this experiment. All professed to have normal visual acuity (corrected or uncorrected).

PROCEDURE

For each subject the experiment began by seating him comfortably with his forehead against the forehead-rest. A sample dial of the design to be exposed on the first stimulus card was illuminated. The sample dial was always 2.8 inches in diameter and had no pointer. As the subject adapted to the illumination conditions, and inspected the sample dial, the experimenter read aloud one of three sets of instructions. The instructions provided for reading the dials 1) to the nearest unit under an accuracy attitude, 2) to the nearest unit under a speed-and-accuracy attitude, or 3) to the nearest round fifth unit (e.g. 5, 30, 45, 0, 85, etc.) under a speed-and-accuracy attitude. Since data obtained under the last instructions are not analyzed in this report, no further reference will be made to this procedure or to the results obtained by it. For the accuracy attitude, the instructions to the subject were:

"....Read aloud each dial to the nearest unit as accurately as possible. Think of your reading as similar to that in using a slide rule where extremely accurate readings must be made in order to result in future correct computations ..... Remember, read the dials to the nearest unit and read them as accurately as possible."

For the speed-and-accuracy attitude, the instructions were:

"....Read aloud each dial as rapidly and accurately as possible ..... Remember, read the dials to the nearest unit and read them as accurately and rapidly as possible."

The instructions also called for the subject to read the stimulus dials by rows in order from left to right and from top to bottom. Any questions as to the instructions were answered and the instructions were repeated until the experimenter felt certain that the subject fully understood the task. Since these instructions are not intended for future use in more definitive experiments, they are not reproduced in further detail here.

The experimenter then inserted the first stimulus card in its holder and after inquiring, "Ready?", slid the card into reading position. As the stimulus card came into position, the illumination was switched to it and the two clocks were started. When the subject had read the first of the twelve dials, one of the two clocks was stopped by the experimenter. As the last dial on the card was read, the second of the two clocks was stopped as the experimenter switched the illumination back to the sample dial. A rest interval of about twenty seconds followed. A new sample dial like the next group of stimulus dials was then put in place. After the subject had inspected the sample for about ten seconds, the experimenter called, "Ready?", and a new stimulus card was exposed and so on for a series of nine cards. Between each series of nine cards, a rest period of about three minutes intervened. At any one sitting all forty five cards were presented but the first nine cards (one of each design and size) to be presented were presented again at the end of the series giving a total of fifty four cards or 648 dials read at the sitting. The readings of the first nine cards were eliminated from all data* in order to control warm-up effects (except in a specific study of warm-up to be discussed below). Reading all the fifty four cards under any single set of instructions required from fifty to seventy five minutes and constituted a single sitting. For any one subject an interval of one day intervened between successive sittings.

The experimenter recorded the subject's response on a previously prepared data sheet, merely checking the correct responses and entering the actual response in case of an erroneous reading. The reading times were entered on the same record.

The order of presentation of the stimulus cards was systematically varied to balance out practice and fatigue effects, as well as any remaining warm-up effects. Each design and each size of dial appeared once within the first nine cards and once again in every succeeding set of nine

*In the first run of the experiment there were exceptions to the procedure regarding this point. For some subjects the entire first nine stimulus cards were not repeated; in some cases (seven sittings out of twelve) only six or seven cards were repeated. For cards which were not repeated the data for the first readings were used to complete the basic results.

cards. From sitting to sitting, the order of presentation of the cards was reversed to prevent learning of the series. From subject to subject, the order in which different instructions were given was systematically balanced.

About one month after the first series of sittings, the entire procedure was repeated for each of the six subjects, omitting, however, the reading of the dials to the nearest round fifth unit. The repetition of the experiment permitted a study of practice effects and of reliability of the test procedure.

The experimental design described above may be summarized by saying that it proposed an analysis of the differences in time and in error scores contributed by dial size, dial design, subjects, and subjects' attitude toward speed and accuracy, as well as an analysis of interactions between these variables. The design provided for the control of the effects of practice, warm-up, and fatigue in the main analysis, and for a rough study of these factors in a subsidiary analysis. It also established a factual check on the reliability of any conclusion drawn from the first series of sittings.

RESULTS

The raw data of the experiment consisted of error and time scores obtained by the different subjects, each under the same varying conditions. We shall consider first the analysis of the main factors in the experiment:

attitude, design, and size. Later the subsidiary questions of types of errors, practice effects, warm-up and fatigue, and digit and sector difficulty will be taken up.

Raw Error Data

The main factors must be considered in terms of errors and time separately. For the detailed error analysis we have considered all errors, regardless of magnitude, to be alike. Thus, an error of one unit in reading counts just as much as an error of, say, ten units and we are asking our subjects to read the dials to an accuracy of better than one percent of full scale. The raw data for all errors are presented in Table 1. The table gives the number of errors observed for each subject while making sixty readings on dials of each design and size and under each condition of observation. Mean values for all subjects are also given. Considering all subjects and conditions, it is apparent that the incidence of error ranges from zero to 28 for sixty readings. Individual subjects differ considerably from one another, the error frequency being consistently high for some subjects and low for others.

The data of Table 1 are presented in somewhat simplified form in Figure 4. For this figure the averages for all subjects in the original test and the retest have been combined and are stated in terms of percent of readings in error. Separate pairs of curves are given for each dial design (100 x 10, 100 x 5, and 100 x 1) showing how errors vary with size

TABLE 1. The number of readings in error. The entries show the number of readings in error for each subject in 60 readings of each dial, according to design, size, attitude, and test. Mean values for all subjects are also listed.

		Speed and Accuracy						Accuracy					
		Test			Retest			Test			Retest		
Design	Subject	Size in Inches 0.7	1.4	2.8	Size in Inches 0.7	1.4	2.8	Size in Inches 0.7	1.4	2.8	Size in Inches 0.7	1.4	2.8
100 x 10	1	7	4	4	12	2	5	5	1	2	2	1	1
	2	15	6	3	13	4	2	11	7	3	13	6	1
	3	10	7	5	8	2	0	11	4	3	4	4	1
	4	28	20	16	21	24	16	22	16	12	26	18	9
	5	11	8	9	12	5	3	11	5	2	9	5	3
	6	25	17	15	16	16	16	22	8	10	13	12	11
	Mean	16.0	10.3	8.7	13.7	8.8	7.0	13.7	6.8	5.3	11.2	7.7	4.3
100 x 5	1	3	0	1	6	1	1	1	1	0	2	0	0
	2	2	0	0	2	1	1	2	0	0	1	0	1
	3	8	2	0	1	3	0	4	1	1	2	0	0
	4	16	9	7	14	6	2	17	8	2	9	2	0
	5	11	6	2	4	2	0	1	1	2	9	1	1
	6	20	10	8	17	8	9	14	9	5	11	6	3
	Mean	10.0	4.5	3.0	7.3	3.5	2.2	6.5	3.3	1.7	5.7	1.5	.8
100 x 1	1	6	1	0	5	0	0	3	0	0	0	0	0
	2	3	1	0	2	0	0	2	0	0	0	0	0
	3	10	5	1	2	1	0	2	0	0	3	0	0
	4	23	10	4	28	13	4	14	7	3	11	11	1
	5	8	7	0	4	1	2	7	0	0	2	0	0
	6	21	14	3	18	9	4	15	7	4	9	14	3
	Mean	11.8	6.3	1.3	9.8	4.0	1.7	7.2	2.3	1.2	4.2	4.2	.7

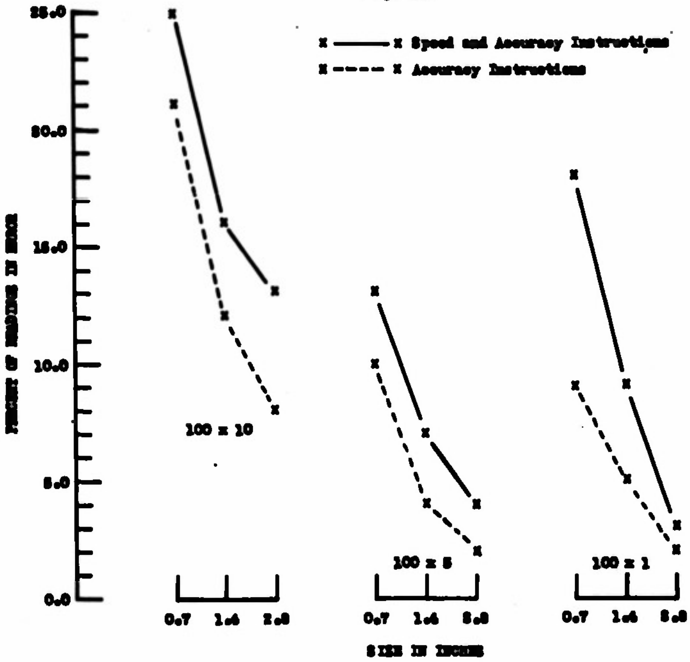

Figure 4. Percent of dial readings in error for 3 dial designs (100 x 10, 100 x 5, and 100 x 1) each in 3 sizes (0.7, 1.4, and 2.8 inches), under accuracy instructions and speed-and-accuracy instructions. Each point represents the percent of errors on 720 readings (120 by each of 6 subjects who made 60 readings on an original test and 60 readings on a retest one month later). The graph shows the effect of the subjects' attitude, the facilitating effect of size of dial, and the inferiority of the 100 x 10 dial.

(abscissa values). For each design the solid curve shows mean errors under the speed and accuracy attitude and the broken-line curve shows mean errors under the accuracy attitude.

Figure 4 clearly illustrates the effects of the three major variables in the experiment: attitude, design, and size. The accuracy attitude is superior to the speed-and-accuracy attitude and this conclusion holds for every comparison. The larger the size of dial, the better is the accuracy of reading. And the 100 x 10 dial is poorer than the other two dials for any single size comparison. There is no clear evidence, however, of a difference between the 100 x 5 and the 100 x 1 dials. The statistical analysis of the significance of the differences will follow below.

Raw Time Scores

The raw time scores suggest essentially the same conclusions as do the raw error scores. Table 2 gives the summed time scores for each subject for each dial and size under each condition and the means of these subject scores for the dial designs and sizes. For time, as for errors, the differences between subjects are extreme.

To show the effects of the experimental variables, the time data have been summarised for all subjects in Figure 5. In this figure, time per reading for the original test and retest combined is given on the ordinate and all other features are to be read as they were in Figure 4. At no point are the time data inconsistent with the conclusions reached from a

TABLE 2. Raw time scores. The entries show the total time (rounded to the nearest second) taken by each subject in making 60 readings of each dial, according to design, size, attitude and test. Mean values for all subjects are also listed.

		Speed and Accuracy						Accuracy					
		Test			Retest			Test			Retest		
		Size in Inches			Size in Inches			Size in Inches			Size in Inches		
Design	Subject	0.7	1.4	2.8	0.7	1.4	2.8	0.7	1.4	2.8	0.7	1.4	2.8
100 x 10	1	112	88	81	118	100	88	331	340	255	547	395	357
	2	103	103	102	143	131	119	147	140	143	177	251	130
	3	139	134	124	150	129	102	169	130	138	193	193	159
	4	79	68	62	90	73	66	126	119	88	118	100	99
	5	122	109	109	122	105	103	147	145	149	165	139	149
	6	117	94	86	102	83	70	141	106	100	138	113	116
	Mean	112	99	94	121	104	91	177	163	146	223	198	168
100 x 5	1	100	73	66	104	74	71	260	185	169	272	147	156
	2	95	85	97	122	93	93	123	115	130	136	96	114
	3	131	110	101	126	100	91	137	133	108	180	131	117
	4	78	67	67	91	75	70	111	126	98	110	90	82
	5	139	124	120	126	110	106	159	128	135	165	139	155
	6	127	92	86	106	86	71	134	111	105	159	111	116
	Mean	112	92	90	112	90	84	154	133	124	170	119	123
100 x 1	1	96	74	64	100	77	64	296	208	139	327	182	113
	2	100	81	77	106	93	81	122	113	105	128	97	92
	3	146	125	103	132	108	86	151	130	114	179	146	104
	4	78	65	62	88	75	69	109	107	92	118	98	86
	5	140	113	114	128	104	97	157	141	122	156	139	128
	6	114	88	89	103	77	66	140	110	100	140	125	109
	Mean	112	91	85	110	89	77	162	135	112	175	131	105

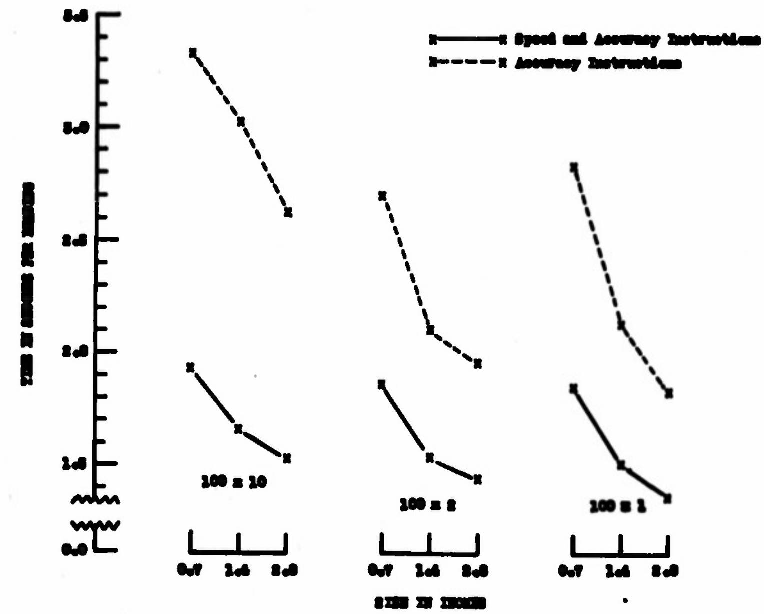

FIGURE 6. Time in seconds per dial reading for 3 dial designs (100 x 10, 100 x 2, and 100 x 1) each in 3 sizes (0.7, 1.4, and 2.8 inches), under accuracy instructions and speed-and-accuracy instructions. Each point represents the average on 720 readings (120 by each of 6 subjects who made 60 readings on an original test and 60 readings on a retest one month later). The graph shows the effect of the subjects' attitude, the facilitating effect of size, and the inferiority of the 100 x 10 dial.

consideration of the raw error scores.

In their raw form, as tabulated and plotted above, the data do not lend themselves to an analysis of variance. Such analysis requires the assumptions that the data are normally distributed and that the sub-populations are homogeneous in variance. The error data may be expected to be binomial or nearly so. For the time scores it is logical to expect that the variance of a set of scores from a very slow subject or from a condition producing general slowness would be greater than the variance of a set of scores from a fast subject or from fast conditions. Analysis of variance thus requires the transformation or conversion of both the error scores and time scores into a new and proper form.

Analysis of Variance on Transformed Error Scores

For the error data, the angular transformation* may be expected to place the data in the normal, homogeneous form required for the analysis of variance. Accordingly, the individual raw error scores from the cells of Table 1 were transformed according to the formula

$$\Phi' = (\sin^2)^{-1} \frac{x + \frac{1}{2}}{n + 1}$$

where x = error score and $n = 60$.

The results of the analysis of variance of the transformed error scores are given in Table 3 for the test and retest data separately.

*The angular transformation and its merits as applied to psychological data of the type discussed above are described in (1).

Table 3: Summary of Analysis of Variance on Transformed Error Scores

Variable	df	Test Mean Squares	Retest Mean Squares
Attitudes	1	444.50**	248.14**
Subjects	5	935.05**	854.23**
Sizes	2	1149.22**	905.53**
Designs	2	839.74**	695.71**
Attitudes x Subjects	5	15.83	22.16
Attitudes x Sizes	2	14.42	33.72*
Attitudes x Designs	2	6.36	6.85
Subjects x Sizes	10	15.99	32.46**
Subjects x Designs	10	15.66	45.13**
Sizes x Designs	4	19.42	7.83
Attitudes x Subjects x Sizes	10	4.81	8.09
Attitudes x Subjects x Designs	10	7.51	16.82
Attitudes x Sizes x Designs	4	23.15	14.82
Subjects x Sizes x Designs	20	7.14	18.03
Attitudes x Subjects x Sizes x Designs	20	10.24	8.87

Total Degrees of Freedom = 107

** 1% level of confidence
* 5% level of confidence

For both the test and the retest all the principal effects were significant; they would be expected to occur by chance alone in less than one percent of experiments. Since the effects of attitude, size, and design were statistically significant when tested against the interactions of subjects with these variables, these results may well hold for other groups of subjects. In the original test when the interactions were tested against the residual terms, none of the interactions were statistically significant. In the retest, however, three interactions were statistically significant; attitudes by sizes, subjects by sizes, and subjects by designs. This change in the results suggests that practice is a variable which will have to be investigated rather carefully in so far as inter-action effects are concerned.

As an indication of the general reliability of the testing procedure, it should be pointed out that the magnitudes of the mean squares for sizes, subjects, designs, and attitudes follow the same rank order in the test and retest.

Consideration of Time Scores

When the time scores were examined it became apparent that subject variability did not increase in a linear way with subject mean time. The relationship between subject variabilities and means was obtained for each test and attitude separately by computing the standard deviation of the times taken on the five cards for a given size-design combination and averaging these for all nine size-design combinations. This average was then taken as the best estimate of the variability of that subject for that test and attitude. Comparable mean times were computed for each subject. When the estimated variabilities were plotted against their comparable means, it was seen that variability increased approximately as the square of the mean time.

However, a similar plot was made of the relationship between the standard deviations and mean times for particular sets of five cards. Such plots were prepared for each subject, for each test, and for each attitude. For these plots no consistent relationship emerged between variability and mean time.

Since there was disagreement between the two methods of studying the relationship between variability and mean time, we have postponed further quantitative analysis of the time scores. The key to an appropriate transformation has not yet been found. More must be known about the variability of time scores before such a transformation can be chosen wisely. First, we must recognise that differences in difficulty from card to card within a set of fives have been confounded in our present measures of subject variability in reading speed. Second, we know from observation that subjects tend to pace themselves when reading a bank of twelve dials in succession. Perhaps an interruption of this pace, caused by the occurrence of several particularly difficult readings on one card, is disturbing the relation between variability and mean time. These matters need further examination. Until they are understood more completely, we may simply note again that the time data do not disagree with the conclusions on major variables, as formulated above from the analysis of error data.

Classification of Errors

In the foregoing treatment, errors of different magnitude were not distinguished. Table 4 shows the frequency of errors of one, two, and ten units and errors of miscellaneous size. In this table errors of nine or eleven units were entered both as unit errors and as ten-unit errors. The miscellaneous errors included eleven errors of five, twelve of twenty (plus or minus one), and one each of thirty and forty units. Reversal errors (e.g. reading 37 for 43) were difficult to identify and seemed so rare as to warrant no separate analysis. The table shows the distribution of the major classes of errors by dial design, dial size, and attitude, for all subjects and test-retest combined.

Inspection of Table 4 shows that errors of one and two units were reasonably similar in their distribution. There is a strong suggestion that tens and miscellaneous errors were distributed differently than errors of one and two. The table also shows the rarity of the larger errors. In a total of 12960 readings there were only 178 errors of more than one unit, and only 149 of more than two units. For the designs and sizes studied, errors greater than one or two percent of full scale were very few in number. Nevertheless, as will be shown below, even these designs could be improved to afford a marked reduction in the number of errors of ten units.

Table 4. Distribution of errors of various amounts by dial design, dial size, and attitude. Because some errors appear twice (e.g. an error of eleven appears as an error of ten units and also as an error of one unit) the grand total will not agree with that of Table 1. For each design and each size 4320 readings were taken; the corresponding figure for each attitude was 6480 and the total number of readings was 12960.

	Designs			Sizes			Attitudes		
Amount of Error	100 x 10	100 x 5	100 x 1	0.7	1.4	2.8	Speed and Accuracy	Accuracy	Total for Type
One	619	254	277	639	317	194	679	471	1150
Two	24	4	1	18	7	4	22	7	29
Ten	40	43	36	44	46	29	66	53	119
Miscellaneous	4	9	17	13	11	6	20	10	30

The Location of Specific Errors

The relative ease or difficulty of specific dial settings has been investigated for the present data and the detailed results will contribute to a later report devoted specifically to the problem of digit and sector difficulty. Here it should be remarked, however, that certain final digits and certain sectors of the dial appear to be considerably more difficult than others. For the different final digits the data do not oppose the expected principles, 1) that settings on stressed scale divisions are relatively easy, 2) that difficulty increases as one departs from a stressed division, and 3) that bisection is easier than other forms of interpolation. For the different sectors around the dial, the reasons for differences in difficulty are not obvious.

In the course of this analysis of errors for specific dial positions, an important type of error was found for the settings 52 and 53. In reading these two settings alone there were fifty six errors of ten units, nearly half of all the ten-unit errors in the whole experiment. These settings were read as numbers in the sixties in every instance of this sort. The reason became clear upon inspection of the dials. At these settings the pointer partially obscured the numeral 5 and made it resemble a partially obscured numeral 6 (an example is shown in Figure 2). Several subjects seemed to be somewhat aware that they were misreading settings in the fifties generally, but analyzed their difficulty as confusion due to the memory of the position of six on a clock face. Inspection of the numerals shown in Figure 2 will suggest that a similar type of error may be expected at pointer positions other than 52 and 53, for instance at 88 and 31. These observations suggest that numeral designs should be closely scrutinized before adoption, bearing in mind the relation to pointer design and to the position of the numeral on the dial face.

From the methodological point of view, the existence of specific difficulties indicates the importance for many experiments not only of matching settings on all dials to be tested, but even of including all, or nearly all, possible settings in certain experimental series. The problem will be particularly acute whenever the expected differences in the effects of dial variables are small and when the experiment is concerned with scales which are graduated to the same number of units. Fortunately for our analysis of variance of errors, the specific errors in reading 52 and 53 were distributed with reasonable uniformity over experimental variables, but our procedure of choosing "random" settings gave no guarantee that this fortunate result would occur.

Practice Effects

One purpose of this experiment was to study practice effects and, in particular, to find out whether the test situation was one in which allowance would have to be made for training. For this reason, readings were made by all subjects at two periods, separated in time by almost a month. When the results of the original test were compared with the results of the retest, it was found that the errors were reduced by about 20 to 25 percent for each attitude. Accompanying this shift was the appearance of several statistically significant interactions as shown in Table 3 above. Time scores showed no similar change, although time on the 100 x 10 dial was considerably slower for the retest under the accuracy attitude than for the original test under the same attitude.

In order to obtain an indication of the possible within-series practice effects, "work curves" were plotted for each subject, showing his performance on successive sets of nine stimulus cards throughout the fifty four cards of a sitting. For the time scores there was a general trend toward improvement within the test period but little, if any, change within the retest. For the error scores the indication of within-series practice effects was less clear because of variability within the series, yet the same trend probably existed for the test period. No early improvement attributable to "warm-up" effects was observed in the curves. The comments of the subjects indicated that temporary attitudinal shifts and changes in judgment criteria occurred in the course of some sittings. This may have accounted for some of the variability in the work curves and, in the future, attempts will be made to improve the control of these factors by more precise instructions to the subjects.

From this consideration of changes in performance within and between series, it is concluded that practice is a factor which must be regarded in future experiments. More retest sessions are needed to determine the improvement limits. There is a suggestion in the present data, however, that most of the improvement in reading may occur in the first session. If this is so, practice effects may be minimized by scheduling a preliminary practice or familiarization session for all subjects. This will be done in forthcoming studies.

Speed of Reading the First Dial on Each Card

In designing the experiment, it was suspected that the time of reading the first dial on a card might not be typical of the time for the other dials. Were this the case, there would be a difference between the time data obtained by William's procedure of reading a single dial at a time and data obtained by the procedure of reading a number of dials in succession. Hence, provision was made for a separate measure of the time of reading dial 1 on every card. When the average time for the first dial was compared with the average time for the other eleven dials on the cards, the suspicion was confirmed; average time for the first dial was 2.9 seconds as compared with an average of 2.0 seconds for the other eleven. However, the differences between dial designs, sizes, and conditions, which were described above for data based on all twelve dials of each card seemed to be present in the data for the first dials alone. There was only a slight, non-significant difference between errors on the first dial and errors on the remaining dials, 9% as compared with 10% of readings. Nevertheless, in view of the length of the first-dial times and our interest in getting more reliable time measures, it seemed appropriate to plan future experiments so that the first dial readings on each card will be omitted from all computations and comparisons. A somewhat similar line of reasoning, although not yet based on factual data, leads us to expect that results for the last dial on any card should also be eliminated.

Summary and Conclusions

A procedure has been developed and tested for the study of precision of dial reading. It consists of presenting twelve dials simultaneously to an individual subject, and scoring his performance in reading the dials in terms of errors and average time. Six subjects were used to test the procedure in a preliminary study of dial size, dial design, reading attitude, subject differences and practice effects. All dials were scaled from 0 to 100 over the full circumference. Sizes were 2.8, 1.4, and 0.7 inches scale diameter. Graduation was by tens, fives, and units. The following conclusions are drawn for the data of the experiment:

1. The analysis of all errors showed that error frequency was lower for the larger and the more finely graduated dials, and for reading instructions that emphasized accuracy (see Table 1, p. 24). Speed of reading was faster for the larger and more finely graduated dials and slower for reading instructions that emphasized accuracy (see Table 2, p. 27). The differences between the two larger dials were not great and the differences between the dials graduated by fives and by units were not only small but they were also inconsistent. There are indications that some of the variables studied in the experiment may interact with one another.

2. Until more satisfactory measures are available for subject variability in speed of reading, time scores are more difficult to analyze than error scores. In so far as it is possible to analyze

the time scores by crude methods, the time scores support the conclusions reached from the analysis of error data.

3. For the dials and subjects used, there were very few errors greater than one unit, that is, greater than one percent of the full scale (see Table 4, p. 34). The percent of total readings in error was 10.1. The percent of total readings in error by more than one unit was 1.3.

4. Numeral design may be responsible for large dial reading errors since partially concealed numbers may be confused with others. Army-Navy Aeronautical Design Standard for numerals, AND 10400, permits ready confusion of the numeral 5 with the numeral 6 for our pointers as used on our dials which place the numeral five at the bottom of the dial.

5. Until more is known about them, practice effects must be recognised as variables of importance. In this experiment they resulted in a drop of twenty to twenty five percent in error scores from test to retest and a change in the importance of some of the interactions.

The following conclusions are drawn for the experimental procedure:

1. Subject differences and subject interactions (see Table 3, p. 30)

appear to demand an analysis of the data subject by subject rather than an analysis of group averages.

2. A test procedure which requires single dial readings appears to result in longer reading times per dial than when readings are made in sequence. When a bank of dials is read, it is probably best to omit the first dial read from the analysis.

3. Selecting different random sets of numbers for the settings to be used on different comparison dials is poor practice. This conclusion follows from the existence of marked differences in the reading difficulty of particular dial settings. Since the origin of all such specific difficulties cannot be determined in advance, allowance must be made for them in planning experiments. Hence, where dial variables may be expected to produce relatively small differences in performance, the only safe procedure is to match settings for all comparisons or, if this be impossible because of the differences in the total scale values of the dials to be compared, to use all or nearly all possible settings.

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