Effects of Transient Weightlessness on Brightness Discrimination

W. J. White, Ph.D.

Contrast thresholds of six semisupine, visually adapted subjects were obtained under short (10-14 sec.) periods of weightlessness and under 1 G control conditions. The target, viewed binocularly, subtended 1.5° and the background 2.6°. Three background luminance levels were used: 0.03, 0.28 and 30.0 ft-L. The contrast required to detect the target was found to be slightly, but consistently, lower under the weightless condition than under the control 1-G condition. Under the weightless condition the contrast required to detect the target averaged 12.56 per cent at 0.03 ft.-L background luminance, 6.49 per cent at 0.28 ft.-L background luminance and 3.99 per cent at 30.0 ft.-L background luminance. The corresponding contrasts required under the control 1-G condition averaged 15.14, 7.05 and 4.45 per cent respectively.

ACCELERATION IN EXCESS of 4 G produces gross visual symptoms, such as loss of peripheral vision and even temporary blindness. Accelerations of lesser magnitude have been shown to reduce visual acuity, increase the absolute visual-intensity threshold and decrease the sensitivity of the eye to differences in brightness. These effects may be due to reduced blood pressure in the eye, lowered oxygen content in the arterial blood, mechanical pressures on the eye or some combination of these.[10]

The effects of weightlessness and accelerations of less than 1 G upon vision are less well known. Pigg and Kama[7] reported that transient weightlessness had a slight detrimental effect on visual acuity but that it was not of practical importance. Astronauts Carpenter and Cooper reported seeing geographic and cultured features during orbital flight. During the 22nd orbit of Mercury-Atlas-9 mission, for example, Astronaut Cooper reported the sighting of roads and rivers, villages and houses, trucks and trains. At the time of these sightings his altitude was approximately 100 miles, illumination levels were high and weather conditions were clear. O'Keefe and his colleagues,[6] after analyzing the factors which influence visibility, found no reason to doubt the accuracy of these observations, nor did they see ". . . the need for postulation of improved visibility resulting from weightless conditions . . ." (p. 334). From space-flight experience and experimental work in zero-gravity aircraft it appears that flight crews can perform visual duties with little disturbance by the conditions of weightlessness. These data may also suggest that weightlessness causes no serious disturbance of physiological functions.

One of the most direct and fundamental tests of visual functioning consists of measuring the sensitivity of the eye to differences in brightness. Brightness contrast is a measure of the degree to which target luminance (B_t) differs from the background luminance (B_d). The equation for obtaining brightness contrast is:

$$\text{Contrast in per cent} = \frac{B_b - B_t}{B_b} \times 100$$

The unit used in this equation is the foot-lambert (ft.-L).

The present study examines the effect of transient weightlessness on the differential brightness or contrast threshold of the human eye. This study is an outgrowth of two earlier experiments on the effects of acceleration and body position on brightness discrimination.[3,4] These experiments suggested that threshold measurements taken during weightlessness would be lower than those obtained at 1 G or higher levels of acceleration.

METHOD

Production of Weightlessness. Although there are several methods of producing weightlessness the Air Force has found that the use of the airplane to achieve short-term weightlessness is both convenient and practical. In this study a C-131B was flown on a "Keplerian Trajectory." In this maneuver the aircraft follows a ballistic path, or parabola, so that the aircraft and objects inside are in a state of free fall and effectively weightless. The typical weightless period was 11 seconds, with a range of 10 to 14 seconds. The aircraft and objects inside were subjected to a 2.5 G pull-up immediately prior to and following each weightless period. Two parabolas were combined in one double maneuver for flight efficiency. Fifteen double maneuvers were flown during each test. Altitudes, airspeed and angles for a double maneuver of the C-131B are shown in Figure 1.

Apparatus. Brightness discrimination was measured by the apparatus of Braunstein and White.[4] Figure 2 shows the display box, a subject in the test position, the safety monitor and the experimenter. The stimulus display consisted of an achromatic circular target projected onto an achromatic circular background. The target and background subtended visual angles of 1.5 and 2.6 degrees respectively. The display was viewed binocularly.

The background was generated by a matrix of five 25-W bulbs behind two sheets of flashed opal. The target was projected onto the rear surface of a viewing screen by a 300-W slide projector. Voltage to the pro-

From the Advance Biotechnology Department, Douglas Aircraft Company, Inc., Missile & Space Systems Division, Santa Monica, Calif.

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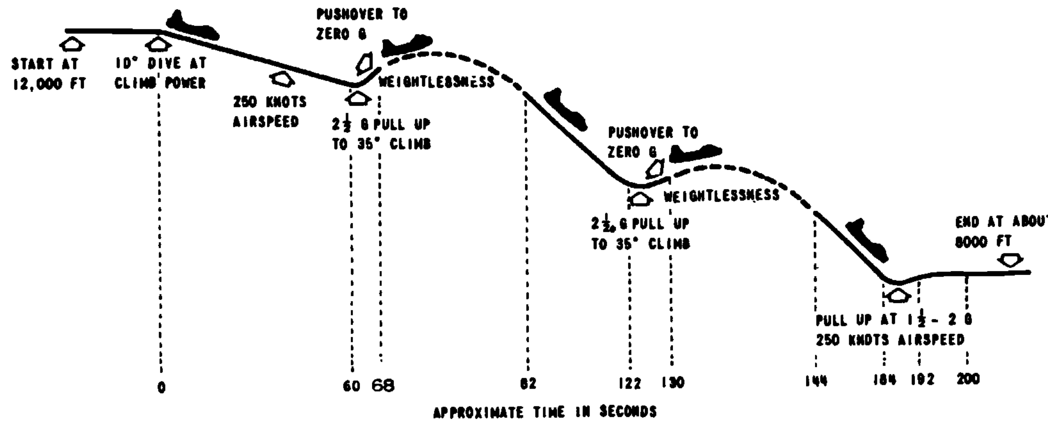

Fig. 1. Diagram of double zero-gravity parabola produced in the C-131B aircraft.

jection bulb was controlled by a motor-driven Variac operating at 4 V/sec. Neutral density filters were placed in front of the viewing screen to produce the desired levels of background luminance. A flat-black painted box containing the target and background display was mounted 28 inches in front of, and in line with, the subject's eyes. The apparatus was located at approximately midstation in the aircraft. Although the windows of the aircraft were covered further control over ambient illumination was achieved by means of enclosing the subject and display in a light-tight cloth hood.

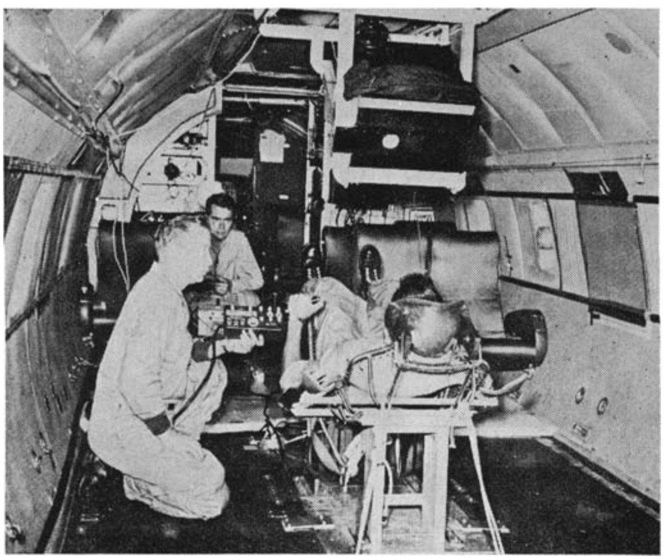

Fig. 2. Arrangement of the equipment, subject and monitors in the C-131B aircraft. The hood used to shield the subject from stray light is shown on top of the display box.

It has been shown[2] that tolerance to accelerations greater than 1 G is maximum when the vector is at right angles to the long axis of the body. Therefore, the supine body position was used to minimize the effects on vision of the 2.5 G pull-up immediately prior to and following each zero-gravity parabola. The subject was placed in a net couch so that a $+G_x$ vector was obtained. Relative motion between the display and the subject was minimized by the use of a body-restraint harness and a shaped headrest.

The subject was provided with a response button which initiated, after a time delay, a change in target luminance. A continuously rotating cam with three unequally spaced grooves activated a microswitch at intervals of 1.5, 2.0 and 2.5 seconds. After the button was pushed relays were set so that the rotation of the motor on the Variac controlling target luminance was reversed the next time the microswitch was activated. The total time between the subject's response and reversal of the direction of the variation in target luminance ranged from nearly zero delay to 2.5 seconds, in a random-appearing manner.

The voltage to the projection bulb at the instant of the subject's response was displayed on a digital voltmeter and recorded on an oscillograph. A spectra-brightness spot meter was used to determine the target luminance values corresponding to these voltage readings and to specify the luinance of the field. A Sola constant-voltage transformer was placed in the electric line between the aircraft 110-volt, 60-cycle power supply and the equipment used for measuring thresholds. Calibration runs were made during flight before and after a subject was tested. Variations between the pretest and post-test results were no more than 0.1 per cent. In addition periodic checks of voltages to the projection lamp were made by comparing voltages recorded during a calibration run with those taken during a test run. This comparison revealed no significant voltage variation. However, the oscillograph records indicated a lowering of line frequency during the 2.5 G pull-up maneuver that preceded and followed each weightless period. The frequency shift was estimated to be of the order of 1 or 3 cycles per second and one record as high as 5 cycles. The oscillograph records did not show evidence of frequency shift during the weightless period or during any other portion of the parabola. Measurement of the voltage to the bulbs generating the background showed that there was no voltage variation as the aircraft went through the zero-gravity parabolas.

The oscillograph recorded, in addition to target voltage and the operation of the response switch, the output of three accelerometers, one for each axis of the aircraft. Thus it was possible to relate accurately the voltage, at the time the subject's switch was operated, to the acceleration environment.

Procedure. The test procedure for measuring thresholds during the experiment was a modification of the psychophysical method of limits, that is, the subject was told to allow the luminance of the target to increase until he saw it against the background before pushing his response button and then to allow the luminance to decrease until the target could no longer be seen before pushing the button again. In this way the luminance of the target was made to oscillate around the threshold of the subject during the course of the experiment. The amplitude of these oscillations at the time the response button was pushed is a measure of the difference limen. This method was adopted because of its efficiency. Prior to the beginning of each test run target intensity was adjusted to a level below the minimum threshold for the background luminance level. The subject was then asked to commence responding, and the target was set to automatically increase in luminance.

In planning the experiment provision was made for obtaining data between weightless conditions, at 1 G, while the aircraft was flying straight and level before and after each double maneuver, and at 1 G immediately after a 2.5 G turn. The last condition was included to determine how the 2.5 G pull-up maneuver that preceded and followed each weightless period influenced subsequent thresholds. The plan of the experiment specified that all subjects would serve under this condition, two subjects at each background luminance level. Otherwise, all subjects served under all of the conditions of the experiment. Thus brightness discrimination thresholds were determined during the weightless condition, at 1 G and at 1 G following 2.5 G. Determinations were made under each of these conditions with background luminances of 0.03, 0.28 and 30.0 ft.-L.

The test procedure required that each flight begin with threshold determination at the lowest luminance level and work up the background luminance range to the highest level. At least 15 minutes of dark adaptation preceded the determination made at the lowest level and at least five minutes of dark adaptation preceded work at each successive higher luminance level. The technique for measuring threshold was the same for all test conditions.

The typical weightless period was 11 seconds, with a range of 10 to 14 seconds. During a double parabola four alternate ascending and descending threshold determinations were possible. Five double parabolas, therefore, implied 20 threshold determinations for each subject at each luminance level. On occasion, however, apparatus difficulties or air turbulence reduced the maximum number of determinations but at least seven ascending and seven descending responses were used; also 20 threshold determinations were obtained for each subject at each luminance level at 1 G and for each of the two subjects at each luminance level at 1 G following 2.5 G.

Each response was converted to foot-lamberts of target luminance by a voltage-to-foot-lambert conversion table. The table was produced by taking readings to the target at every voltage value in the range of responses (20 to 75V) with a spectra-brightness spot meter. The mean target luminance for the responses was divided by the background luminance. In this report all threshold figures are reported as per cent contrast. Since the filter factor was the same for target and background it does not enter into these calculations.

About five minutes after becoming airborne the subject was fitted into the net couch and started making responses at the lowest luminance level. Adaptation was recognized when 10 successive determinations showed less than 1 per cent variation. On reaching a stable level of adaptation the pilots were informed and the experimental runs were begun. The subject remained in the couch and responded to changes in luminance for practically two hours. Programmed rest periods were allowed after each luminance level. Flights were made in both the morning and afternoon.

Subjects.—The six subjects who participated in this experiment were civilian and military personnel of the Aerospace Medical Research Laboratories. Their ages ranged from 20 to 28 years. All had previously served as subjects in psychophysical experiments, all were experienced in this type of flying and none became nauseated during the two hours of in-flight testing. Medical examination showed all subjects were free from optical pathology and had uncorrected visual acuity of 20/20 in both eyes.

RESULTS

A summary of the major results of the experiment are shown in Table I and Figure 3.

TABLE I. BRIGHTNESS DISCRIMINATION THRESHOLDS FOR EACH SUBJECT AS A FUNCTION OF BACKGROUND LUMINANCE AND LEVEL OF ACCELERATION

(Entries are average thresholds in per cent contrast)

	0 G			1 G		
Subject	0.03 ft.-L	0.28 ft.-L	30.0 ft.-L	0.03 ft.-L	0.28 ft.-L	30.0 ft.-L
1	11.46	5.82	3.85	13.14	5.98	4.34
2	10.88	5.83	4.12	11.76	6.15	4.38
3	14.60	6.69	3.85	18.86	7.60	3.95
4	13.68	7.34	3.93	16.71	8.19	4.82
5	11.53	5.99	3.88	12.67	6.50	4.55
6	13.23	7.25	4.27	17.69	7.90	4.64
Average	12.56	6.49	3.99	15.14	7.05	4.45

Fig. 3 illustrates the effects of acceleration on the relation between the threshold and background luminance.

An analysis of variance of the thresholds for 36 runs is presented in Table II. The main effects of background luminance and acceleration and the interaction of acceleration and background luminance are considered statistically significant.

Table III shows the brightness discrimination thresholds taken 1 G following a 2.5 G turn. Two subjects were used at each luminance level. These data are to be compared with the threshold data shown in Table I for each of the subjects.

DISCUSSION

A decrease in the contrast required to detect a target is clearly shown to occur during weightlessness. This decrease is most marked in the case of the dimmest

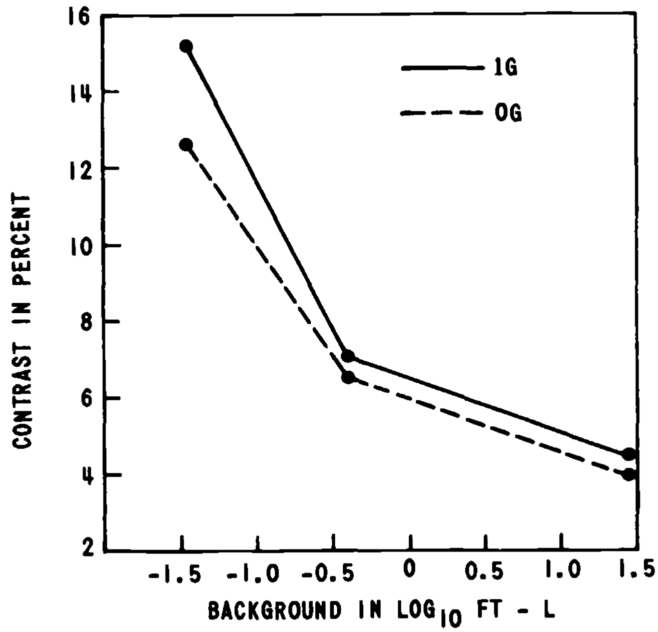

Fig. 3. Relation of brightness discrimination threshold to background luminance for two levels of acceleration.

background luminance studies, 0.03 ft.-L. At this level 12.6 per cent contrast was required to detect a target during weightlessness, as compared with 15.1 per cent at 1 G. The data in Table I shows that the thresholds recorded during weightlessness for each subject are lower than their corresponding threshold determinations at 1 G.

The 2.5 G pull-up that precedes and follows each parabola does not appear to have a consistent effect on subsequent thresholds. Although the mean thresholds of the subjects under each luminance level are higher than those obtained during 1 G (straight and level flight), a comparison by subjects shows inconsistencies. This can be seen by comparing the data in Table I with those in Table III. Subjects 3 and 6 had lower thresholds following the 2.5 G maneuver than they did at 1 G.

TABLE II. ANALYSIS OF VARIANCE OF THRESHOLD DATA
(Significance tests use the interaction of the effect tested with subjects as the error term)

Source	df	Mean Square	F
Luminance	2	0.029904	111.58*
Acceleration	1	0.001298	24.96*
Subjects	5	0.000592	—
L x A	2	0.000426	10.65*
L x S	10	0.000268	—
A x S	5	0.000052	—
L x A x S	10	0.000040	—
Total	35	0.001950	—

*$p < .005$

At the highest luminance level subject 2 had a lower threshold after the 2.5 G maneuver than he did at 1 G, while subject 4 showed no difference between the thresholds for the two conditions. Thus this aspect of the experiment must be judged as inconclusive.

An examination of these data and a study of the theories of visual function suggest at least one hypothesis to account for the observed effects. After considering the data in terms of threshold mechanisms, neural pathways and the dioptrics of the eye, only the oculomotor mechanism offers a reasonable framework in which to consider the data.

TABLE III. BRIGHTNESS DISCRIMINATION THRESHOLDS FOR EACH SUBJECT AS A FUNCTION OF BACKGROUND LUMINANCE AND 1 G IMMEDIATELY AFTER A 2.5-G TURN
(Entries are averaged thresholds in percent contrast)

Subject	Background Luminance in ft.-L 0.03 ft.-L	0.28 ft.-L	30.0 ft.-L
1	—	7.77	—
2	—	—	4.25
3	15.62	—	—
4	—	—	4.81
5	—	7.92	—
6	15.17	—	—
Average	15.35	7.84	4.53

Role of Physiological Nystagmus. In normal vision the eye is constantly in motion. Small involuntary movements persist even when the eye is fixed on a stationary object. As a result the image of the object on the retina is kept in constant motion. Under conditions of steady fixation the limiting motion of the eye is a tremor (physiological nystagmus) whose angular extent is typically from 10 to 20 seconds of arc or about half the diameter of a single-cone receptor. The frequency of these involuntary movements ranges from 20 to 150 cycles per second. The importance of "dither" is reasonably well understood as a result of the research of Riggs[8] and Ditchburn.[5] In general the tremor is thought of either as an averaging mechanism which rectifies the image on the retina or the means by which the illumination on a given receptor is rapidly changed from one level to another with consequent increase in effective stimulation.

Independently Riggs and Ditchburn devised a technique for immobilizing the retinal image and were able to show that motion plays a significant role in the sensory function of the eye. The most striking subjective effect reported is the rapid fading out and ultimate disappearance of objects within the test field. Consequently constant illumination of the retinal mosaic is not a physiological stimulus since the image fades as a result of adaptation of the photoreceptors. Experiments reveal that this fading is practically abolished by doubling the motion found in normal vision. Exaggerated nystagmus was produced by an optical system.

On the basis of this evidence the hypothesis is proposed that the decrease in the contrast required to detect a target during weightlessness is a result of exaggerated motion of the retinal image. There is, in other words, an increase in physiological nystagmus during weightlessness that minimizes adaptation of the photoreceptors and results in lower contrast thresholds for the eye.

The most direct approach in considering how weightlessness might produce exaggerated tremor is to consider the eye as a dynamic system and consider the mechanical constants of the orbital tissues which govern the dynamic response of the eye in changing position.[9] Characteristics of the eye which determine its motion behavior are the mass and the friction and damping developed during movement. An increase in acceleration increases the weight of the globe. This increase probably increases the frictional and/or the damping forces created between the eyeball and its supporting structure. The work of Beckman, Duane and Coburn[1] on eye movements during increased G could be considered as support for this argument. They report that subjects exposed to acceleration show progressive loss in ocular mobility with increasingly higher levels of acceleration.

During weightlessness the mass of the eyeball remains constant but the frictional and damping forces developed during movement would probably decrease. Thus for a given level of reciprocal activity of the eye muscles a reduction in the forces tending to oppose the motion of the globe should result in an increased amplitude of nystagmus. If reduction in friction or damping of the system resulted in increasing the amplitude over the normal range of 10 to 20 seconds of arc it is possible that weightlessness produces the exaggerated motion that Riggs and his co-worker found good for overcoming the loss in vision due to uniform stimulation of retinal receptors.

Evidence for the role of nystagmus in vision during weightlessness is indirect. Tests of this hypothesis can come only from additional flight testing with sophisticated instrumentation.

Limitations of the Present Study. In-flight research requires compromise in the direction of the safety of the subjects and the operational capability of the aircraft. The present experiment may properly be regarded as exploratory. It does not provide a complete answer to the role of weightlessness in visual function. Instead, there are a great number of problems to be investigated.

During the course of a double parabola the subjects were of necessity exposed to variations in noise, vibration, odors and cabin altitude. Partially as a result of these variations our thresholds at 1 G and the lowest luminance level are higher than those reported by Braunstein and White and Braunstein and Siegfried[3] in using the same apparatus and procedures in the laboratory. These authors report contrast thresholds of the order of 10 per cent at 0.03 ft.-L and at the highest luminance level Braunstein and White report thresholds to be about 2 per cent lower than those found here. Pigg and Kama report that sensory thresholds obtained in the 1 G environment of flight are higher than those obtained in the laboratory.

Comfort and safety of the flight crews prevented the testing of every subject under all of the conditions required for rigid experimental control. The control runs at 2.5 G adequately simulated the pull-up maneuver before zero gravity and were, therefore, too short to produce any worthwhile data on the effects of acceleration ($+G_x$) on brightness discrimination. The 2.5 G control runs lasted for less than eight seconds, whereas at least 10 seconds were needed to determine the upper and lower contrast limens. Finally, the variability of individuals in making their judgments was due partly to combined stresses and partly to inadequate practice. The subjects used in the study received less practice than subjects used in laboratory experiments of this kind.

SUMMARY

Brightness discrimination was measured on six subjects while they were exposed to short periods of weightlessness aboard an aircraft flown through zero-gravity trajectories. This aspect of vision was measured at background luminances of 0.03, 0.28 and 30.0 ft.-L. Control measurements were taken at 1 G and at 1 G following a 2.5 G pull-up maneuver. The subjects were in the semisupine body position ($+G_x$) while being tested.

Within the scope of this experiment the following conclusions are stated:

(a) The percentage contrast required to detect an increment in luminance decreased with increased luminance of the background.

(b) Contrast required to detect an increment in luminance decreased during weightlessness.

(c) The effects of weightlessness were most marked at the lowest background level studied, 0.03 ft.-L.

(d) The 2.5 G pull-up maneuver has an inconsistent influence on the data obtained while the subjects were weightless.

The hypothesis is advanced that the relative improvement in brightness vision obtained during weightlessness is a result of an increase in the amplitude of physiological nystagmus.

Limitations of the present study were noted and the need for carefully planned and executed experiments with sophisticated apparatus is shown.

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