NASA TECHNICAL NOTE

NASA TN D-5162

c. 1

NASA TN D-5162

THE RELATIONSHIP BETWEEN OPTICAL DISTORTION AND BINOCULAR DEPTH PERCEPTION

by L. R. Loper and R. C. Stout

Manned Spacecraft Center
Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1969

NASA TN D-5162

THE RELATIONSHIP BETWEEN OPTICAL DISTORTION AND BINOCULAR DEPTH PERCEPTION

By L. R. Loper and R. C. Stout

Manned Spacecraft Center
Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

ABSTRACT

Binocular depth perception, a vital function during spacecraft docking and lunar landing, could be degraded by any spacecraft system optical transparency. A study of the relationship between binocular depth perception and optical distortion in the Apollo pressure suit helmets and visors was made to aid in setting optical distortion limits for the helmets and visors. Data obtained from the study indicated that all the helmets and visors which were tested degraded binocular depth perception. As measured by the Howard-Dolman apparatus, there is evidently a systematic effect of optical distortion in the Apollo helmets and visors on binocular stereoscopic depth perception. A program for studying this problem in greater depth is outlined.

THE RELATIONSHIP BETWEEN OPTICAL DISTORTION AND BINOCULAR DEPTH PERCEPTION

By L. R. Loper and R. C. Stout
Manned Spacecraft Center

SUMMARY

A study of the effects of optical distortion in the Apollo pressure suit helmet and visors on binocular depth perception has indicated that binocular depth perception was degraded by all the helmets and visors tested. In this study, the Howard-Dolman apparatus was used to measure depth perception, and a projection test was used to measure optical distortion. The data indicated that there is a significant difference between the base-line Howard-Dolman scores and the Howard-Dolman scores taken through any of the helmets or visors. There is evidently a systematic effect of optical distortion in the Apollo helmets and visors on binocular stereoscopic depth perception as measured by the Howard-Dolman apparatus. A program of applied research and development for further study of this problem is outlined.

INTRODUCTION

Binocular stereoscopic vision is important in any task requiring precise visual localization of objects in space. Good stereoscopic vision is necessary in the operation of cranes, drag lines, remote-controlled mechanical hands, and machine tools requiring hand and eye coordination. Good stereoscopic vision is of special importance during the docking of spacecraft and during the later stages of lunar landing. Any of the spacecraft system optical transparencies (the spacecraft windows and the pressure suit helmet and visors) through which the astronaut must look can potentially degrade or destroy binocular depth perception. The better the fidelity with which these transparencies transmit the viewed scene, the better will be the response of the eyes to stereoscopic cues.

This is a report of a study of the relationship between binocular depth perception and optical distortion in the Apollo pressure suit helmets and visors. The objective of this study was to obtain data which would aid in setting realistic optical distortion limits for pressure suit helmets and visors. These limits would then be based on a physical measurement of optical distortion in the helmets and visors, and this measurement is related to a vital visual function — binocular depth perception.

Research for this effort was performed in the Visual Optics Laboratory of the Biomedical Research Office, Medical Research and Operations Directorate, NASA Manned Spacecraft Center, during June, July, and August 1967 and is documented under the visual optics program area as a work unit in ophthalmic transparencies. The work was done in support of the Crew Systems Division development of the Apollo block II pressure suit. Frank A. Michelli of the Biomedical Technology Division performed the statistical analysis of the data.

BINOCULAR STEREOSCOPIC VISION

Binocular stereoscopic vision is the highest and most complex form of primate vision (refs. 1 to 4). This function is a result of the two eyes fixing the same object, yet viewing it from slightly different angles. The resulting dissimilar images falling on the retinas form the single perceptual image which stands out in full relief. Each eye must have good visual acuity, the luminance of the two images must be approximately the same in the two eyes, the two images must be approximately the same size, and the two uniocular images must fuse into a single perceptual image. Anything which degrades or destroys these balances will degrade or destroy stereoscopic vision.

In addition to the binocular cues, there are monocular or empirical cues to depth perception which are mediated by each eye acting as a separate unit (ref. 1, p. 133). The monocular function takes over at distances beyond the function of stereoscopic vision and adds to depth perception at nearer distances. Monocular depth perception is the only form of depth perception for one-eyed individuals and for two-eyed individuals whose eyes do not function as a unit.

Stereoscopic vision functions from near the eyes to approximately 650 meters (710 yards or approximately one-fourth mile) (ref. 1, p. 137) and varies with the distance between the eyes (interpupillary distance) and with stereoscopic acuity. Binocular stereoscopic acuity is extremely sensitive to relative changes of the size and shape of the two retinal images (ref. 1, p. 142). Optical distortion in transparencies causes variation in the size and shape of the retinal images of the eyes. It is expected that a relationship exists between optical distortion and binocular stereoscopic vision. For this study, optical distortion is defined as random deviations of light rays caused by random curves, irregular thicknesses, and inhomogeneities of optical transparencies. Schachter and Chapanis (ref. 5) and Cibis et al. (refs. 6 and 7) studied the effects of optical distortion in transparencies on binocular depth perception. These studies were concerned principally with plane-parallel transparent plates and with the effects of tilting and rotating the plates before the eyes. Valuable data were obtained; however, it is difficult to relate the results to standard optical distortion tests. The physical form and optical defects of the Apollo helmets and visors under study are not amenable to analysis by the methods used in the studies cited previously.

EFFECTS OF OPTICAL DISTORTION ON BINOCULAR DEPTH PERCEPTION

Method and Instrumentation

This study was conducted in three phases. Phase I was a pilot study to determine if there is a systematic effect of optical distortion on binocular depth perception. Three Gemini visors, one Army polycarbonate flight-helmet visor, and one Apollo two-piece helmet were used in phase I. Phase II was a study of six Apollo visors, and phase III was a study of one Apollo helmet, a stack of two Apollo visors, and a stack of three Apollo visors. Phase III was conducted to study the effects of multiple layers of transparencies on binocular depth perception.

The test items producing the optical distortion in this study were transparent polycarbonate visors and helmets for the Gemini and Apollo pressure suits (ref. 8). The one exception was an injection-molded polycarbonate visor for the Army flight helmet used in phase I. These transparencies were clear, uncolored, with a luminous transmittance of approximately 85 percent. The average thickness of the material was 0.178 centimeter (0.070 inch) with an index of refraction of 1.586. The nominal radius of curvature of the Gemini visors was 11.7 centimeters horizontally and 19.2 centimeters vertically; of the Apollo visors, 14.2 centimeters horizontally and 16.3 centimeters vertically; of the Apollo helmet, in the primary visual zone, 11.7 centimeters horizontally and 15.1 centimeters vertically; and of the Army flight-helmet visor, 13.0 centimeters horizontally and 16.5 centimeters vertically. The pressure suit visors and helmets are formed with the thinnest point in the front upper center, the "optical center." A slight prismatic effect radiates in all directions from this point. A small, inherent refractive power generated by the concentric surfaces occurs in the visors and helmets. In the Apollo helmet, this refractive power varies considerably from point to point because of the complex curves. The haze value of the helmet material was approximately 0.50 percent. Inhomogeneities, such as minute bubbles and lint, were found throughout the transparencies.

The projection test used to provide a physical measure of the optical distortion in these transparencies was method 3041 of Federal Standard Number 406. In this test, a Clason visual acuity meter (ref. 9) was focused on a screen 7.62 meters (25 feet) away. A square image 25.4 centimeters (10 inches) on a side was formed on the screen. No target was used in this projector. The item under test was held next to the screen and then gradually moved away from the screen toward the projector. A distortion or D score is obtained by noting the distance in inches that the transparency can be moved from the screen before dark and light patches form on the screen. The greater the distance, the less distortion in the transparency. There is little variability in determining D scores at short distances, such as 25.4 centimeters (10 inches), for the poorer transparencies; however, for the higher scores at 101.6 centimeters (40 inches) and beyond, the variability may be ±7.62 centimeters (3 inches). The theory is that small optical deviations in the transparency will not form distortion images except at considerable distance from the transparency. Conversely, the more pronounced optical deviations will form distortion images at shorter distances. The D scores used were averages of five trials taken by the same experimenter.

The Howard-Dolman (H-D) apparatus (ref. 10) was used in this study to measure binocular stereoscopic acuity. Two vertical black rods were placed 5.7 meters from the subject's eyes. The right-hand rod was fixed; but with a string pull, the left-hand rod could be moved away from or nearer to the subject in a track along the anterior-posterior axis. The rods were of equal diameter, 0.95 centimeter. The horizontal separation of the rods was 6.0 centimeters, center to center. A black mask with an opening 10.3 centimeters vertically and 18.3 centimeters horizontally was placed 5.5 meters from the subject's eyes. A uniform white field was placed 30.5 centimeters behind the fixed rod. The luminance of this field was 175 foot-lamberts. The subject was seated on a stool in front of an adjustable instrument table. A head-and-chin rest was fixed to the instrument table to keep the subject's head immobile. The visor test items were fixed in a jig attached to the head-and-chin rest so that all subjects viewed the H-D apparatus through the same area of the test objects. The helmet test items were held in place by an overhead jig attached to a chair. The illumination on the black rods of the H-D apparatus was 400 foot-candles from above. The illumination at the position of the subjects' eyes was 150 foot-candles from above and 98 foot-candles from the front.

All subjects were tested on the Bausch and Lomb modified Ortho-rater (ref. 11) for monocular distant visual acuity, corrected and uncorrected; vertical and horizontal heterophoria; and depth perception. Only subjects with corrected visual acuity of 20/25 or better in each eye and with single, simultaneous binocular vision as determined on the Ortho-rater depth perception test were selected. To qualify as a subject, a person was required to have an average score for 10 trials of 35 millimeters or less separation of the posts on the H-D apparatus for phase I and 30 millimeters or less separation for phases II and III. Thus, it was assured that each subject had good visual acuity and binocular vision and relatively good binocular stereoscopic acuity. Twenty-one subjects participated in phases I and III, and 23 participated in phase II. Some of the subjects participated in all three phases.

In the trials, the subject was first tested on the Ortho-rater and later seated at the head-and-chin rest or on the chair, depending upon whether visors or helmets, respectively, were being tested. The experimenter placed the movable rod of the H-D apparatus either to the front or to the rear of the track and directed the subject to pull the string until the two rods appeared to be side by side or equidistant. The subject would then drop the string on the floor. The subject was allowed to use only one hand and could not move the rod back and forth. Each subject was given 10 trials for practice, after which the test items were presented in random order. Included was a series of 10 trials without a test item before the eyes for a base line. The H-D score for each subject behind a single test item was the average of 10 trials. Distant binocular visual acuity was taken through each test item by using a pasteboard U. S. Armed Forces visual acuity chart placed beside the H-D apparatus. The luminance of the visual acuity chart was 79.5 foot-lamberts. In no case did a test item degrade visual acuity as measured in this manner.

Results

Table I summarizes the results from phases I, II, and III. Figure 1 is a composite of all three phases. The base-line H-D score for phase I (without helmet or visor before the eyes) is 18.6 millimeters (standard deviation $\sigma = \pm 7.7$); for phase II, 17.0 millimeters ($\sigma = \pm 5.7$); and for phase III, 16.7 millimeters ($\sigma = \pm 7.4$). These data indicate a statistically significant difference between the base-line H-D scores and the H-D scores taken through any of the helmets or visors. There is evidently a systematic effect of optical distortion in the Apollo helmets and visors on binocular stereoscopic depth perception as measured by the H-D apparatus.

TABLE I. - SIGNIFICANCE OF HOWARD-DOLMAN SCORES

FOR EACH VISOR OR HELMET AS COMPARED WITH THE BASIC

HOWARD-DOLMAN SCORE BY A PAIRED t TEST

Phase	Test item	D score, cm (in.)	Mean H-D score, mm	Standard deviation, σ	t (a)
I	No transparency	- -	18.6	7.7	-
	Apollo helmet	119.38 (47)	27.7	11.4	3.80
(N = 21)[b]	Gemini visor	101.6 (40)	26.5	12.4	3.16
	Army polycarbonate	63.5 (25)	27.8	10.3	2.83
	Gemini visor	35.56 (14)	34.6	16.0	5.61
	Gemini visor	25.4 (10)	68.0	27.5	8.22
II	No transparency	- -	17.0	5.7	-
	Apollo visor	101.6 (40)	20.7	9.4	2.38
	Apollo visor	76.2 (30)	22.8	9.8	2.89
(N = 23)	Apollo visor	66.04 (26)	29.8	11.2	5.09
	Apollo visor	50.8 (20)	28.1	16.4	3.62
	Apollo visor	43.18 (17)	42.7	20.7	5.36
	Apollo visor	25.4 (10)	57.4	31.6	5.67
III	No transparency	- -	16.7	7.4	-
(N = 21)	Stack of two transparencies	76.2 (30)	23.0	8.1	3.30
	Stack of three transparencies	63.5 (25)	29.9	10.3	4.71
	Apollo helmet	53.34 (21)	33.3	13.8	4.70

[a] All t values are significant at the 0.025 level of significance.

[b] N indicates the number of subjects.

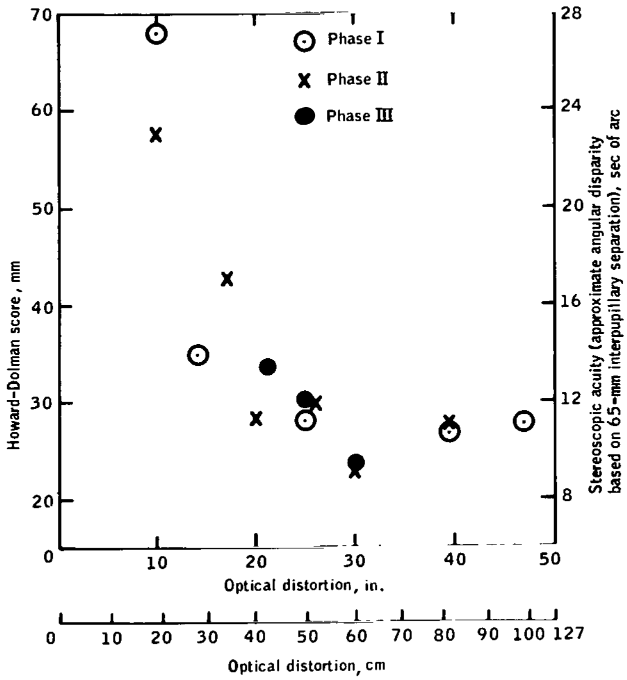

Figure 1. - The effect of optical distortion in the Apollo helmet on stereoscopic depth perception.

Discussion

Examination of the data in table I indicates that all the transparencies tested degrade binocular depth perception. The paired t test (ref. 12) shows a significant difference at the 0.025 level of significance between the H-D scores with each transparency and the base-line H-D scores without the transparency before the eyes. The data points in figure 1 become asymptotic to the distortion score axis, providing a strong indication that there is an inherent defect in the helmet insofar as stereoscopic vision is concerned. The base-line (no transparency) H-D scores are well within the range reported by Howard (ref. 10) in his original experiment.

The projection test D scores discussed previously show more variability on the higher scores of the better transparencies. The projection test, a composite of several optical factors, is based on localized refractive power, prismatic deviation, haze, and inhomogeneities. These data indicate that although an optical transparency does not degrade visual acuity, it can seriously degrade binocular stereoscopic vision and other visual functions such as muscle balance. Tasks such as spacecraft docking and lunar landing will probably be degraded in situations where monocular depth-perception cues are at a minimum and where more dependence is placed on binocular depth-perception cues. Setting of the D score limit for optical distortion based on these data alone would be tenuous since performance data are lacking. The effect of stacking the transparencies and looking through several layers is apparently the same as the effect of looking through a single transparency with the same D score as that of the stack.

This study is an examination of the effect of the Apollo pressure suit helmet and visors on binocular depth perception. The effects of these transparencies on visual function should be examined in greater depth. A reasonable program of study in this area would include (1) the development of improved tests for the physical characteristics of transparencies, (2) more extensive studies on the effects of optical distortion on visual function, and (3) studies to determine the effects of optical distortion on mission task performance. In the third category, Apollo mission tasks requiring binocular depth perception should be used to determine the significance of optical distortion on actual required tasks. The program outlined in this report can be expected to yield data indicating the relative significance of optical distortion in Apollo pressure suit helmets and visors on task performance. These data can then be used in developing a specification for optical distortion. In addition, an objective test for optical distortion will be established.

CONCLUSION

Spacecraft system optical transparencies (spacecraft windows and pressure suit helmets and visors) can potentially degrade binocular depth perception, a function of vital importance in spacecraft docking and in lunar landing. This study, which consisted of three phases, used a Howard-Dolman apparatus to measure binocular stereoscopic acuity and a projection test to measure optical distortion. All three phases of the study indicated a systematic effect of optical distortion in the Apollo helmets and visors on binocular stereoscopic depth perception as measured by the Howard-Dolman apparatus. The data showed a statistically significant difference between the base-line Howard-Dolman scores and the Howard-Dolman scores taken through any of the helmets or visors. In the tests, all the helmets and visors degraded binocular depth perception.

A program to examine this problem in greater depth has been proposed. This program should include the development of improved tests for the physical characteristics of transparencies, more extensive studies on the effects of optical distortion on visual function, and studies to determine the effects of optical distortion on mission task performance. Data obtained from these studies can be used to develop a specification for optical distortion.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, February 3, 1969
914-50-95-21-72

REFERENCES

1. Ogle, Kenneth N.: Researches in Binocular Vision. W. B. Saunders Co., 1950, pp. 1, 2, 133, 137, 142.

2. Adler, Francis Heed: Physiology of the Eye. The C. V. Mosby Co., 1965.

3. Graham, C. H., ed.: Vision and Visual Perception. John Wiley and Sons, Inc., 1965, pp. 523-529.

4. Duke-Elder, Sir W. Stewart: Text-Book of Ophthalmology, Vol. I. The C. V. Mosby Co., 1946.

5. Schachter, Stanley; and Chapanis, A.: Distortion in Glass and its Effect on Depth Perception, Memorandum Report, TSEAL 3-695-48B. Aero Medical Laboratory, Wright-Patterson AFB, Ohio, April 27, 1945.

6. Cibis, Paul A.; and Haber, F.: Studies on Effects of Windshields and/or Air of Different Densities on Stereoscopic Vision, Vol. I, Mathematical Principles Concerning Displacement Effects on Bidimensional Perception of Direction, Size, and Distance, and Tridimensional Perception of Depth. USAF School of Aviation Medicine, Nov. 1950, ATI 93914.

7. Cibis, Paul A.; Wilson, M. R.; and Fleck, H. G.: Studies on Effects of Windshields and/or Air of Different Densities on Stereoscopic Vision, Vol. II, Description of a Stereo-Meter and Method for Measuring Cyclo-Incongruities. USAF School of Aviation Medicine, Nov. 1950, ATI 110631.

8. Anon.: Plastic Molding Material, Polycarbonate, Injection and Extrusion, Federal Specification L-P-393a, January 31, 1964.

9. Anon.: Clason Acuity Meter, Threshold Determination of Visual Acuity. Bausch and Lomb Optical Co., Rochester, N.Y.

10. Howard, H. J.: A Test for the Judgment of Distance. Am. J. of Ophthalmology, Vol. 2, 1919, pp. 656-675.

11. Anon.: Instructions, Master Ortho-Rater and Modified Ortho-Rater. Bausch and Lomb, Inc., Rochester, N.Y.

12. Steel, R. G. D.; and Torrie, J. H.: Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., 1960, pp. 78-80.

NASA-Langley, 1969 —— 5 S-210

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

[illegible] 69086 00903
[illegible] LABORATORY/AFWL/
[illegible] AIR FORCE BASE, NEW MEXICO 87117

[illegible] ACTING CHIEF TECH. LI

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546