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PROJECT NO. 7216
TASK NO. 71712

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the Biophysics Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, under Project 7216, Task 71712, with Dr. E. P. Hiatt acting as project engineer. The experimental data were collected while the senior author was a member of the staff of the Engineering Psychology Branch, Aero Medical Laboratory.

ABSTRACT

~~This study concerns~~ the manner in which the accuracy of quantitative scale readings varies as a function of illumination and acceleration.

The following basic findings resulted from an analysis of the data from this experiment:

(1) At the higher levels of instrument illumination, increasing acceleration and decreasing luminance produce relatively small increase in reading errors;

(2) At marginal levels of illumination, acceleration and luminance interact to produce a relatively large increase in error;

(3) Intensity of illumination can compensate for the decline in visual performance at stress levels above 1 g.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Andres I. Karstens

ANDRES I. KARSTENS
Colonel, USAF (MC)
Assistant Chief, Aero Medical Laboratory
Directorate of Laboratories

THE EFFECTS OF POSITIVE ACCELERATION ON THE RELATION BETWEEN ILLUMINATION AND INSTRUMENT READING

The present study was designed to determine whether or not a pilot's ability to read aircraft instrument dials at various brightness levels is impaired by accelerative force less than that required to produce temporary blindness.

METHOD

Apparatus. The Wright Air Development Center human centrifuge was used in this study.

Instrument reading performance was measured by using the apparatus and procedures developed by Chalmers, Goldstein, and Kappauf (2) as a standardized method for studies of dial reading behavior. The reading material consisted of a panel of twelve dials. The dials were scaled from 0 to 100 over the full circumference, and one type was graduated by fives while the other was graduated in units. See Figure 1. The panel was located directly ahead of the subject and at 28 inches from the eye.

Illumination of the instrument panel was provided by modified aircraft high intensity lights symmetrically located on either side and to the rear of the subject. The intensity of the white illumination was controlled by neutral density filters placed in holders attached to each light source. At the highest brightness level the white portion of the dial was 42 millilamberts. This luminance was measured with the Macbeth illuminometer. The background of the dials and panels was matte black and less than one-tenth as bright as the white instrument markings.

Subjects. Six selected subjects were used in this study. All subjects had an uncorrected visual acuity of 20/20 or better in both eyes as measured with American Optical Company Sight Screener. Only persons with considerable experience riding the centrifuge were selected as subjects.

Procedure. The day prior to the first test ride on the centrifuge, the subjects were individually indoctrinated concerning the test procedure. During this indoctrination the subjects gained knowledge about the test routine, became acquainted with the two types of dials and had an opportunity to make readings at the different luminance levels to be used in the experiment.

The test procedure required that each session begin with readings at the highest or second highest luminance level and work down the luminance range by using every second level, and then taking the remaining levels in increasing order. Five minutes of adaptation preceded work at each successive lower or higher luminance level.

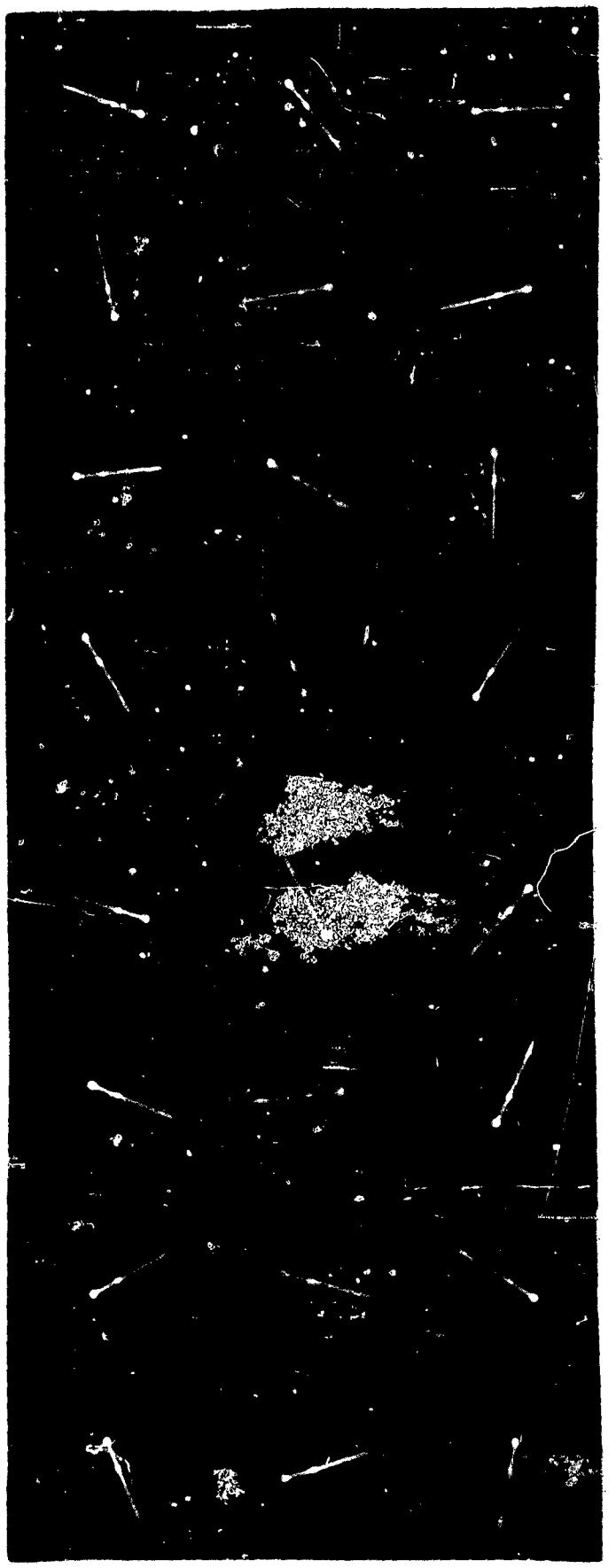

FIGURE 1 - DIAL PANEL

An instrument panel, a sample of the design to be exposed on the first experimental trial, was always in front of the subject. When the experimentor was ready for a test trial, a verbal command was given the subject, who released a catch which allowed the test panel to slide into place and cover the sample panel. The subject began reading aloud immediately. Oral reading responses were placed on a magnetic tape recorder. These recordings were later played back, and two independent listeners scored the subjects' responses.

The subjects were instructed to read both types of instrument dials to the nearest unit. The order of reading the dials was not specified, but most subjects read the panel from left to right, top to bottom. The subjects were neither informed of the acceleration levels to which they would be exposed, nor were they told of the quality of their performance or how they compared with each other.

The subjects were exposed to accelerative levels ranging from 1 to 4 g. The upper limit was set on the basis of the relation between acceleration and dimming of vision. It was decided that the highest acceleration would remain at least one g unit below the value at which dimming of peripheral vision would occur. Since the subject wore CSU-3/P anti-g suit, peripheral dimming could be expected at about 5 g. The specific sequence of acceleration, luminance levels and type of dial used for each subject was determined in advance. Over the entire experiment, there was systematic balancing of all order effects judged to be important.

RESULTS

The data of this experiment consist of error scores made by the same group of six subjects at five luminance levels and four conditions of acceleration. Figure 2 shows the percent of readings in errors plotted as a function of illumination. The parametric values represent performance under the various acceleration conditions. In specifying this relation, all errors, regardless of magnitude, are considered alike. That is, an error of one unit in reading counted as much as an error of ten units.

The data indicate (1) that at the highest luminance level there are no differences in the percentage of errors among the four acceleration conditions, (2) that at the three highest luminance levels, for values up to 3 g, there are no significant differences in the percentage of reading errors, (3) that at the two lower luminance levels, errors are inversely related to luminance and directly related to acceleration, (4) that at the 4 g condition there is a systematic increase in errors with decreasing brightness, and (5) that the 2 g level of acceleration cannot be distinguished from the 1 g or static condition.

In Figure 3, the data are plotted to show the relation between acceleration in g units and percent of total readings in error. The effect of luminance on this relationship is also shown.

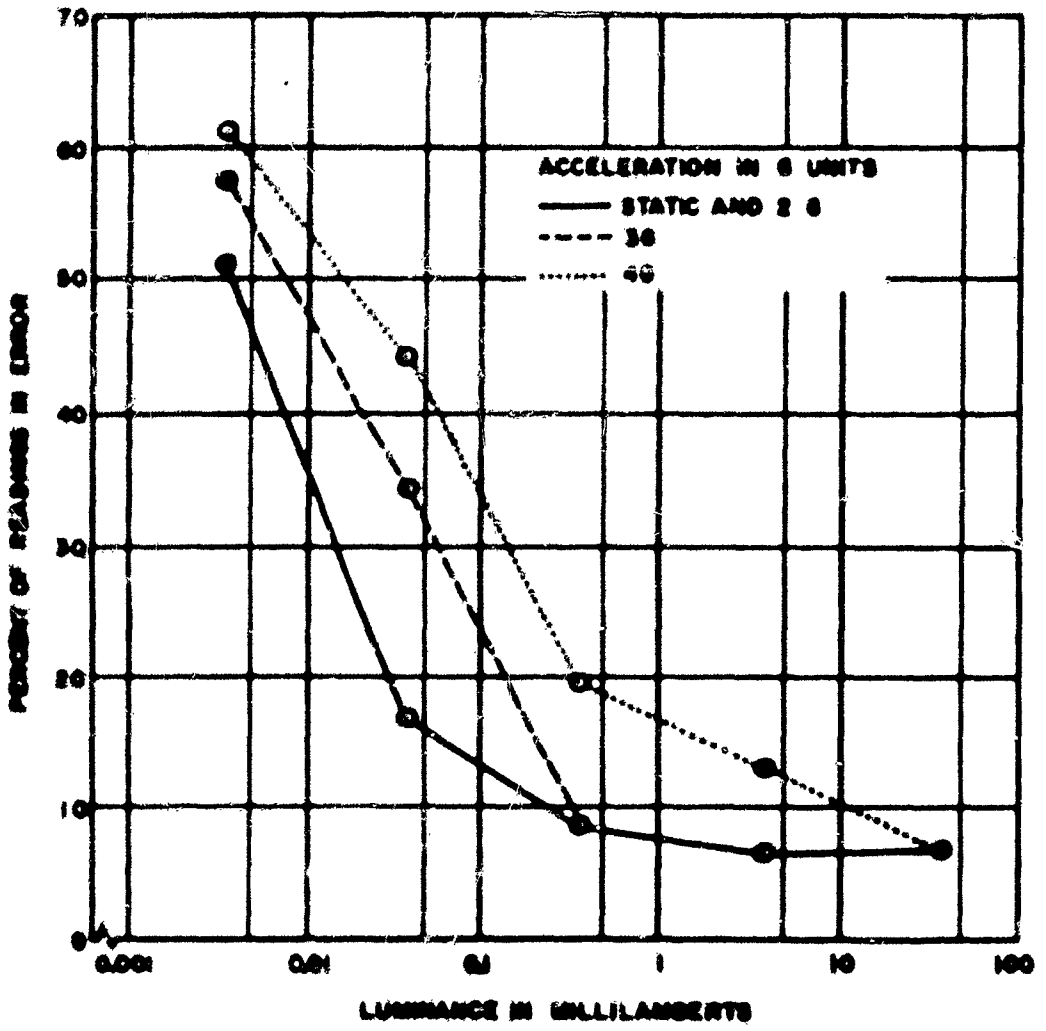

Figure 2 PERCENTAGE OF READINGS IN ERROR AS A FUNCTION OF LUMINANCE LEVEL FOR EACH G VALUE. THE DATA SHOW THAT THE INTENSITY OF ILLUMINATION COULD COMPENSATE FOR THE DECLINE OF VISUAL PERFORMANCE WITH ACCELERATION.

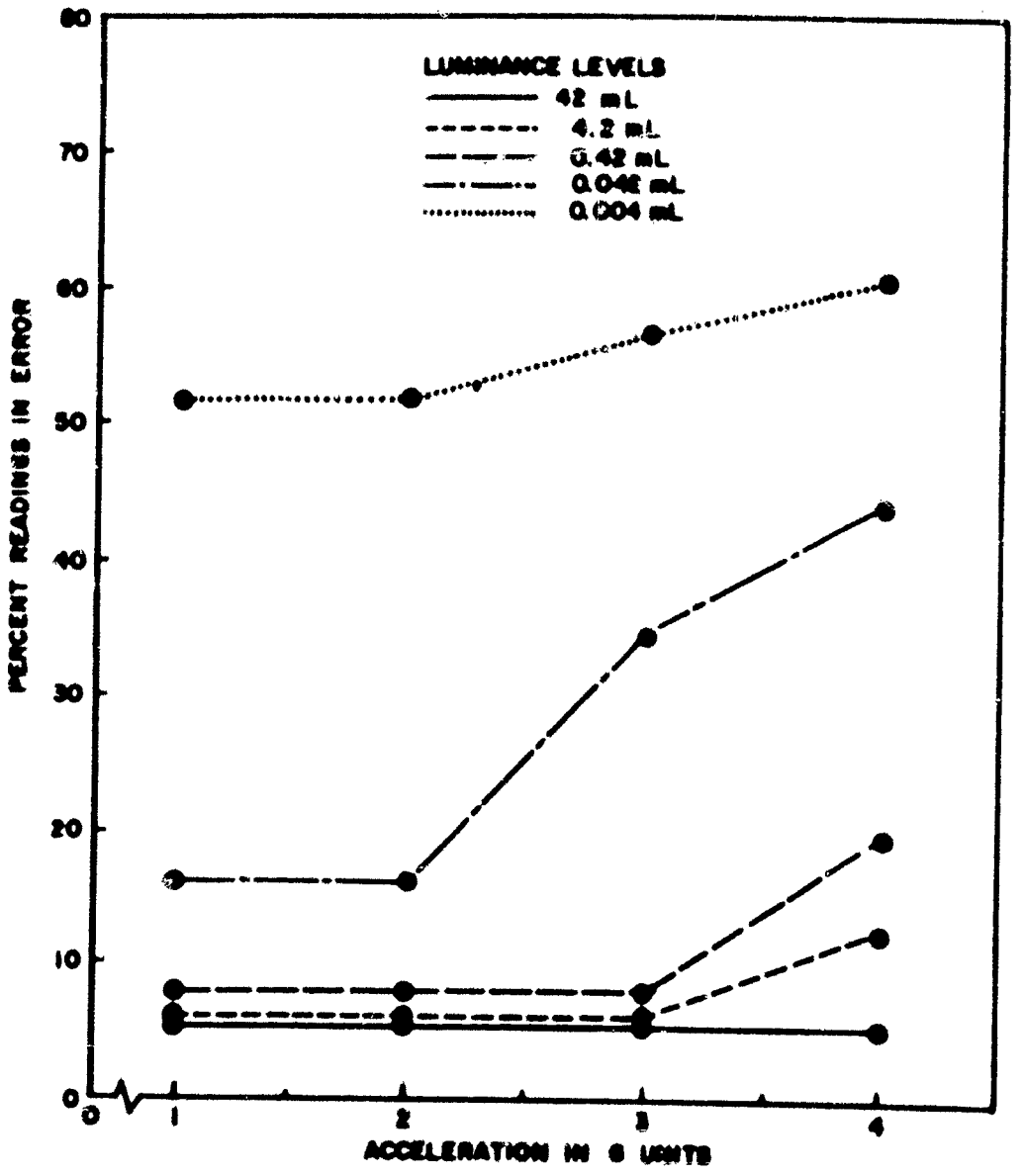

Figure 3 PERCENTAGE OF READINGS IN ERROR AS A FUNCTION OF ACCELERATION LEVEL. THE DEPENDENT MEASURE, PERCENT READINGS IN ERROR, INCLUDES READING IN ERROR BY 5 SCALE UNITS OR MORE AS WELL AS ERRORS OF 1 TO 4 UNITS.

An analysis of the data provides some evaluation of the kinds of errors made during the experiment. A tabulation of errors of one to four units and of errors of five units or more provides a basis for interpreting the graphic description of the results. Gross errors, that is errors of five units or more, account for slightly less than 13 percent of all the dial reading errors made. Of this 13 percent, 60 percent occurred at the lowest luminance level, and at this luminance level, these errors are not related to acceleration in any systematic manner. In view of the small percentage of gross errors, the data shown in Figures 2 and 3 are primarily an expression of errors of one to four units.

The error data were examined in yet another way to see if the dial graduation scheme interacted with acceleration and illumination. This analysis showed that the percentage of total readings in error for dials graduated in units and graduated by fives was identical (i.e., 20 percent) and bore no systematic relation to acceleration.

The reading errors were then related to the 12 locations on the instrument panel and examined in terms of acceleration and luminance. On this basis the data did not yield a significant relation.

A summary of the data is given in Table I. The entries shown in this table are the total errors, regardless of kind or dial type with which they were associated. The frequency of errors under certain experimental conditions prompted a combination of these for purpose of summarizing the data in graphic form.

TABLE I

SUMMARY OF TOTAL ERRORS BY LUMINANCE LEVEL AND ACCELERATION (72 READINGS PER CELL)

LUMINANCE LEVEL	ACCELERATION IN G UNITS			
	1	2	3	4
42 mL	3	4	5	5
4.2	6	5	4	9
0.42	8	6	8	14
0.042	10	13	26	32
0.004	37	38	41	44

DISCUSSION

The data obtained under the 1 g conditions are in agreement with previous studies of the effect of illumination on dial reading (2, 4, 7). That is, below a critical luminance, decreases in luminance are associated with increasingly poor performance, and above this value, increases in luminance produce little or no improvement. The task now at hand is to consider the changes in dial reading performance under conditions of 2, 3, and 4 g.

Warrick and Lund (5) have reported an investigation of the effects of moderate levels of acceleration on the ability to read instrument dials. They found that the number of readings attempted at two levels of acceleration was about the same, but the errors increased from 18 percent at 1.5 g to 24 percent at 3 g. Since they did not report the illumination level nor control data for the 1 g condition, a comparison is not possible. They were able to show, however, that positive g less than that required to produce blackout causes impairment in instrument reading ability.

The data from this experiment resemble in some respects the findings of studies on the effect of hypoxia on visual functions (1). Investigations of visual acuity under low oxygen tension show that the same relation holds between visual acuity and luminance as under normal oxygen conditions, the only change being a shift of the curve toward higher luminances. Such a shift results in relatively large decreases in acuity at low luminances. At increasing luminances, hypoxia produces less and less change. At very high luminances, the decrease is negligible.

Although dial reading is not a visual acuity task in a strict sense, there are similarities. In those studies where instrument reading errors have been compared with errors in reading Landolt rings at various luminance levels, there is a general similarity between curves of these two functions. This means that the acuity task and the dial reading task depend upon similar visual discriminations, that is, discrimination of detail.

On this basis it is possible to think of the effect of acceleration as being equivalent to that of placing an optical filter before the pilot's eyes. At 4 g, for example, the increase in errors is almost equivalent to reducing the luminance of the instrument reading task by one logarithmic unit.

In terms of equipment design, these data imply that cockpit lighting systems could be designed to minimize the reading errors which arise as a consequence of increased g.

Another possible cause of the observed decrement in performance needs to be mentioned. It has been shown that with high degrees of accommodation, the lens of the eye is displaced in the direction of gravity (3). This finding bears directly on the data obtained in this study, since a similar change in lens position may be expected as a function of acceleration stress. The relation between visual acuity and acceleration has been reported (6). Under conditions similar to those in this experiment, it was shown that acuity decreases progressively as

the magnitude of the acceleration is increased above 1 g. This decrease in acuity is reported to be a result of a displacement of the lens of the eye by the inertial force resulting from acceleration.

SUMMARY

This experiment was designed to determine whether or not a pilot's ability to read aircraft instrument dials at various levels of illumination is impaired by positive-g forces less than that required to produce blackout.

Twelve dials were presented simultaneously to an individual subject and his performance in reading the dials was scored in terms of errors and average time. Dials were scaled from 0 to 100 over the full circumference, graduated by fives and units. From a maximum brightness of 42 ml, the brightness of the dial marking was decreased in four equal logarithmic steps. The g-forces were produced experimentally in the WADC human centrifuge. The g-force was increased in unit steps from 1 to 4 g. The six subjects, experienced in centrifuge research, had normal vision and each wore an Air Force g-suit.

Upon analysis of the data it was found: (1) at the three highest brightness levels errors were at a minimum and no systematic increase in total error was found for values up to 3 g; (2) at the two lower brightness levels, the total error increased directly as a function of g and inversely as a function of brightness; (3) at all of the brightness levels used in the study, the 4 g condition yielded a systematic increase in total error with decrease in brightness; (4) total error and reading time vary in a generally similar way as a function of brightness level and g-value.

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