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DESIGN OF INSTRUMENT DIALS FOR MAXIMUM LEGIBILITY - PART V. ORIGIN LOCATION, SCALE BREAK, NUMBER LOCATION, AND CONTRAST DIRECTION - AND APPENDIX

KAPPAUF, WILLIAM E. MAY '51 30PP TABLES, DIAGRS, GRAPHS

WADC, RESEARCH DIV., WRIGHT-PATTERSON AIR FORCE BASE, DAYTON, O., USAF CONTR. NO. W33-038-AC-14480 (AF TECHNICAL REPORT NO. 6366)

INSTRUMENTS - READING ERRORS	PSYCHOLOGY (63)
INSTRUMENT DIALS - LEGIBILITY	EXPERIMENTAL PSYCHOLOGY (3)

UNCLASSIFIED

AF TECHNICAL REPORT No. 6366 May 1951

DESIGN OF INSTRUMENT DIALS FOR MAXIMUM LEGIBILITY

Part V. Origin Location, Scale Break, Number Location, and Contrast Direction

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Air Force-WPAFB-(A)-O-5 OCT 51

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AF Technical Report No. 6366 May 1951

DESIGN OF INSTRUMENT DIALS FOR MAXIMUM LEGIBILITY

Part V. Origin Location, Scale Break, Number Location, and Contrast Direction

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Contract No. W33-038 ac-14480
E. O. No. 694-15

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Wright Air Development Center
Wright-Patterson Air Force Base, Dayton, Ohio

FOREWORD

This report was prepared at Princeton University under USAF Contract No. W33-038 ac-14480 covering work on legibility problems in instrument design. The contract was initiated under the research and development project identified by Expenditure Order No. 694-15, and was administered by the Psychology Branch of the Aero Medical Laboratory, Engineering Division, Air Materiel Command, with Dr. Walter F. Grether acting as Project Engineer.

ABSTRACT

This report deals with an investigation of the effects which origin location, scale break, number location, and contrast direction have upon the speed and accuracy of dial reading. Specific errors which are examined and discussed include reversal errors and errors of plus one numbered scale division. The data are based on a total of 10,400 readings contributed by 46 subjects tested in a group testing situation.

Within the limits of design variation studied, the results indicate that the best design for a simple dial which is to be numbered every 10 units and read quantitatively at any and all scale values, is one which has a scale break at zero, locates the zero near the bottom of the dial, and locates the numbers outside the scale. At daytime illumination levels like those used in the present experiment, it makes no difference whether the dial is of black-on-white or white-on-black design.

Both the error of plus one numbered division (plus 10 units in the present case) and the reversal error are found to be associated with the reading habit of consulting the scale number which is nearest the pointer. The plus 10 units error is most common in the numerical scale region 0 to 9 no matter where that region appears on the dial. The reversal error is more common in the lower half of clockwise dials where the scale proceeds from right to left than in the upper half where the scale proceeds from left to right.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

Robert H. Blount
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Colonel, USAF (MC)
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I. INTRODUCTION

This experiment was planned with several objectives in mind:

(1) to learn more about the origin of the ≠ 10 units error on scales which are numbered every 10 units. This error has been described by Kappauf and Smith (1950a) as occurring with especially high frequency in the scale region between 0 to 9. Factors suggested in the foregoing paper as possibly related to the occurrence of this error included location of the scale origin and presence or absence of a scale break at the origin or zero mark. Accordingly it was planned to study these variables.

(2) to inquire into the dependence of reversal errors on dial design. In particular, a good opportunity to examine the influence which scale direction might have on these errors was promised once the variable of scale origin location had been manipulated in order to satisfy objective (1).

(3) to determine whether there is a significant difference in gross error frequency or in reading time between dials where the numbers are arranged inside the scale circumference and dials where they are arranged outside the scale. Instruments which have dials with numbers inside permit the use of a more expanded scale within a given area of panel space. For the most part, therefore, they can be read with greater interpolation accuracy, having a longer arc per scale unit or, in the terminology of Garner and Gebhard (1949), a greater size of "called interval" (see data of Grether and Williams, 1947 or 1949; Kappauf and Smith, 1950b). Should it turn out, however, that gross errors are more frequent on dials with numbers inside, even when number reading confusions are minimized through the use of slender pointers, the additional gross errors would probably outweigh in significance the interpolation advantage of these dials. This would point to the adoption of the numbers outside design wherever practical.

(4) to determine whether there is a significant difference in the frequency of gross errors or in reading time between black on white instrument dials and white on black dials. Chalmers, Goldstein and Kappauf (1950) have inferred, from indirect evidence, that contrast direction should have little effect on dial reading, but it remained a part of the laboratory's program to obtain direct data on this variable as soon as convenient in some other experiment.

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*Among those who assisted in the conduct of this experiment and in the processing of data were M. Boekhoff, R. M. Brown, E. L. Chalmers, M. Goldstein, C. Payne, H. R. Van Saun.

The present investigation was thus concerned with the study of two specific kinds of errors and with the evaluation of a series of dial design variables: scale origin location, scale break, number location and contrast direction. For convenience in assessing these variables, the scales chosen for study were alike in scale range, graduation and numbering. All were graduated and numbered by tens from 0 to 50. The known low frequency of gross errors on scales of this sort suggested the need for a large number of reading trials and, in fact, for some form of group testing situation. The study, as reported below, involved the testing of 46 subjects who made a total of 40,400 readings. More data would have been desirable for some of the breakdowns, but work had to be terminated when it became necessary to relinquish the laboratory space being used for the study.

When referred to in other reports of this series, the present investigation will be called Experiment 6.

II. APPARATUS AND GENERAL PROCEDURE.

Equipment was developed which permitted the simultaneous testing of as many as 20 subjects. Subjects sat in a short three-row section of bleacher seats at distances of 8, 10 and 12 feet from an extended black screen at the center of which the test dials were exposed. The dials were presented in sets of 12 on large plywood panels, four by four and one-half feet in size. Four such panels had been constructed. Each was suspended from rollers on an overhead track so that it could be manouvered quickly into display position. A panel, having been brought to this position, was exposed to the subjects by the lowering of a black cloth curtain. When all subjects had completed their readings, the curtain was drawn, the panel slid aside and a new panel moved into place. The dial pointers on the withdrawn panel were then reset in anticipation of the reuse of that panel several trials later. Panel orders were varied, as well as dial arrangements within panels. Panel illumination was not specifically controlled, but was always at a "daytime level" as provided by a combination of general daylight room illumination and the light of two floodlighting tungsten lamps. Minor variations in illumination at this level are known not to affect reading times or the incidence of gross errors (see Chalmers, Goldstein and Kappauf, 1950).

Eight of the 16 dial types which were studied in this experiment are shown in Figure 1. The remaining eight were like these except that the display presentation was white on black rather than black on white. Dials with numbers located inside the scale had a scale diameter of 10 inches; those with numbers outside had a scale diameter of six inches. All numerals and scale marks were such that at the 10 foot viewing distance they conformed in visual angle size to the dimensions recommended for major markings on instrument displays by the U.S. Army-Navy-NRC Vision Committee (1947).

Three dials of each of the 16 types were used. The four test panels were assembled so that one white panel contained the 12 black on white dials with numbers inside the scale, a second white panel contained the 12 black on white dials with numbers outside, while the third and fourth were corresponding black panels with the white on black dials.

A basic schedule of readings was set up so that each dial type would be read in each of the 51 possible different pointer positions, from 0 to 50 inclusive, in the course of 17 presentations of every panel. Such a round of 17 presentations of each test panel in use with a particular subject group is here called a "test run". If

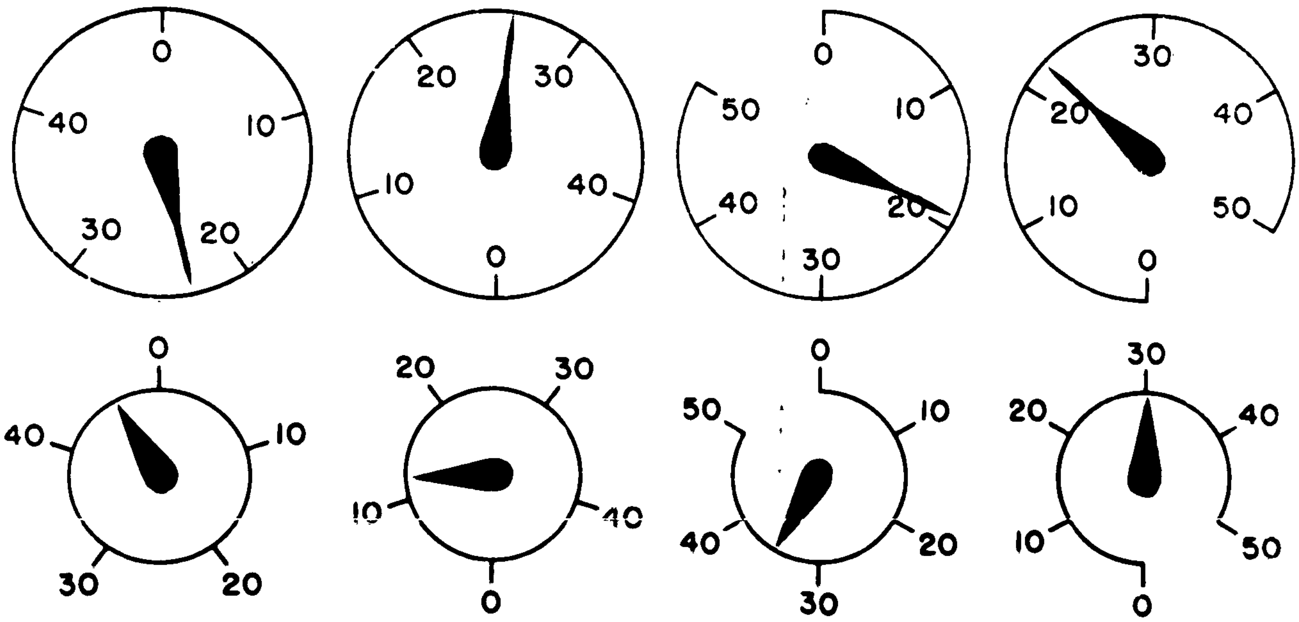

Figure 1. Dials which were used in the experiment.

but two test panels were in use with a group of subjects, a test run could be completed in a single experimental session. When all four test panels were in use, a test run required two experimental sessions, the first with eight presentations of each panel and the second with nine.

Panel orders, dial arrangements within panels, and pointer setting sequences were planned in advance of testing. Panel orders were varied systematically during each test run so that practice effects would not influence panels differentially. The dial arrangement within each panel was always such that no given type of dial appeared more than once in any of the three rows or any of the four columns of dials on the panel. Further, the arrangement on every panel was mirrored from right to left twice during the course of every test run. Pointer setting sequences for each dial type were determined from random number tables. Settings for various companion dials were balanced by requiring that the group of settings used in the first half of the test run with one dial, be used in the last half of the test run with the other, and visa versa. All pointer settings were made manually by assistants who worked from prearranged lists of settings and made use of a series of light pencil marks (not visible to the subjects) which identified every unit scale position on all the dials.

Each subject recorded his readings on a writing tablet strapped to his leg just above the knee. One page of this tablet, four inches wide and 14 inches long, was used to record data for a single panel presentation. Notches along the left edge of the tablet provided a guide which the subjects used initially to space successive readings down the page. After a few practice trials, most men were able to write their readings quickly without looking at the pad and without superimposing entries. Between trials, each subject prepared a new record sheet. At a ready signal he looked up, and at the lowering of the curtain he read the dials, left to right and row by row. At the completion of the twelfth reading, he read a digital timer located just to the right of the last dial. He entered this finishing time in seconds at the foot of his record sheet. Starting time for the panel was recorded by the experimenter, and reading time was calculated subject by subject at the conclusion of the experiment.

Subjects were instructed to read all dials as rapidly as possible and to make each reading to the nearest unit. Accuracy of reading, as such, was not mentioned in the instructions, but emphasis was placed on "reading to the nearest unit". These instructions were identical with those used in recent studies of this series (Kappauf and Smith, 1950a, 1950b). They were repeated before each test session.

Twelve panels were presented for practice at the beginning of the first experimental session with each group of subjects. Eight practice panels were presented prior to test readings on subsequent test days. The typical session of 40 to 50 panels required an overall time of about one and one-quarter hours.

III. SUBJECT GROUPS AND THE SPECIFIC PROCEDURE WITH EACH.

Three groups of subjects served in the experiment.

Group I consisted of 17 college students. The group came to the laboratory on two successive days and completed one test run using all four test panels. No member of the group had binocular visual acuity at distance of less than 20/29 as measured with the Ortho-Rater.

Group II included both college students and graduate students, and numbered 12 men. The intended testing program was the same as for Group I, but through a scheduling error at one point the pointer settings used did not correspond exactly to the uniform series of 51 different settings for each dial type. Again for this group, no member had binocular visual acuity poorer than 20/29.

Group III consisted of 17 high school students from grades 9 to 12. This group read the white on black panels only. The entire group completed two test runs on these panels, one on each of two successive days. Nine members of the group returned for a third test run. Dial arrangements and pointer setting sequences were varied from run to run. No student had acuity poorer than 20/33.

IV. HANDLING OF THE DATA

Data Transcription

Errors and reading times were transcribed on summary sheets by a procedure which involved bringing together all subjects' record sheets for a given panel of dials. A spot check based on a re-tally of about 12% of the data demonstrated the tallying procedures to be of high accuracy. Ambiguity of subject responses due to overlap of entries on the record sheets was negligible. Handwriting interpretation was occasionally difficult for some subjects, but the re-tally picked up only three readings which were then considered correct after having been scored originally as gross errors.

Error Classification

The observed reading errors were tallied in the following categories:

(1) Total gross errors: This category included all errors of four or more units. There were 536 such errors, constituting 1.33% of the readings recorded in the experiment.

(2) Errors of +10 units: This category, a portion of category (1), included all errors of +9, +10 or +11 units. The same tolerance for scoring this error was used by Kappauf and Smith (1950a). Errors of this type totaled 236.

(3) Reversal errors about the scale zero: These errors occur on dials without a scale break and involve reading the scale in the wrong direction from zero when the pointer is in the last scale interval. Thus the scale region bounded by the numbers 0 to 40 is interpreted as a region from 0 to 10. There were 82 gross errors of this type.

(4) Reversal errors within the scale: This category included all positive and negative reversal errors about the numbered scale marks at 10, 20, 30 and 40. All errors two units and larger which were within one unit of being an "exact reversal" were scored in this category. There were 118 of these errors, 84 of which were gross errors and 34 of which were errors of two or three units. This count does not include 30 errors which have been tallied as +10 units errors but which might also have been interpreted as reversal errors (e.g. reading 15 as 25). These 30 errors were clearly of ambiguous origin, but the occurrence of about twice as many +10 units errors as reversal errors in this experiment indicated that classification errors would be minimized by keeping these in category (2). Figure 5 below suggests that this "probability" method of classifying the errors was satisfactory.

(5) Remaining gross errors: The 134 gross errors which remained unclassified in categories (2), (3) or (4). Of these, 61 were errors of -10 units ±1, not including 13 errors of -10 which were put in category (4) as reversal errors. It was assumed, as above, that classification errors would be minimized by keeping these 13 in the category of the more frequently made error, in this case in the reversal error category.

It will be noted that the use of a tolerance in scoring 10 units errors and reversal errors is necessary in order to allow for simultaneously made errors of visual interpolation or for the possible operation of number preferences.

Basis of Error Comparisons

In order to simplify certain aspects of the treatment of the error data, the present analysis is based upon 50 (not 51) readings per dial type per test run. These are the readings made for pointer positions 0 to 49.

Because of the similarity in composition of Groups I and II, the error data for these two groups have been combined in conducting the statistical analyses of the effects of the various dial design variables. Comparisons are made between the performance of this combined group and that of Group III.

Error Transformation

Prior to the application of significance tests, the error data were subjected to the angular transformation (see Snedecor, 1940; Kappauf, 1947). If not achieving perfect homogeneity for data of the present sort, this transformation at least puts the data in the most acceptable form known for their analysis. The transformation applied was of the form

$$\theta = \sin^{-1}\left(\frac{x + 0.5}{N + 1}\right)^{\frac{1}{2}}$$

where x is the number of errors observed in N readings. The transformed values given in the various analysis tables in the Appendix represent θ in radians $x10^3$.

V. RESULTS: THE EFFECT OF DIAL DESIGN VARIABLES ON READING ERRORS.

A general summary of the recorded errors is presented in Table I. Seeming gaps in this table reflect (1) the fact that Group III did not read the black on white panels and (2) the fact that reversals at zero could not occur on dials with a scale break.

TABLE I: GENERAL SUMMARY OF OBSERVED ERRORS

			Dials with Zero at Top, No Scale Break			Dials with Zero at Bottom, No Scale Break			Dials with Zero at Top, Scale Break			Dials with Zero at Bottom, Scale Break		
	Subj. Group		I	II	III	I	II	III	I	II	III	I	II	III
	No. Subjects		17	12	17	17	12	17	17	12	17	17	12	17
	No. Readings/ dial type		[illegible]	600	2150	[illegible]	[illegible]	2150	[illegible]	[illegible]	2150	[illegible]	[illegible]	2150
TOTAL GROSS ERRORS	Wh. on Black	In	9	[illegible]	[illegible]	5	3	[illegible]	12	7	[illegible]	[illegible]	[illegible]	27
		Out	4	5	[illegible]	7	17	[illegible]	0	1	21	3	4	21
	Bl. on White	In	10	4		14	6		12	3		[illegible]	1	
		Out	12	5		5	14		11	5		8	2	
/10 UNITS ERRORS	Wh. on Black	In	4	4	28	0	2	31	4	6	22	1	1	14
		Out	2	2	16	2	7	19	4	1	13	2	[illegible]	[illegible]
	Bl. on White	In	3	1		5	2		0	2		2	1	
		Out	7	2		3	6		2	2		1	0	
REVERSAL ERRORS AT ZERO	Wh. on Black	In	1	3	8	1	5	13						
		Out	1	[illegible]	8	3	3	13						
	Bl. on White	In	2	2		4	2							
		Out	1	0		1	7							
REVERSAL ERRORS WITHIN SCALE	Wh. on Black	In	6	0	8	2	0	5	2	0	7	4	1	5
		Out	2	1	6	0	5	11	1	1	[illegible]	3	2	4
	Bl. on White	In	4	2		2	1		4	3		1	0	
		Out	0	1		2	1		6	2		3	1	
REMAINING GROSS ERRORS	Wh. on Black	In	1	2	6	3	1	10	6	1	10	3	0	10
		Out	0	0	6	2	4	16	1	0	7	3	0	[illegible]
	Bl. on White	In	4	1		3	2		3	0		5	0	
		Out	4	2		1	0		2	1		5	1	
	Contrast Direct.	No. Loc.												

Note: Values in this table are observed error frequencies.

Contrast Direction

Error data for the effect of contrast direction, obtained with Groups I and II, have been extracted from Table I and are separately summarized in Table II. The two subject groups together made a total of 11,600 readings on the eight different white on black dials, and the same number with corresponding pointer settings on the eight different black on white dials.

The data in Table II provide no evidence of a real difference between the white on black and black on white displays. Hence, data for dials of both contrast directions have been lumped together in the remainder of this report. Such treatment permits no examination of interactions between contrast direction effects and the effects of other variables, but the likelihood of such interactions being significant appears small.

The Remaining Design Variables

Study of the effects of the remaining experimental variables on reading errors was carried out by analysis of variance methods. For this purpose it was convenient to consider different classes of errors separately in view of the possibility of relating particular errors to specific dial design features. A summary of the successive steps in this analysis and a statement of the results is given in Table III. Details of the analysis are presented in the Appendix where Tables A,B,C and D deal respectively with ≠10 units errors, reversal errors at zero, reversal errors within scale, and remaining gross errors.

Best Design Combination

On the basis of the results given in Tables II and III, it is concluded that the most satisfactory design for a dial which is to carry a short scale with numbers every 10 units, is one which

(1) has a scale break <u>and</u> has the scale zero near the bottom, and

(2) has numbers outside if it is to be read by high school level personnel (although the numbers might be placed either inside or outside if the dial is to be read exclusively by college level personnel).

This design eliminates the possibility of reversal errors at zero, and reduces the occurrence of the two most common errors on the simple decimal scale - the ≠10's error and the reversal error within scale. The number of remaining unclassified gross errors is not influenced by these design choices. Contrast direction is unimportant and need not be specified unless other tasks carried out by the dial reader dictate a preference.

Best Design for No-Break Dials

Certain long-scale instruments are designed as multiple-revolution indicators. Undesirable as some forms of these indicators are, others appear to be quite acceptable (Grether,1947). The scales on such instruments are no-break scales because their pointers or indicators are currently engineered to move continuously. Assuming that readings of these multi-revolution indicators involve the same kinds of errors as were recorded for the present no-break scales, one would recommend that the scale zero on

TABLE II

ERROR FREQUENCIES FOR WHITE ON BLACK DIALS AND BLACK ON WHITE DIALS

Data for Groups I and II

		Dials without Scale Break	Dials with Scale Break	All Dials and Groups
	Subj. Group	I ≠ II	I ≠ II	
	No. Subjects	29	29	
	No. Readings/ dial type	5800	5800	11,600
TOTAL GROSS ERRORS	White on Black	64	48	112
	Black on White	70	50	120
≠ 10 UNITS ERRORS	White on Black	23	21	44
	Black on White	27	19	46
REVERSAL ERRORS AT ZERO	White on Black	19		19
	Black on White	19		19
REVERSAL ERRORS WITHIN SCALE	White on Black	16	14	30
	Black on White	13	20	33
REMAINING GROSS ERRORS	White on Black	12	14	26
	Black on White	17	17	34

such indicators be located at the top and that the scale numbers be located outside if high school level personnel are included among the readers (see left half of Part 3, Table A). This design reduces the incidence of reversal errors at zero, as compared with the zero bottom design, and reduces the likelihood of ≠10 units errors by high school readers.

VI. RESULTS: THE EFFECT OF DIAL DESIGN VARIABLES ON READING TIMES

The assignment of dials to test panels according to contrast direction and number location made it possible to determine the effect of these two variables on reading time. Table IV summarizes the reading time data. The breakdown is by subject groups, test day, and experimental variable. Values in the table are average reading times per dial in seconds. The entries for total readings are based on 51 readings per test run per dial type per subject.

Contrast Direction

The averages for Group I ≠II indicate a reading time of 1.39 seconds for white on black dials and of 1.38 seconds for black on white dials. This difference is not

Table III

OUTLINE OF ANALYSIS AND RESULTS
FOR REMAINING DESIGN VARIABLES.

A. ANALYSIS OF ≠10 UNITS ERRORS FOR ALL DIALS: This analysis applies to the first objective of the experiment and is also the most fitting starting point in looking at the dial design question, because this was the most commonly observed gross error.

Significant effects on ≠10 units error found for:

Groups (1% level) -- Groups I and II made fewer errors than Group III.

Group X Number Location Interaction (5% level) -- Groups I and II were not critically influenced by number location, but Group III made significantly fewer errors when the numbers were outside.

Zero Location X Scale Break Interaction (5% level) -- The combination of zero at the bottom and scale break led to significantly fewer errors than the other three combinations.

B. COMPLETION OF ANALYSIS FOR BREAK DIALS ONLY IN TERMS OF OTHER KINDS OF GROSS ERRORS: Consideration of break dials alone is appropriate now because the ≠10 units error data and the occurrence of reversals at zero on no-break dials both point to the use of break dials wherever possible.

Significant effect on reversals within scale found for:

Zero Location (5% level) - Zero at the bottom led to fewer errors.

Significant effect on remaining gross errors found for:

Groups (5% level) - Groups I and II made fewer errors than Group III.

C. COMPLETION OF ANALYSIS FOR NO-BREAK DIALS: This analysis is pertinent to the design of certain multi-revolution instruments which require no-break scales.

Significant effects on reversals at zero found for:

Groups (5% level) -- Groups I and II made fewer errors than Group III.

Zero Location (1% level) -- Zero top led to fewer errors than Zero Bottom.

No significant effects found in analysis of reversal errors within scale, or, remaining gross errors.

significant, so it is concluded that contrast direction does not affect dial reading speed at daylight illumination levels. This agrees with what Chalmers, Goldstein and Kappauf (1950) had inferred from measurements of reading times for visual acuity chart figures. The present dial reading data and the acuity chart data thus indicate that the conclusion of one wartime report to the effect that white on black dials require 25% longer reading times than black on white when both are viewed at daylight levels (GB. Medical Research Council, 1941) is either generally incorrect or does not apply to the particular case of displays marked with number and letters approximating the U.S. Army-Navy aeronautical design standard AND10400 (1944).

TABLE IV

AVERAGE READING TIMES PER DIAL IN SECONDS

DAILY AVERAGES

		Group I		Group II		Group III		
		Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 3
No. Subjects		17	17	12	12	17	17	9
Total read/panel		1632	1836	1152	1296	3468	3468	1836
White on Black	Nos. In	1.31	1.22	1.59	1.41	1.86	1.63	1.43
	Nos. Out	1.40	1.26	1.67	1.45	1.87	1.55	1.47
Black on White	Nos. In	1.33	1.19	1.61	1.40			
	Nos. Out	1.32	1.24	1.68	1.46			

AVERAGES FOR GROUP I + II

	Nos. In	Nos. Out	Averages by Contrast Direction
White on Black	1.36	1.42	1.39
Black on White	1.36	1.40	1.38
Averages by Number Location	1.36	1.41	
GRAND AVERAGES FOR ALL GROUPS, Days 1 and 2	1.48	1.52	

Number Location

The grand average for all subjects over days 1 and 2 indicates an average difference of 0.04 seconds per dial in favor of shorter reading times for dials with numbers inside the scale. Although this difference is a statistically reliable one, with day by day results showing significantly more than half the subjects reading faster on the numbers inside arrangement, the difference is probably of little practical significance.

VII. RESULTS: ORIGIN OF THE +10 UNITS ERROR.

Figure 2 shows the manner in which the observed +10 units errors were distributed around each of the several dial types used in the experiment. The data presented are for Groups I and III and represent the errors made in 154 readings at each scale position on each of the diagrams. Group II data have been omitted here so that the figure would describe results based on exactly balanced readings around every dial, the readings by Group II having been somewhat irregular (see section III above). Actually, the inclusion of the Group II errors would have altered in no way the conclusions drawn from the figure.

Two summary tallies are derived from the plot of the individual errors in Figure 2. One is a summary of the number of errors made in each scale region of the several dials. This is indicated by the encircled numbers located around the outside of the dial diagrams in Figure 2 itself. The second is a summary distribution of errors by pointer position within any interval between scale numbers. This is given in Figure 3.

Two facts were reported by Kappauf and Smith (1950a) as characterizing the +10 units error made on scales numbered every 10 units:

(1) On dials with zero at the top and having no scale break, it occurs most frequently in the scale region 0 to 9.

(2) It is commonly associated with the latter half of the numbered interval, i.e. with pointer positions where the units digit to be read is 6, 7, 8 or 9.

These facts are confirmed in Figures 2 and 3 and are extended as follows:

(3) Distribution of the error around the dial is not influenced by number location, inside or outside the dial (see coded error symbols in Figure 2).

(4) The error is characteristic of the 0 to 9 region of the scale whether the zero is at the top or bottom of the dial, whether the scale has a break at the origin or not, and whether the subject calls out his readings (as in Experiments 3 and 4 of this series) or writes them down (as in the present experiment).

(5) Occurrence of the error in the last numerical region of the scale is observed only on break dials where the final scale number actually appears.

To these statements may be added the result of a breakdown not previously cited which shows that

(6) The error is not due to the perseverating use of the tens digit given on the just preceding reading, and hence is not a function of the sequential reading procedure used in the present experiment.

Taken together, these statements provide the basis for the following description of the +10 units error: Over the portion of the scale beyond 10, the +10's error is the result of reader habits (a) to consult the scale number nearest to the pointer and (b) to add to the consulted number the value of the scale portion which the pointer has swept off between numbers. These procedures result in correct readings when the pointer is in the lower half of a numbered interval, but produce the +10 units error when the pointer is in the upper half of the interval and the number consulted is beyond the pointer. This means that the error may be regarded as equivalent to that

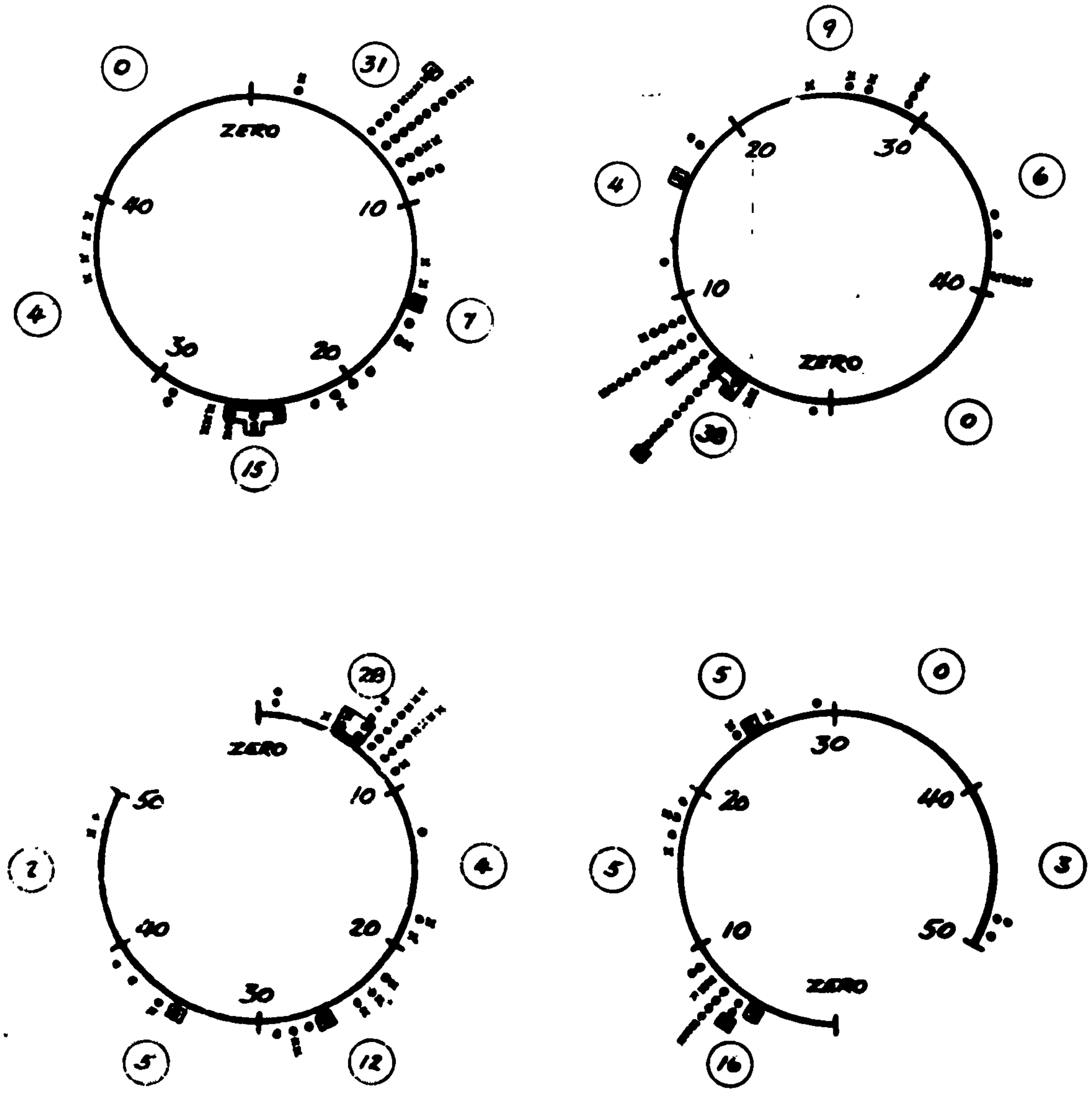

Figure 2. Distribution of ±10 units errors on dials varying with respect to zero location and scale break. Data for groups I and III.

o - errors on dials with numbers inside
x - errors on dials with numbers outside
enclosed symbols - errors which might also have been treated as reversal errors

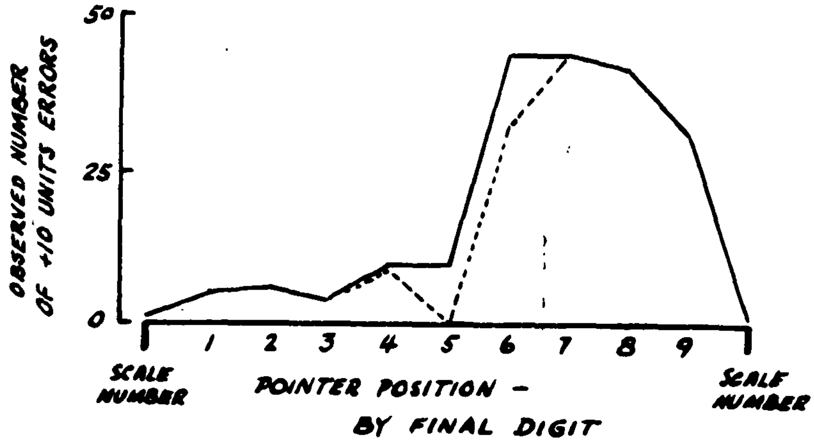

Figure 3. Distribution of +10 units errors within the interval between scale numbers. Data for Groups I and III.

made in reading combined coarse and fine scale indicators, where the coarse indication is taken too large by one cycle or division and not corrected downward when the fine indication is read (see Bray, 1948; Grether 1947; Kappauf, 1949). Over the portion of the scale from 0 to 9 the error quite probably has the same general basis just described but unless it were helped along by some other factor, it would certainly not occur with a frequency which is some six times greater in this region than in other regions of the scale. Several possible helping factors have been eliminated in (4) and (6) above, so it now seems that the responsible factor must reside in the reader in the form of a habit or tendency to include the same number of digits in all his readings. There is an "honest" tens digit in any reading beyond 10, but for indicated readings below 10, the tens digit is properly 0. The hypothesized tendency to "round out" readings to the same number of digits would well account for the reader's added willingness to pick up the tens digit "1" from the consulted number 10 and use it in his reported reading.

In sum, then, the +10's error is conceived of as an error which the subject makes because of an "adding on" habit. He consults a number and he "adds on" the value of the scale portion which the pointer has marked off between numbers. He is more likely to add on to 10 because this makes his reading a two-digit value comparable to most of the other readings being taken. Although the error under discussion here is specifically one of +10 units on scales which are of the simplest possible form, it is of general interest in that it represents a class of errors which could occur on any scale -- an error of one numbered division. For this reason, the results of the analysis of variance of the +10's errors by dial types may provide suggestions for ways of generally reducing the incidence of errors of plus one numbered division on all scales. The design recommendations based on the present data would be to:

(1) Use dials with the origin of the scale near the bottom and with a scale break. So far, no rationale for the advantage of this particular design has been presented, but one is suggested by a somewhat different look at the data. The paired diagrams in Figure 2 permit a comparison of the likelihood that +10's errors will involve a given numbered mark when that mark is in opposite dial positions. When an analysis of these paired error numbers is made, in a manner which will be outlined in more detail in the following section on reversal errors, and if one deals only with the

errors made in the various scale sections beyond 10, it is found that significantly more +10's errors are made when the presumably consulted number is in the lower half of the dial than when it is in the upper half (5% level, by "t" test on transformed errors). The unsatisfactory aspect of this test, of course, is that it has been somewhat "rigged" by the exclusion of the error comparisons for the 0 to 9 scale regions. If these are included in the analysis, the top-half bottom-half difference is no longer statistically significant. None the less, the suggestion seems worth making that errors of plus one numbered division may be less frequent in the top dial half than in the bottom dial half. Were this true, it would permit the general prediction that the dial to use for minimizing the incidence of these errors would be one with a break in the lower half.

(2) Use dials with numbers outside if they are to be read by high school level personnel. Perhaps this arrangement is successful in reducing the errors made by less skilled readers because it forces them into a more deliberate and proper use of the number scale.

(3) Avoid, whenever possible, the use of scales which cover a numerical range within which there is a change in the number of digits required in different readings. Such a change seems to be the basis for the high incidence of +10's errors in the 0 to 9 region on the present scales, and could result in similar errors of +100 in the 0 to 99 region of scales numbered by 100 unit steps.

VIII. RESULTS: ORIGIN OF REVERSAL ERRORS

A plot of the location of observed reversal errors around the several dials is presented in Figure 4. This plot parallels Figure 2 exactly, and leads again to the development of two summary distributions: one for errors by dial region, the other for errors as a function of pointer position relative to the numbered graduation mark through which the scale was reversed.

Figure 5 shows the latter distribution. Reversals within scale (solid line) and reversals at zero (dashed line) are plotted separately. The dotted increment to the distribution for reversals within scale identifies the group of ambiguous errors in the region of 4, 5, and 6 which have been handled as +10 units errors. The fact that this block of errors would have made the distribution of reversals within scale more irregular and less like the distribution of reversals at zero lends support to the decision to work with them as +10 units errors. Inspection of Figure 5 indicates that in some 50% of the cases where the direction of a scale was reversed, it was reversed through the numbered mark nearest to the pointer. Inasmuch as it is difficult to understand how a reader would confuse scale direction if he consulted the numbers on both sides of the pointer, reversal errors must be symptomatic of the use of but one of the adjacent scale numbers. The present data therefore reveal, as did Figure 3, the tendency of readers to consult just the nearer of the two numbers which bracket the pointer.

But another aspect of the solid-line curve for reversals within scale in Figure 5 deserves comment. Note that there are many more reversals which result in readings larger than the indicated value (positive reversals, shown in the left two-thirds of the distribution) than there are reversals which lead to readings smaller than the indicated value (negative reversals, shown at the right in the distribution). In Figure 4 these two classes of reversals are distinguished as tallies outside and inside the circle of each of the dial diagrams. The count of positive to negative reversals is 76 to 21. This indicates that the more common reversal error involves an "adding on" operation; that the reader consults the nearest scale number and then adds to this the value of the perceived pointer deviation. Subtracting into a reversal error is less common (perhaps even less common than here indicated, for among the 21 negative reversals in the tally, 13 were errors of -10 units about which an arbitrary class-

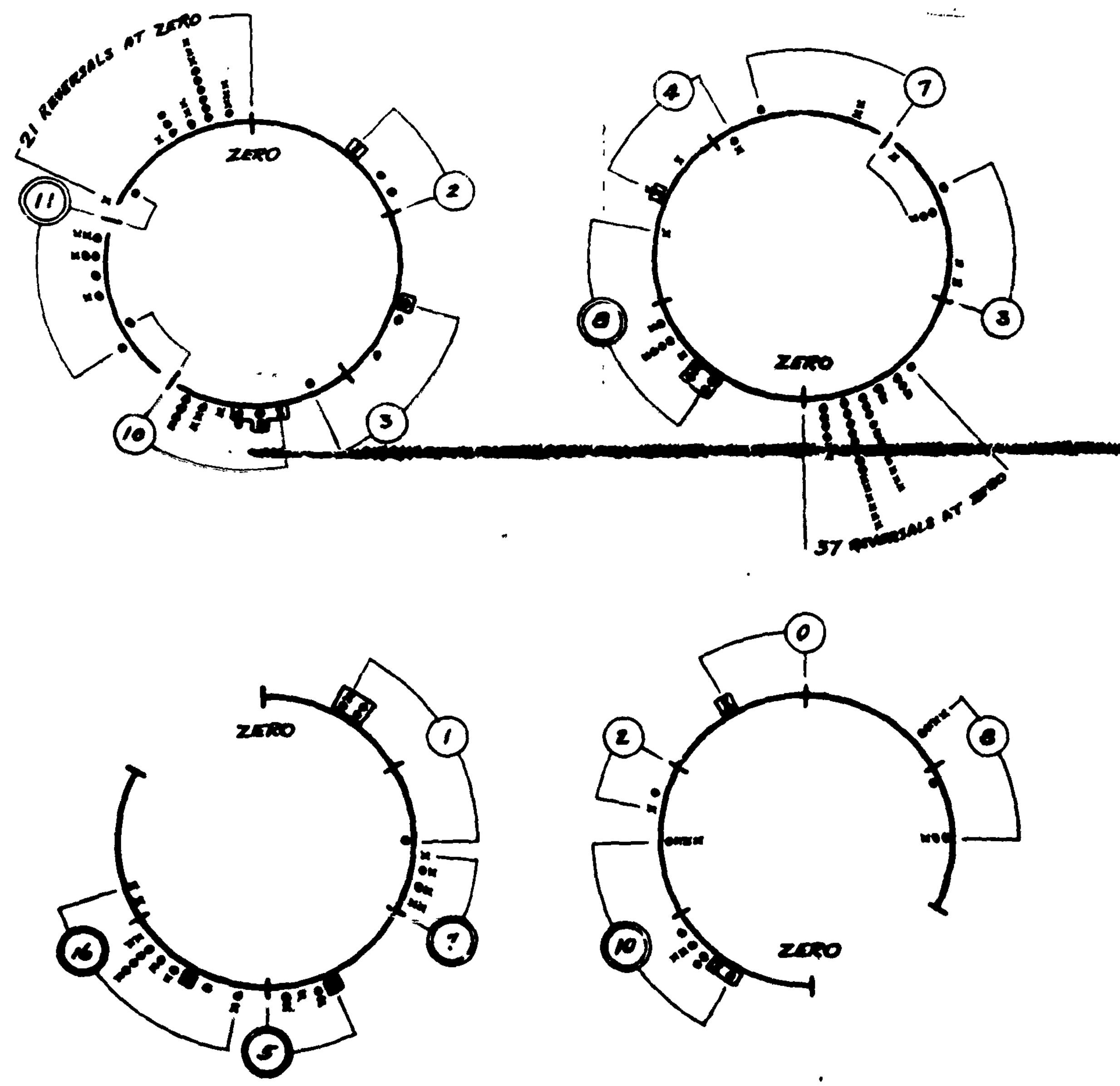

Figure 4. Distribution of reversal errors on dials varying with respect to zero location and scale break. Data for Groups I and III.

o - errors on dials with numbers insides
x - errors on dials with numbers outside
enclosed symbols - errors scored as /10 unit errors
Contained error frequency at least twice as large as frequency for correspondingly numbered mark on companion dial.

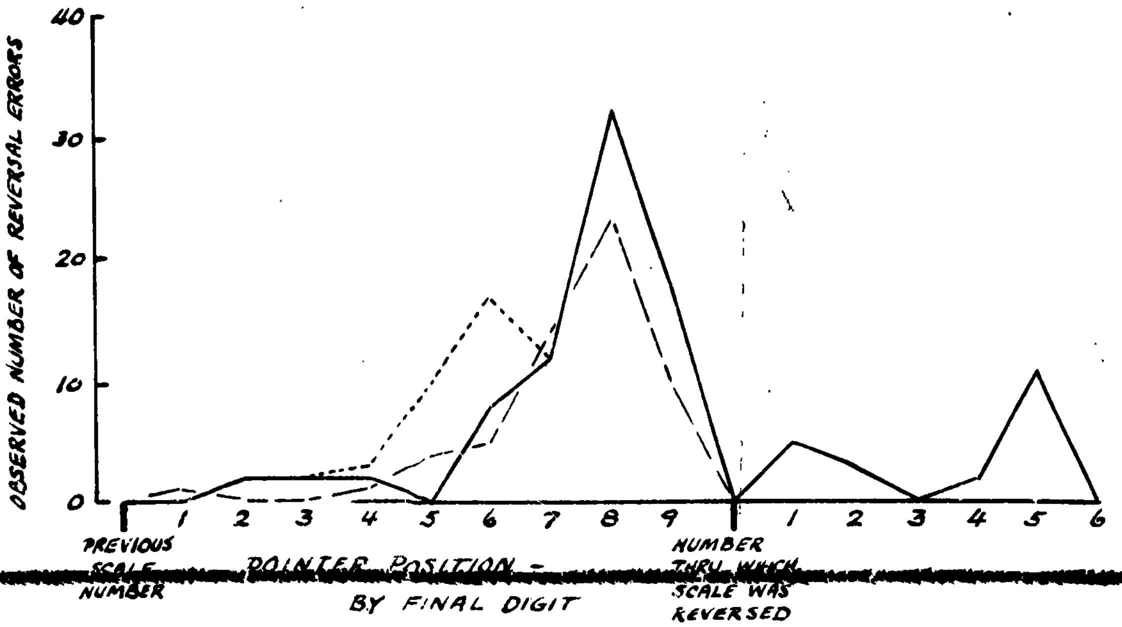

Figure 5. Distribution of reversal errors with relation to the numbered graduation mark through which the scale was reversed. Data for Groups I and II.

——————— reversals within scale
- - - - - - - reversals at zero

ification decision had to be made. See page 5 above). It is thus seen that the typical reversal error and the ≠10 units error share in common the adding on tendency and the habit of working from the nearest scale number.

The question of whether reversal error frequency is influenced by dial region has attracted attention in the past with reference to the design of specific dials and scales. According to one hypothesis, a reader would be expected to reverse scale direction more often where the scale is proceeding in increasing value from right to left, in opposition to left-right print reading habits, than where the scale is proceeding from left to right in accord with these other habits. According to a second hypothesis, a reader would be expected to reverse more often when the scale is proceeding in increasing value downward than when it is proceeding in increasing value upward, the latter being thought of as a more "natural" and familiar way of registering increasing amounts.

The data in Figure 4 may be used in a test of these hypotheses. Inasmuch as reversals occur with specific reference to and through some numbered mark, the present analysis has been set up to answer the question whether reversal error frequency is influencedby the location of the numbered mark through which the scale reversal occurs. Accordingly, the encircled error frequencies which appear around the dial diagrams in Figure 4 refer to the graduation marks and indicate the number of times that each was involved in reversal errors. The enclosed symbols, representing errors scored as ≠10's errors, were not counted in these tallies. By consulting the paired diagrams in the figure, one can compare the frequency of observed reversals at any given numbered mark when this mark was opposite dial positions. Only the zero point on each diagram is specifically marked, but the scale values of the other graduation marks may readily be identified.

The data in Figure 4 reveal no significant difference between reversal error rate on the left and right dial halves. The trend, in fact, is in the direction opposite to that predicted by the second hypothesis above, more errors having been made on the left, upward going half than on the right. The data do support the first hypothesis, however. Consider first the two lower diagrams for the dials with scale break. Reversals through the 10 mark were more common on the zero bottom dial. Reversals through the 20, 30 and 40 marks were more common on the zero top dial. In every case, more reversals were made through a given numbered mark when it was in the lower half of the dial, where the scale proceeds from right to left, than when that mark was in the upper half of the dial. On the no-break dials, the same result is noted for reversal through the 0, 10 and 30 marks; errors at the 20 mark were about the same for the two mark positions, and errors at the 40 mark showed an opposite difference. A "t" test on the nine pairs of error frequencies just considered, indicates that the top-half bottom-half difference is statistically significant (exactly at the 5% level for test on transformed frequencies). Over all, the split in the number of reversals between the top halves and the bottom halves of the dials was 35 to 62 for reversals within scale, and 21 to 37 for reversals at zero. The evidence then is sufficient to justify the following conclusions: (a) that although reversal errors may occur in any portion of a circular dial, they occur with greater frequency when readings are made in a region where the scale is going from right to left; and (b) that the best estimate of the amount by which probability of reversal errors is increased in a right to left scale region as compared with a left to right scale region is of the order of 50 to 100%.

The foregoing analysis is general in the sense that it leads to a general conclusion about reversal errors which is independent of dial design and makes it possible to infer certain dial design effects on reversal errors. It is interesting therefore to point out that it makes understandable the analysis of variance results on reversal errors which were cited in Table III above. The analysis of reversal errors at zero on the no-break dials turned up an effect of zero location, and led to the recommendation that such dials should have the scale zero located at the 12 o'clock position, rather than the 6 o'clock. Similarly, the analysis of reversal errors within scale for the break dials indicated the superiority of the zero bottom design. Both of these results follow from the fact that the bottom half of the dial is the higher error region.

In summary, the present data offer the following evidence about reversal errors: that they may occur in any region of the dial; that they result from the readers' tendency to consult only the number which is nearest to the pointer; that they typically involve a reader tendency to add to the consulted number the amount of the pointer deviation from that number; they occur with greater frequency when the scale direction opposes the left to right reading habit; and that they are especially likely to occur on no-break dials when the number consulted happens to be zero.

<u>Relations Between Reversal Errors and +10 Units Errors.</u>

It has been indicated in Figures 3 and 5 and in the discussions of them that the reversal error and the error of plus one numbered division have two basic reading habits which are the same: the tendency to refer to the scale number nearest to the pointer, and the "adding on" tendency. What is added on in the two cases is different, but it might be supposed that the incidence of these two errors would be related, i.e., that conditions which would cause an increase in the occurrence of one would also increase occurrences of the other. There is a possible indication of this in the present data. If one excludes the +10's errors in the 0 to 9 region as a special class, the +10's errors which remain seem to be influenced by scale direction in the same way that reversal errors are. It would appear that left to right scales would minimize them both.

IX DISCUSSION

Previous Studies of Reversal Errors

Two previous studies tie in closely with the present discussion of the nature of reversal errors. Both were by Christensen (1946,1948).

In the second of these, Christensen worked with clockwise and counterclockwise dials, all scaled from 0 to 50 and all lacking a scale break. Although the pointer settings which were used were specifically limited to scale values ending in the digits 4, 5, and 6, the dials themselves so closely resembled some of the dials used in the present study that it seemed appropriate to re-work Christensen's records to determine whether the present results would be borne out in his data. Accordingly the errors observed in Christensen's experiment were re-examined in the Princeton laboratory, classified according to type of reversal, and tallied as a function of scale direction and as a function of pointer position in relation to the mark through which the scale was reversed. The net result was that every one of the statements made in the preceding paragraph in Section VIII just above was confirmed, both for the clockwise and the counterclockwise dials. Reversals within scale and reversals at zero were made more frequently when the pointer was four units away from the consulted scale number than when it was six units away (109 to 22 for reversals within scale, 162 to 67 for reversals at zero). Reversals typically involved the "adding on" tendency (159 positive reversals to 29 negative reversals). They occurred with greater frequency when scale direction was right to left (see Table V). And, reversals at zero outnumbered the observed reversals within scale (see Table V), far exceeding the expected number of reversals at zero if reversal about every scale number had been equally likely.

Christensen's 1946 study dealt with the design of air navigation plotters. These plotters use a counterclockwise scale which, for convenience, is designed as a 180 degree protractor. One of the questions which Christensen sought to answer was whether plotter readings would be more accurate if the protractor was laid out as the upper half of a circle with the scale running from right to left or if it was designed as the lower half of a circle, with the scale running from left to right. Reversal error frequencies for the two designs were not significantly different, but the difference was once more in the direction of fewer reversals for the left to right scale.

Table V brings together the results of the present study and the two Christensen papers as regards the effect of scale direction on reversal errors.* Whereas the evidence for the effect of downward scale direction is inconsistent, that for the effect of right to left scale direction is completely consistent as indicated in the foregoing discussion.

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*The reversal data cited by Kappauf and Smith (1950a) are omitted from this table both because of the small number of errors involved and because most of them were of ambiguous origin and would have been classified differently had the present "probability" method of categorizing errors been used. In regard to error classification, it should be mentioned that Christensen's records contained some twenty times more reversal errors than ≠10 units errors (unquestionably a function of the reading task) and so ambiguous errors in this case were classed as reversals.

TABLE V

SUMMARY OF DATA ON REVERSAL ERRORS AS A FUNCTION OF SCALE DIRECTION

	Number of Observed Reversals within Scale When numbered mark is in Left-to-Right Region	Number of Observed Reversals within Scale When numbered mark is in Right-to-Left Region	Number of Observed Reversals at Zero on No-Break Dials Where Scale Starts to Right	Number of Observed Reversals at Zero on No-Break Dials Where Scale Starts to Left
Christensen Study of Navigator Plotter (1946)	33	43		
Christensen Clockwise Dials (1948)	17	26	7	51
Christensen Counter-Clockwise Dials (1948)	62	83	75	118
Present Study-Clockwise Dials (Groups I, III)	35	62	21	37

	Number of Observed Reversals within Scale when numbered mark is in Upward Going Region	Number of Observed Reversals within Scale when numbered mark is in Downward Going Region
Christensen Clockwise Dials (1948)	16	27
Christensen Counter-Clockwise Dials (1948)	56	89
Present Study-Clockwise Dials (Groups I, III)	61	31

The Number Location Problem

An effect of practical significance due to number location was observed for the ≁10 units errors made by high school subjects. Errors of this type were roughly half as frequent for these subjects when the scale numbers were outside than when they were inside (see Table I). The effect of this difference in ≁10's errors was to cut the total number of gross errors for the high school subjects during the three day test by 25% on the numbers outside dials as compared with the numbers inside dials. Day by day the group made fewer gross errors, but each day the ≁10 units errors came to account for a greater proportion of the gross errors made. In view of the fact that the present test situation used slender dial pointers and involved pointer settings at exact units values on the scale, all number reading difficulties which normally occur when the pointer overlaps certain inside numbers were completely avoided. Thus, the error saving here reported for the numbers outside dials has to a certain extent been minimized. Clearly the result deserves rechecking with other dials, marked with numbers which are as distinguishable as possible, equipped with pointers of a practical width, and set at a random series of scale values.

Use of the numbers outside design, incidentally, would entail a 3% increase in reading time to judge from the present data, and an increase in the frequency of interpolation errors which may be predicted for particular scales on the basis of the data of Grether and Williams (1947 or 1949) or Kappauf and Smith (1950b).

X. CONCLUSIONS

If there is need for a simple dial numbered every 10 units which will be used to obtain quantitative readings at any and all values throughout the scale, gross reading errors [illegible] with the zero located near the bottom of the dial, and with the scale numbers and graduation marks arranged outside the scale circumference.

If there is need for a dial numbered every 10 units which will be used principally for critical quantitative readings within some limited portion of its entire extent, the occurrence of gross errors among these readings will be minimized if the dial is designed so that the scale proceeds from left to right through the critical region (to reduce reversal errors) and if the scale units or reference zero are so chosen or manipulated that critical readings are not required in the numerical region 0 to 9 (to reduce ⁄10 units errors).

Both the error of ⁄10 units and the reversal error are associated with the tendency of scale readers to consult the scale number which is nearest to the pointer and then add the value of an observed pointer deviation to the number which has been read.

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APPENDIX

DETAILS OF STATISTICAL ANALYSIS

Analysis of ±10 Units Errors

The analysis of the ±10 units errors is summarized in Table A. Part 2 of this table shows the initial analysis of variance results. Second-order interactions are all non-significant, so these terms have been pooled with the remainder to give a new residual of 81.6 with 5 degrees of freedom. When tested against this pooled error, the first-order interactions of Group X Number Location and Zero Location X Scale Break are significant at the 5% level. Because the variable of Number Location represents a complete classification, the Group mean square involves no Group X Number Location component and may be tested against the pooled error. The resulting F ratio of 41.6 is highly significant, indicating a real difference in the rate of making ±10 units errors for Groups I/II vs. III when averaged over the two conditions of number location. The other primary effects when tested against the appropriate significant interactions are not themselves significant.

More meaningful, however, is a direct inspection of the nature of the interactions. Hence the follow-up, 4 x 4 analysis presented in Parts 3 and 4 of the table. This analysis yields a remainder mean square which may be used to conduct "t" tests of the difference between the row means and between the column means. The least significant difference between margin means, as listed in Part 4 of the table for the 5% level of confidence, is 15.7. In terms of this LSD, it is clear that dials with zero at the bottom and having a scale break are (for the groups and number locations used) significantly better than the other three combinations which themselves are all much alike. Similarly, among the row means, it is clear that a distinctly inferior combination is Group III reading dials with numbers inside (a conclusion which applies generally, as well as to the case of the break or no-break dials separately). Group I/II appears to do equally well with both number locations. Group differences are significant for numbers inside, but not at the 5% level for numbers outside.

Analysis of Reversal Errors at Zero

The very occurrence of these errors on no-break dials is, of course, a sufficient argument for the adoption of dials with scale break. Among the no-break dials, however, zero location and groups are significant sources of variance (see Table B). Consistently fewer reversal errors at zero are made by Group I/II than Group III, and by either group when the zero is located at the top of the dial.

Analysis of Reversal Errors at 10, 20, 30, or 40

This analysis appears in Table C. No effects are significant in the over-all analysis (Part 2 of table) but the effect of zero location is significant at the 5% level for the break dials considered alone. The data for reversal errors at zero in Table B and the discussion of reversal errors in the text lead one to expect an effect of zero location on reversal errors within scale. This gives one confidence in the present result for break dials even though a comparably significant effect is not observed for the no-break dials.

Analysis of Remaining Gross Errors

This analysis is summarized in Table D. The only significant factor here is the difference between groups which is significant at the 1% level when tested against pooled error based on the last 11 values in the table. The direction of the difference between groups is like that observed for the ±10 units errors: Groups I and II make fewer errors than Group III. The group difference is also significant in the analysis of the data for the scale break dials alone.

The results of the foregoing analysis have been consolidated in Table III of the Text.

TABLE A

ANALYSIS OF +10 UNITS ERRORS

1. Table of Transformed Data.

	Dials with Zero at Top No SB		Dials with Zero at Bot. No SB		Dials with Zero at Top Scale Break		Dials with Zero Bottom Scale Break	
Subject Group	I+II	III	I+II	III	I+II	III	I+II	III
Number Subjects	29	17	29	17	29	17	29	17
No. Read/dial type	2900	2150	2900	2150	2900	2150	2900	2150
Dials with Nos. In.	57	115	57	121	80	102	44	82
Dials with Nos. Out.	71	88	80	88	66	70	44	66

2. Summary of Initial Over-all Analysis.

Source of Variance	d.f.	Mean Sq. (= Sum of Squares)	d.f.	Mean Square	F ratio (using pooled error)
Groups	1	3393			41.6**
Zero Loc.	1	281			
No. Loc.	1	452			
Scale Break	1	946			
Gr x ZL	1	60			
Gr x NL	1	1073			13.2*
Gr x SB	1	233			
ZL x NL	1	68			
ZL x SB	1	588			7.2*
NL x SB	1	95			
Gr x ZL x NL	1	10.6	5	81.6	
Gr x ZL x SB	1	85.6			
Gr x NL x SB	1	248			
ZL x NL x SB	1	45.6			
Remainder	1	18.1			

3. Table for Follow-up Analysis.

	Zero Top No SB	Zero Bot. No.SB	Means for No Br Dials	Zero Top SB	Zero Bot. SB	Means for Br Dials	Means for all Dials
I+II, Nos. In.	57	57	(57.0)	80	44	(62.0)	59.5
I+II, Nos. Out.	71	80	(75.5)	66	44	(55.0)	65.2
III, Nos. In.	115	121	(118.0)	102	82	(92.0)	105.0
III, Nos. Out.	88	88	(88.0)	70	66	(68.0)	78.0
Means	82.8	86.5		79.5	59.0		

4. Summary of Follow-up Analysis.

Source of Variance	Sum of Squares	d.f.	Mean Square	F Ratio
Group and N.L.	4917.2	3	1639.1	17.1***
ZL and SB	1814.2	3	604.7	6.3*
Remainder	863.5	9	95.9	

*5% level
**1% level
***0.1% level

$LSD_{5\%}$ for row or col. means of 4 entries = 15.7
$LSD_{5\%}$ for row means based on 2 entries = 22.2

TABLE B

ANALYSIS OF REVERSAL ERRORS AT ZERO

1. Table of Transformed Data.

	Dials with Zero at Top, No Scale Break		Dials with Zero at Bottom, No Scale Break	
Subject Group	I ≠ II	III	I ≠ II	III
Number Subjects	29	17	29	17
No. Read dial Type	2900	2150	2900	2150
Dials with Nos. Inside	54	63	66	85
Dials with Nos. Outside	39	63	71	79

2. Summary of Analysis.

Source of Variance	d.f.	Mean Sq. (= Sum of Squares)	d.f.	Mean Square	F ratio (Using pooled error)
Groups	1	450			15.6*
Zero Loc.	1	840			29.1**
Number Loc.	1	32			1.1
Gr x ZL	1	4.5	4	28.9	
Gr x NL	1	2			
ZL x NL	1	24.5			
Remainder	1	84.5			

* exceeds 5% significance level
** exceeds 1% significance level

TABLE C

ANALYSIS OF REVERSAL ERRORS WITHIN SCALE

1. Table of Transformed Data.

	Dials with Zero at Top No SB		Dials with Zero at Bot. No SB		Dials with Zero at Top Scale Break		Dials with Zero Bottom Scale Break	
Subject Group	I/II	III	I/II	III	I/II	III	I/II	III
Number Subjects	29	17	29	17	29	17	29	17
No. Read/dial type	2900	2150	2900	2150	2900	2150	2900	2150
Dials with Nos. In.	66	63	44	51	57	59	47	51
Dials with Nos. Out.	39	55	54	73	60	66	57	46

2. Summary of Over-all Analysis

Source of Variance	d.f.	Mean sq. (= Sum of Squares	d.f.	Mean Square	
Groups	1	100			
Zero Loc.	1	110			
No. Loc.	1	9			
Scale Break	1	0.25			No Significant
Gr x ZL	1	0.25			F Ratios
Gr x NL	1	25			
Gr x SB	1	90			
ZL x NL	1	240			
ZL x SB	1	100			
NL x SB	1	20			
Gr x ZL x NL	1	42			
Gr x ZL x SB	1	49			
Gr x NL x SB	1	110	5	107	
ZL x NL x SB	1	324			
Remainder	1	9			

3. Summary of Analysis for Scale Break Dials

	d.f.	Mean Sq.	d.f.	Mean Sq.	F Ratio
Groups	1	0.12			
Zero Loc.	1	210			9.1*
No. Loc.	1	28			
Gr x ZL	1	28			
Gr x NL	1	15	4	23	
ZL x NL	1	3			
Remainder	1	45			

4. Summary of Analysis for No Break Dials

	d.f.	Mean Sq.	
Groups	1	190	
Zero Loc.	1	0.12	
No. Loc.	1	1	
Gr x ZL	1	21	No Significant
Gr x NL	1	120	F Ratios
ZL x NL	1	561	
Remainder	1	6	

TABLE D

ANALYSIS OF "REMAINING GROSS ERRORS"

1. Table of Transformed Data

	Dials with Zero at Top No SB		Dials with Zero at Bot. No SB		Dials with Zero at Top Scale Break		Dials with Zero Bottom Scale Break	
Subject Group	I/II	III	I/II	III	I/II	III	I/II	I[illegible]
Number Subjects	29	17	29	17	29	17	29	[illegible]
No. Read/dial type	2900	2150	2900	2150	2900	2150	2900	21[illegible]
Dials with Nos. In.	54	55	57	70	60	70	54	[illegible]
Dials with Nos. Out.	47	55	51	68	39	59	57	[illegible]

2. Summary of Over-all Analysis.

Source of Variance	d.f.	Mean Sq. (=Sum of Squares)	d.f.	Mean Square	F Ratio (Using pooled error)
Groups	1	770			11.0**
Zero Loc.	1	315			4.5
No. Loc.	1	60			0.9
Scale Break	1	1.6			
Gr x ZL	1	68			
Gr x NL	1	60			
Gr x SB	1	3.1			
ZL x NL	1	138			
ZL x SB	1	95			
NL x SB	1	105	11	70.1	
Gr x ZL x NL	1	0.6			
Gr x ZL x SB	1	150			
Gr x NL x SB	1	60			
ZL x NL x SB	1	5.1			
Remainder	1	86			

3. Summary of Analysis for Scale Break Dials

	d.f.	Mean Sq.	d.f.	Mean Sq.	F Ratio
Groups	1	338			87*
Zero Loc.	1	32			
No. Loc.	1	162			
Gr x ZL	1	8			
Gr x NL	1	0	4	39	
ZL x NL	1	98			
Remainder	1	50			

4. Summary of Analysis for No Break Dials

d.f.	Mean Sq.
1	435
1	378
1	3.1
1	210
1	120
1	46
1	36

No Significant F Ratios

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