MEMORANDUM REPORT

U. S. AIR FORCE
AIR MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO

NUMBER MCREXD-694-1-N 12 JULY 1948

DESIGN OF INSTRUMENT DIALS FOR MAXIMUM LEGIBILITY: II.

A PRELIMINARY EXPERIMENT ON DIAL SIZE AND GRADUATION

PREPARED BY

PRINCETON UNIVERSITY

FOR

AERO MEDICAL LABORATORY

ENGINEERING DIVISION

Form No. 80-34C
Jun 47)

U. S. AIR FORCE
HEADQUARTERS, AIR MATERIEL COMMAND
ENGINEERING DIVISION

No. of Pages - 17

MCREXD-9/PMF/ml

MEMORANDUM REPORT ON

Date: 12 July 1948

SUBJECT: Design of Instrument Dials for Maximum Legibility: II. A Preliminary Experiment on Dial Size and Graduation.

SECTION: Aero Medical Laboratory

SERIAL NO.: MCREXD-694-1-N

Expenditure Order No. 694-15
Contract No. W33-038 ac-14430

A. PURPOSE:

1. The purpose of the present report is to summarize the results of a preliminary experiment on the effect of dial size and dial graduation on the speed and accuracy of obtaining quantitative information from instruments. The report supplements and extends the data presented in Engineering Division Memorandum Report No. TSEAA-694-1L, 20 October 1947.

B. FACTUAL DATA:

2. The research reported herein was conducted by Princeton University as part of the work being carried on under contract with the Air Materiel Command. The complete report from Princeton is included as Appendix I.

3. The individuals who served as subjects in the experiment read panels of twelve similar instruments under instructions to be as accurate as possible. All readings were made to the nearest unit. Measures of reading time and error frequency were obtained.

4. The dials studied were of two sizes, 1.4 inches and 2.8 inches diameter. Eight dial designs were investigated. Scale ranges from 0 to 100, 0 to 200, 0 to 400 and 0 to 600 units were employed, in combination with graduation markings every 5 units or every 10 units. The eight designs are shown in Figure 2., page 7, of the Appendix.

5. Results may be summarized as follows:

a. Frequency of dial reading errors was primarily a function of the arc length which was devoted to each unit on the circumference of the dial. This finding is in agreement with results preiously reported.

b. The results support the conclusion of a previous study (Memorandum Report No. TSEAA-694-1E, 31 March 1947) that for maximum reading accuracy when each scale division represents 10 units, about 0.06 inches of arc length per scale unit is optimal. By comparison the present study shows that for dials graduated every five units, a slightly smaller arc length per unit is optimal. Additional separation of scale units beyond these optimum values gave no further reduction in reading errors.

c. Dial reading speed was essentially the same for the two dial sizes studied, but was found to vary with the total number of units represented on the scale. Dials with a smaller range of values were read faster. This result differs from that found in an earlier study (MR No. TSEAA-694-1E).

d. Under the conditions of the experiment, 2.8 inch dials graduated from 0 to 100 and with scale marks every 10 units were read with an error of 1 unit only 10% of the time and were never read with errors greater than 1 unit. At the other extreme, 1.4 inch dials graduated from 0 to 600 with scale marks every 10 units, were read with errors of 1 unit 46% of the time and with errors greater than 1 unit 11% of the time. Results for other dial size and scale length combinations for both the present study and an earlier one are given in Table 1 of the Appendix.

C. CONCLUSIONS:

6. If it is desired to increase the range of scale values on a dial and at the same time maintain a constant degree of reading accuracy, the circumference of the dial should be increased in proportion to the amount of increase in the range of scale values.

D. RECOMMENDATIONS:

7. None.

Engineering Division
MR No. MCREXD-694-1-N

Prepared by: William E. Kappauf
WILLIAM E. KAPPAUF, Ph.D.
Princeton University

and: William M. Smith
WILLIAM M. SMITH
Princeton University

Approved by: Paul M. Fitts
PAUL M. FITTS, Ph.D.
Chief, Psychology Branch

Approved by: A. P. Gagge
A. P. GAGGE, Lt. Col., MSC
Chief, Aero Medical Operations

Approved by: Ed Kendricks
EDWARD J. KENDRICKS, Col., MC
Chief, Aero Medical Laboratory

DISTRIBUTION:
See Page 17

APPENDIX I

REPORT NO. 4 from the

Department of Psychology
Princeton University
Princeton, N. J.

DESIGN OF INSTRUMENT DIALS FOR MAXIMUM LEGIBILITY: II.

A PRELIMINARY EXPERIMENT ON DIAL SIZE AND GRADUATION

Prepared for the

Aero Medical Laboratory
Engineering Division
Air Materiel Command
Wright Field
Dayton, Ohio

Prepared by William E. Kappauf
William E. Kappauf

William M. Smith
William M. Smith

Contract # W 33-038 ac 14480

May 1948

DESIGN OF INSTRUMENT DIALS FOR MAXIMUM LEGIBILITY: II.

A PRELIMINARY EXPERIMENT ON DIAL SIZE AND GRADUATION

INTRODUCTION.

This is a report of a short, exploratory experiment on the effect of dial size and dial graduation on the speed and accuracy of obtaining quantitative information from dial type instruments. The purpose of the experiment was to determine approximately the range within which the results of further and more complete studies might fall. In this regard, it supplements and extends the data presented in the first report of this series (1).

APPARATUS AND PROCEDURE.

Figure 1 shows the apparatus as viewed from the subject's side. The subject sits in a three-sided enclosure, four feet square. He puts his head against a cushioned headrest which keeps his eyes at a reading distance of twenty-eight inches from the test material. The single dial at eye height on the panel is a sample dial. This dial, like all the sample dials used, has no pointer. The particular sample which is presented in the panel aperture before each trial indicates to the subject the kind of dial which he will have to read on the next test card. When the subject is ready, the experimenter slides the test card into position and illuminates it. Every test card has twelve dials of identical design which the

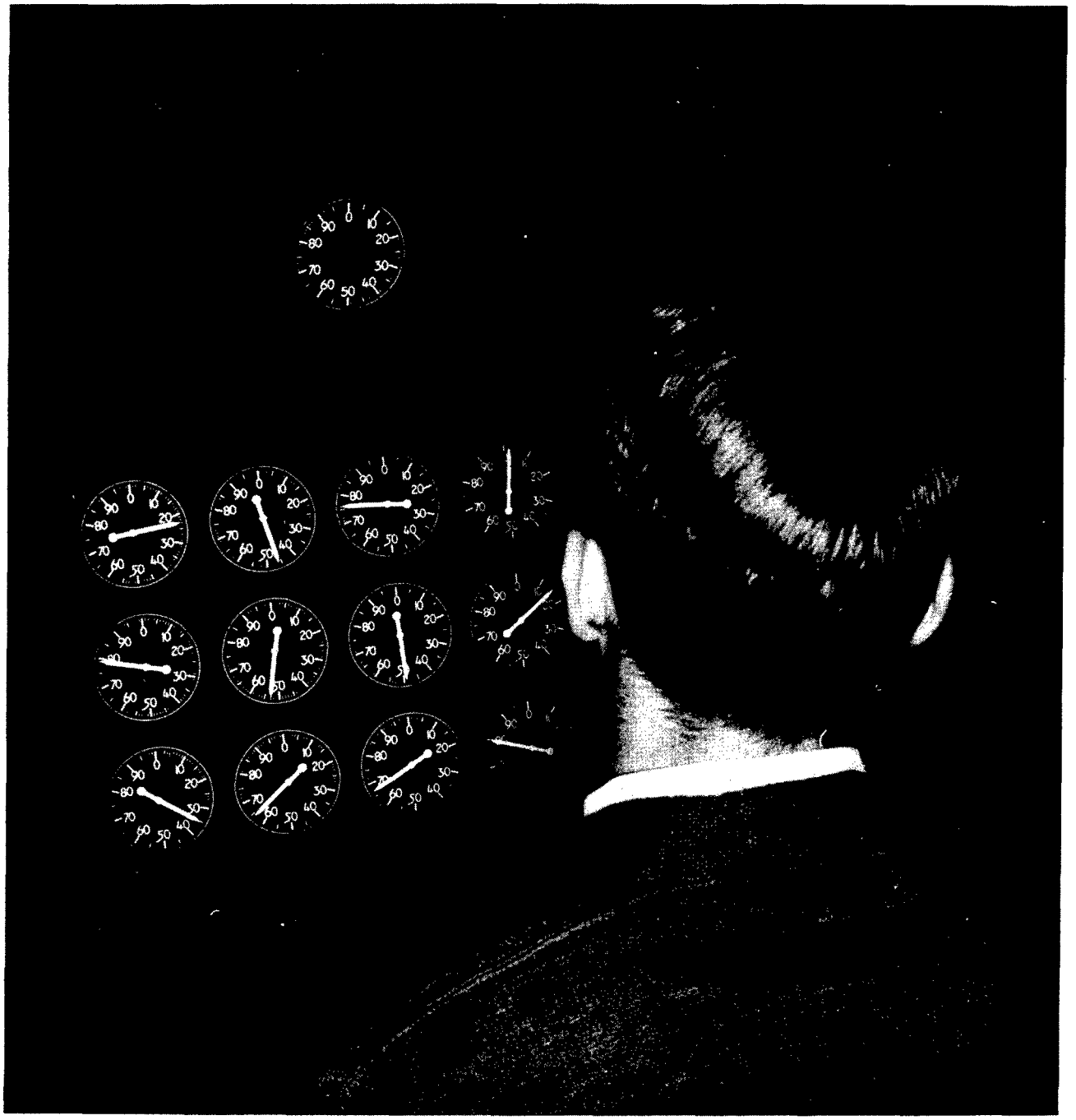

Figure 1

Photograph of the Test Situation

subject reads row by row, from left to right. Actually the subject never sees the sample dial and the test dials at the same time as might be assumed from the figure. Two small projectors, not shown in the picture, are used to illuminate the sample dial and the test card independently.

On the experimenter's side of the apparatus there is (1) a supply bin containing test cards, (2) a slide mechanism for moving the test cards into position before the subject, (3) a second slide for presenting the sample dials, (4) a pair of stop clocks for timing the subject's performance, and (5) a storage bin into which test cards are placed as they are used.

The experimenter inserts a test card in the sliding panel and moves it into place in front of the subject. Next he throws a control switch to change from sample dial illumination to test card illumination. This starts the two stop clocks. The subject begins reading immediately. As the first reading is called out, the experimenter stops the first clock. At the eleventh reading, the second clock is turned off. Illumination goes back to the sample dial after the twelfth reading. Although the subject makes twelve readings on every card, the experimental analysis is based only upon his readings of the central set of ten dials on each card.

STIMULUS MATERIALS.

Eight dial designs were used in the experiment. These designs are shown in Figure 2. There were 100's dials, that is, dials reading from

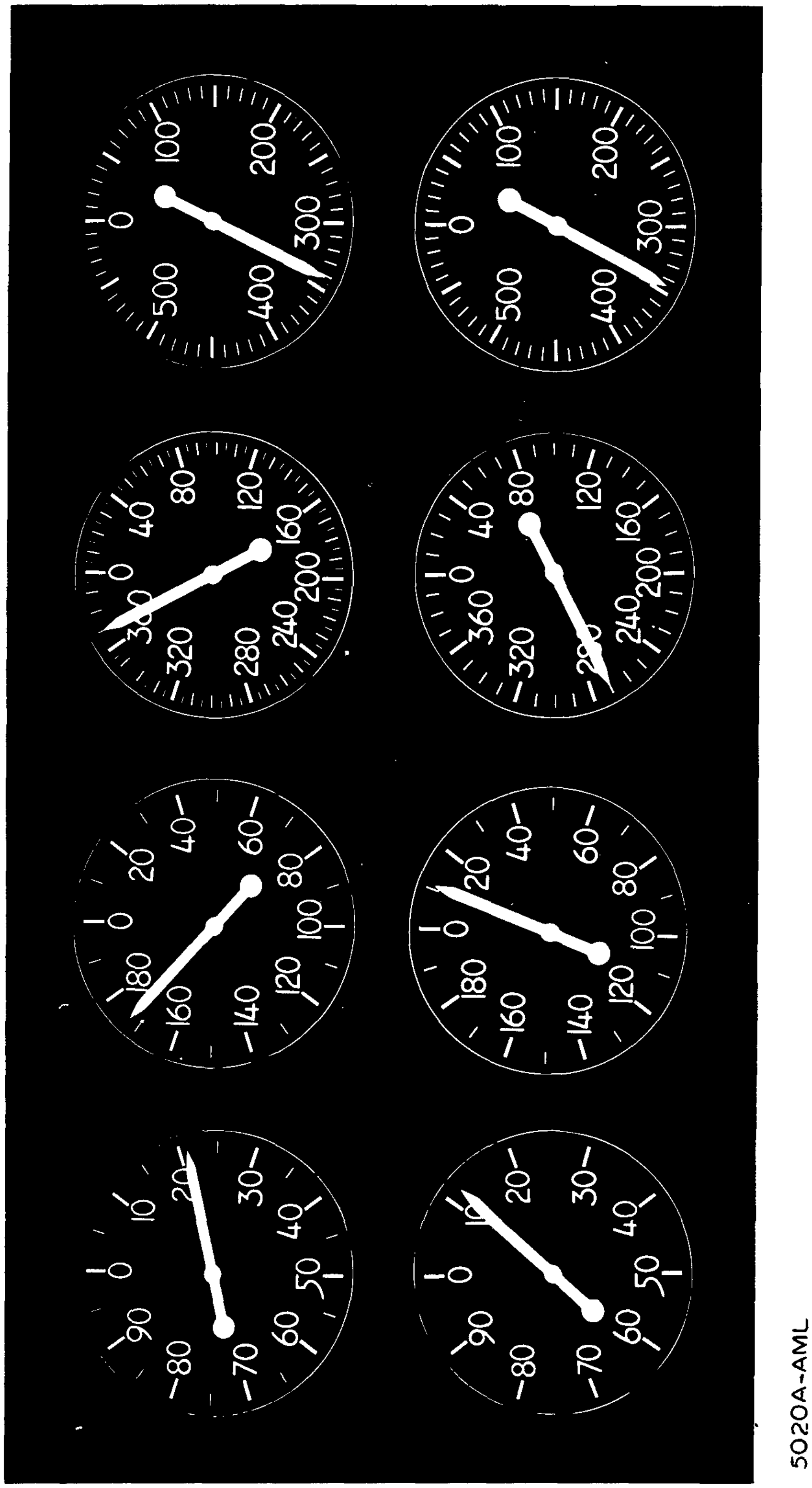

Figure 2

0 to 100; 200's dials, 400's dials, and 600's dials. For each scale length there were dials graduated by fives, shown in the top row in the figure, and others graduated by tens, shown in the lower row. Further, for each type of dial, two sizes were used: one size 2.8 inches in diameter, the other 1.4 inches in diameter. For each type and size of dial, three test cards were available. Thus there were 48 cards in all.

The stimulus materials were photographs printed on mat paper with as high degree of contrast as could be obtained. The illumination was such that the white parts of the dials were at a brightness of 6 foot lamberts. The black areas were at a level of about 0.6 foot lamberts.

All the dial photographs used in the experiment showed the pointer within three tenths of a unit of some exact unit position on the scale. Settings were kept within this precision in order to eliminate ambiguous settings midway between two unit positions. The precision of each setting was checked by projecting the photograph negatives to a twenty-inch diameter size.*

PLAN OF THE EXPERIMENT.

Each subject read 30 dials of each type and size. His instructions were to make each reading to the nearest unit. Since readings were made to units, and not simply to the nearest division, interpolation to fifths

*For a more complete description of the apparatus and rationale of the testing procedure, see Reference 1.

or tenths of divisions was necessary. The subjects were instructed to be as accurate as possible in their readings, to read as carefully as they would when making slide rule calculations. Each subject read 24 of the 48 stimulus cards on the first experimental day and the remaining 24 on the second day. Six subjects, all graduate students in psychology, served in the experiment. The card sequences which were used introduced systematic rotations of the size and design variables. In order to minimize practice or other order effects for the group, the time of appearance of individual cards was counterbalanced for the different men.

RESULTS.

The results of the experiment are shown in Figures 3 to 5. Where differences were observed, they were usually orderly and large. For this reason and because the experiment was conducted as a preliminary test with a restricted amount of stimulus material, no statistical analyses have been made on the data.

Figure 3 shows the frequency of reading errors for the dials which were graduated by fives. Percentage of wrong readings is plotted as a function of the length of arc devoted to each scale unit. Any reading not given exactly to the nearest unit was scored as incorrect. Arc length is given in inches. Thus, as shown at the bottom of the figure, a 600's dial 1.4 inches in diameter has each unit on the scale represented by .007 inches. Clearly, a 200's dial of the 1.4 inch size and a 400's dial of

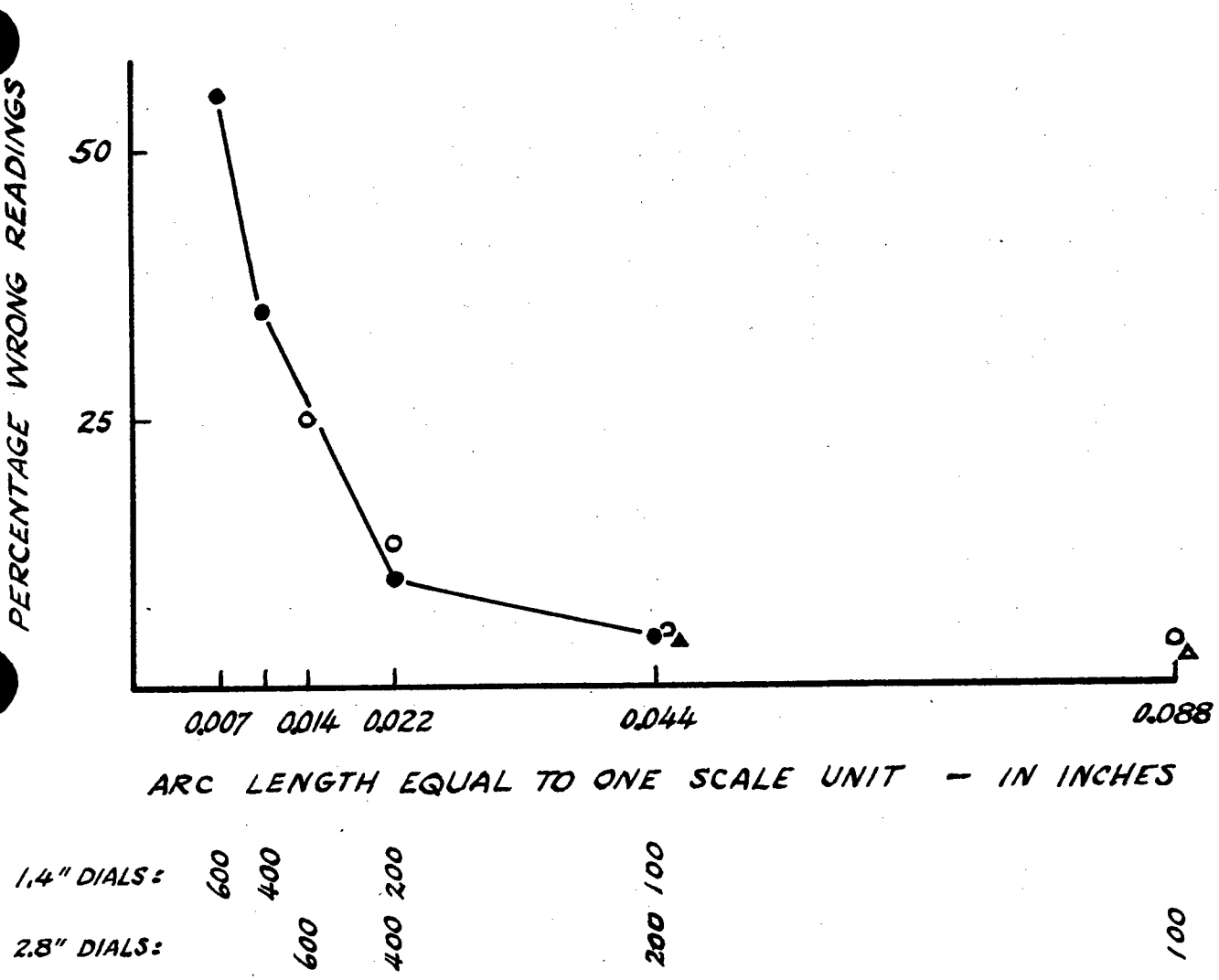

Figure 3

Frequency of Reading Errors For Dials Graduated by Fives

Data for 6 subjects in this experiment: 30 readings each per dial, under accuracy instructions.
Data for 6 subjects in previous experiment, 100's dials only.

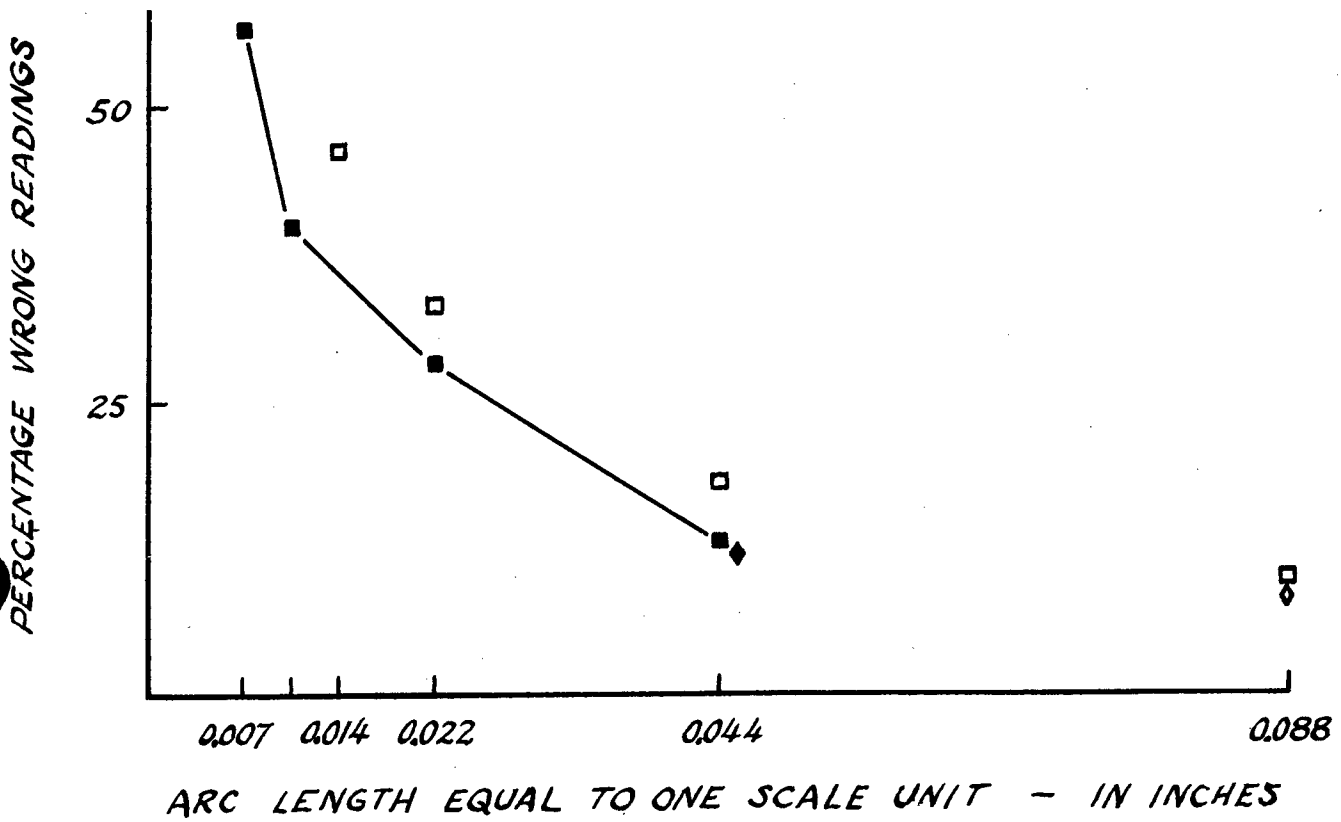

Figure 4

Frequency of Reading Errors For Dials Graduated by Tens

Data for 6 subjects in this experiment: 30 readings each per dial, under accuracy instructions.
Data for 6 subjects in previous experiment, 100's dials only.

the 2.8 inch size have the same arc length for one unit of the scale distance. The same is true for the small 100's dial as compared with the large 200's dial. The solid points plotted in the figure are for the small dials, the open points for the large dials. Points for the smaller dials are connected by straight lines and it is clear that the data for the large dials are fitted well by this curve for the smaller dials. Thus, error frequency for these dials graduated by fives was a function of linear arc length per unit and was independent of dial size. Increase in the percentage of error was very rapid when arc length per unit became less than 0.02 inches. Over the range of scales tested, errors increased in frequency from a minimum of about 4% to over 50%.

Figure 4 shows the data for the series of dials which were graduated by tens. It will be noted that the frequency of errors for these dials was generally larger than for the dials graduated by fives. For the 400's and 600's dials of the smaller size, however, error frequency seemed to be about the same whether graduation was by fives or tens. For the dials graduated by tens, the data for the large dials (open points) and small dials (solid points) are not fitted so well by a single curve as they were in the case of the dials graduated by fives. This suggests that the exact role of dial size will warrant further study.

Figure 5 presents data for speed of reading. It summarizes the time measurements for all the readings which were made for large and small dials and for dials graduated by fives and tens. In this figure, average reading time in seconds is plotted as a function of arc per scale unit,

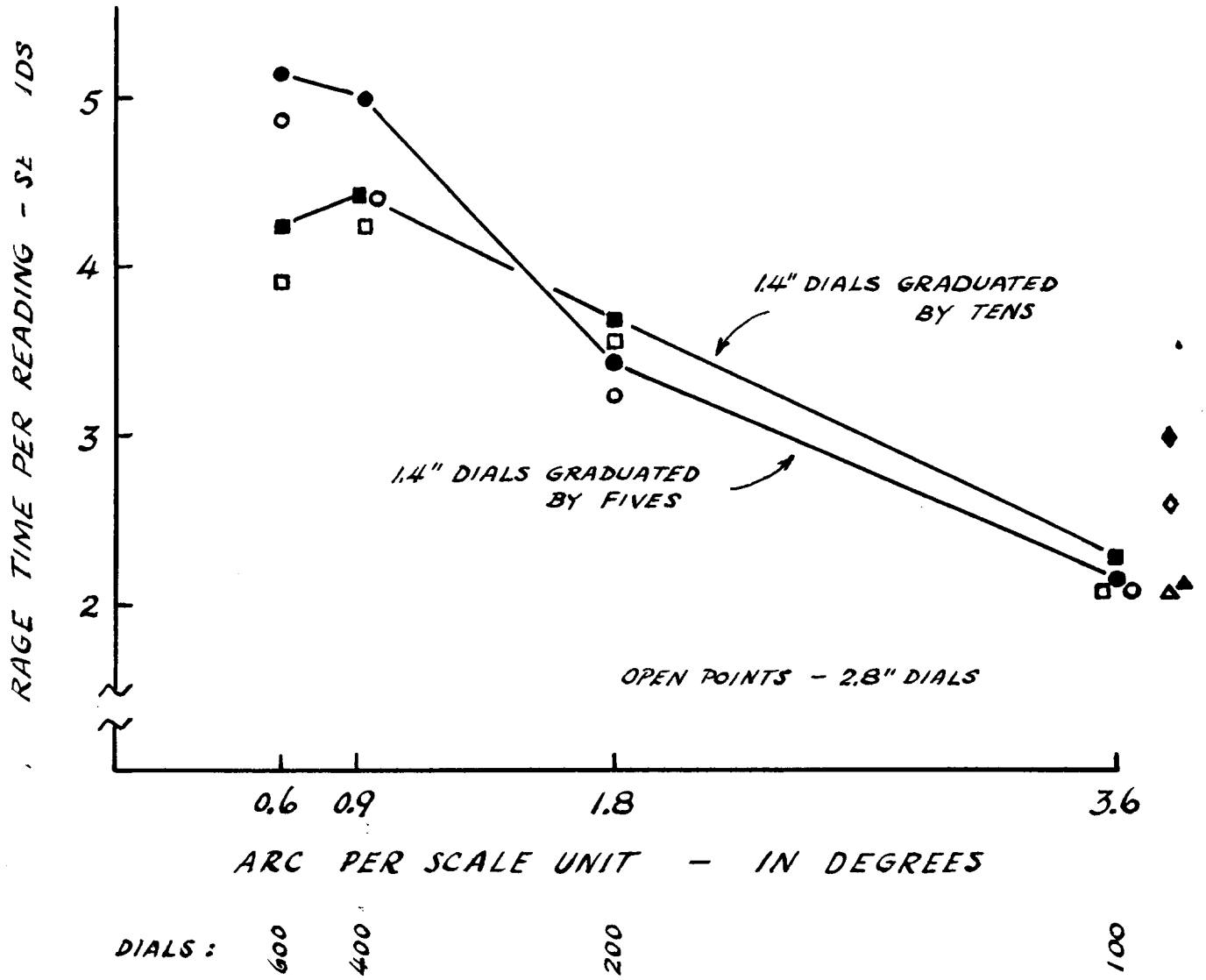

Figure 5

Reading Times For All Dials

Data for 6 subjects in this experiment: 30 readings each per dial, under accuracy instructions.
Data for 6 subjects in previous experiment.

where the arc is measured in degrees. Small dials are again represented by solid points and large dials by open points. Points for the small dials are connected by straight lines. The data show that average reading time increased from two seconds to four or five seconds as the arc devoted to each scale unit decreased from 3.6 to 0.6 degrees. Dial size had a consistent but minor effect. Most significant is the fact that, within the range of dial sizes studied, reading speed was primarily a function of the number of degrees subtended by each scale unit, that is to say, a function of the complexity of the dial or the number of units which were represented on the circumference.

Where direct comparisons are possible, the foregoing results are in good agreement with data reported in the first memorandum of this series (1). That memorandum described the performance of another group of six subjects tested in the reading of 100's dials. Each subject made 120 readings under accuracy instructions on each of the four 100's dials which were used in the current experiment. Average records for this group are represented by the triangular and diamond-shaped marks in Figures 3, 4, and 5. The error frequencies in Figures 3 and 4 and the reading time data for the dials graduated by fives in Figure 5 coincide almost exactly with the group averages for the present experiment. The somewhat longer reading times for the first group on the dials graduated by tens appear to have been due primarily to the extremely long times taken by one subject. Over all, the degree of observed agreement between the results

of the two experiments may be taken as an indication of satisfactory reliability for the test procedure employed.

Further comparison of these results with the study of Williams and Grether (2) is in order. Their study, confined to scales graduated by tens, led to the conclusion that reading errors were at or near a minimum for scales where arc length per scale unit was 0.06 inches. The data in Figure 4 above are consistent with this result. The present data suggest in addition, however, that for dials graduated by fives, see Figure 3, the effective minimum may be reached at somewhat shorter arc distances per scale unit than for dials graduated by tens.

Reference should be made to two differences between the results of the Williams-Grether experiment and the present test. Whereas reading times were independent of the closeness of graduations for Williams and Grether, they were not so in this experiment as shown in Figure 5. Further, the error frequencies recorded by Williams and Grether were greater than those found here. A direct comparison of a portion of the error data from the two experiments, as made in Table I, shows that this difference applied generally for large dial sizes (2.75 and 2.80 inches diameter) and for small dial sizes (1.87 and 1.40 inches diameter). Differences in test conditions, in stimulus material, and in subject populations were sufficiently marked, however, to make differences in these aspects of the results of the two studies not entirely unexpected.

TABLE I

COMPARISON OF ERROR DATA FOR DIALS GRADUATED BY TENS
AS OBTAINED BY WILLIAMS AND GRETHER
UNDER SIMULATED DAYLIGHT CONDITIONS
AND IN THE PRESENT EXPERIMENT

Experiment	Dial Diameter (In Inches)	Arc Length Per Scale Unit (In Inches)	Percentage of Readings Which Were: Correct to Nearest Unit	In Error by 1 Unit	In Error by 2 Units	In Error by More Than 2 Units
W. and G.	2.75	0.096	62	33	2	3
		0.048	53	41	4	2
		0.024	42	42	10	6
		0.012	20	56	17	7
K. and S.	2.80	0.088	90	10	0	0
		0.044	81	18	0	1
		0.022	67	30	1	2
		0.014	54	41	4	1
W. and G.	1.87	0.066	64	31	2	3
		0.033	39	46	9	6
		0.016	45	42	8	5
		0.008	15	35	20	30
K. and S.	1.40	0.044	87	12	0	1
		0.022	71	27	1	1
		0.011	60	33	4	3
		0.007	43	46	9	2

TABLE I

COMPARISON OF ERROR DATA FOR DIALS GRADUATED BY TENS
AS OBTAINED BY WILLIAMS AND GRETHER
UNDER SIMULATED DAYLIGHT CONDITIONS
AND IN THE PRESENT EXPERIMENT

Experiment	Dial Diameter (In Inches)	Arc Length Per Scale Unit (In Inches)	Percentage of Readings Which Were: Correct to Nearest Unit	In Error by 1 Unit	In Error by 2 Units	In Error by More Than 2 Units
W. and G.	2.75	0.096	62	33	2	3
		0.048	53	41	4	2
		0.024	42	42	10	6
		0.012	20	56	17	7
K. and S.	2.80	0.088	90	10	0	0
		0.044	81	18	0	1
		0.022	67	30	1	2
		0.014	54	41	4	1
W. and G.	1.87	0.066	64	31	2	3
		0.033	39	46	9	6
		0.016	45	42	8	5
		0.008	15	35	20	30
K. and S.	1.40	0.044	87	12	0	1
		0.022	71	27	1	1
		0.011	60	33	4	3
		0.007	43	46	9	2

SUMMARY.

Results of a preliminary experiment involving six subjects, eight different dial designs, and two sizes of dials have been reported. Measures of reading time and error frequency were taken. The data obtained must be interpreted in the light of the fact that the subjects were graduate students reading at their own pace under instructions to be as accurate as possible. It was observed that frequency of dial reading errors was primarily a function of the arc length in inches devoted to one scale unit. For maximum reading accuracy, about 0.05 inches per scale unit seems to be required, although this distance may depend in part on whether the scale is graduated by fives or by tens. Regarding speed of reading, it was observed that speed depended most on the angular representation of each scale unit on the dial circumference. Reading speed was relatively independent of dial size within the size limits studied, but varied markedly with the total number of units portrayed on the scale.

BIBLIOGRAPHY.

1. Kappauf, W. E., W. M. Smith, and C. W. Bray. Design of instrument dials for maximum legibility: I. Development of methodology and some preliminary results. Army Air Forces, Air Materiel Command, Memorandum Report TSEAA-694-1L, October 20, 1947.

2. Williams, A. C. and W. F. Grether. Speed and accuracy of dial reading as a function of dial diameter and spacing of scale divisions. Army Air Forces, Air Materiel Command, Memorandum Report TSEAA-694-IE, March 31, 1947.

DISTRIBUTION

MCREXD (Library) (1)

MCREXD-9 (50)

MCID (2) "Release"

MCREOA-6

MCREES

MCREEC

MCREEC-51

MCREER

MCREXE-4

MCREXG

MCREXU-4

MCRW (2)

Watson Laboratories
Red Bank, New Jersey
ATTN: WLENG

Office of The Air Surgeon
United States Air Force
Washington 25, D. C.
ATTN: Psychological Section (10)

Commandant
School of Aviation Medicine
Randolph Field, Texas (2)

Office of The Surgeon
Headquarters Air Training Command
Barksdale Field, Louisiana

Psychological Research & Examining
Sqd E, Indoctrination Div. (Unit
Air Training Command
San Antonio, Texas (2)

Office of The Surgon
Strategic Air Command
Andrews Field, Maryland
ATTN: Psychological Section (2)

Air University
Maxwell Field, Alabama
ATTN: Library

Secretariat, The Aeronautical Board
Room 1052, T-7 Building
Gravelly Point
Washington 25, D. C.

BAGR-CD (4)
Bureau of Aeronautics
Bldg. 11

Chief of Naval Research
U. S. Navy
Washington 25, D. C.
ATTN: Medical Sciences Division

Special Devices Center
Sands Point, Port Washington
Long Island, New York
ATTN: Human Engineering Section (2)

Naval Research Laboratory
Anacostia Station
Washington, D. C.
ATTN: Psychological Section (2)

Aero Medical Equipment Laboratory
Naval Air Materiel Center
Philadelphia, Pennsylvania

RAF Delegation
Box 680, Benjamin Franklin Station
Washington, D. C. (2)
ATTN: Wind Commander S.R.C. Nelson

Navy Electronics Laboratory
San Diego 52, California
ATTN: Dr. Arnold Small

Radio Technical Committee for
Aeronautics
718 Eighteenth Street, N.W.
Washington 6, D. C.
ATTN: Mr. L. M. Sherrer

NACA Liaison Officer with the AMC
TSXNA, Bldg. 14, Room 250 (4)

Civil Aeronautics Administration
Washington 25, D. C.
ATTN: Dr. Dean R. Brimhall
Assistant for Research

Civil Aeronautics Administration
Washington 25, D. C.
ATTN: Mr. O. E. Patton
Airframe & Equipment Eng.Div.

National Research Council Committee
on Aviation Psychology
University of Pennsylvania
Philadelphia, Pennsylvania
ATTN: Dr. M. S. Viteles (2)

Office of Technical Service
Department of Commerce
Washington 25, D. C.
ATTN: Chief, Bibliographic &
Reference Division

Aeronautics Division
Library of Congress
Washington 25, D. C.

Research & Development Board
Committee on Human Resources
1712 "G" Street, N.W.
Washington 25, D. C.
ATTN: Dr. Lyle H. Lanier

Air Transport Association of America
1107 16th Street, N.W.
Washington 6, D. C.
ATTN: Dr. Allan Dallas
Director of Engineering

Institute of Aeronautical Sciences, Inc.
2 East Sixty Fourth Street
New York 21, New York
ATTN: Mr. Welman A. Shroder

Mr. R. L. McBrien
United Air Lines, Inc.
Resident Representative
% Glenn L. Martin Company
Baltimore, Maryland

Department of Psychology
University of California
Berkeley, California
ATTN: Dr. C. W. Brown

Department of Psychology
Indiana University
Bloomington, Indiana
ATTN: Dr. D. G. Ellson

Department of Psychology
Lehigh University
Bethlehem, Pennsylvania
ATTN: Dr. Adelbert Ford

Department of Psychology
University of Maryland
College Park, Maryland
ATTN: Dr. R. Y. Walker

Department of Psychology
Miami University
Oxford, Ohio
ATTN: Dr. Clarke Crannell

Mr. Earl Wynn
The Communication Center
University of No. Carolina
Chapel Hill, No. Carolina

New York University Project
Special Devices Center
Port Washington, New York

Department of Psychology
Princeton University
Princeton, New Jersey
ATTN: Dr. W. E. Kappauf (10)

Department of Psychology
University of Rochester
Rochester, New York
ATTN: Dr. S. D. S. Spragg

Department of Psychology
Tufts College
Medford, Massachusetts
ATTN: Dr. J. L. Kennedy

Department of Psychology
University of Washington
Seattle, Washington
ATTN: Dr. R. B. Loucks (2)

Dr. Donald B. Lindsley
Department of Psychology
Northwestern University
Evanston, Illinois

Department of Psychology
Johns Hopkins University
Baltimore, Maryland
ATTN: Dr. C. T. Morgan

Department of Psychology
University of Illinois
Urbana, Illinois
ATTN: Dr. A. C. Williams, Jr.

Department of Psychology
Purdue University
Lafayette, Indiana
ATTN: Dr. J. A. Bromer

Department of Psychology
State University of Iowa
Iowa City, Iowa
ATTN: Dr. J. S. Brown

Department of Psychology
Connecticut College
New London, Connecticut
ATTN: Dr. Robert M. Gagne

Department of Psychology
Peabody Hall
University of Virginia
Charlottesville, Virginia
ATTN: Dr. Richard H. Henneman

Collins Radio Company
Cedar Rapids, Iowa
ATTN: Mr. W. E. Cleaves
Aviation Sales Manager

Federal Telecommunication Laboratories
500 Washington Avenue
Nutley, New Jersey
ATTN: Technical Documents Section

Kollsman Instrument Division
80-08 Forty Fifth Avenue
Elmhurst, Long Island, New York
ATTN: Mr. Henry Droge

Link Aviation, Inc.
Binghamton, New York

The Psychological Corporation
522 Fifth Avenue
New York, New York
ATTN: Bio Mechanics Division

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

Sperry Gyroscope Company, Inc.
Great Neck
Long Island, New York
ATTN: USAF Representative (2)

Radio Corporation of America
RCA Victor Division
Camden, New Jersey
ATTN: Mr. Hugh H. Spencer