*The Practical Application of Research on Visual Factors in Stereoplotting**

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ABSTRACT: *The physical condition of stereocompilers and the environment in which they work are pertinent factors in photogrammetric mapping. This report presents the results of a research project in this field conducted by the Topographic Division of the U. S. Geological Survey in cooperation with Dr. Wendell E. Bryan, O.D.*

The research, based upon a previous study in 1959, was initiated in 1961. This project, involving 60 stereo-compilers, explored the effect of visual deficiencies of the human eye in addition to environmental conditions and some of the psychological effects of stereoscopic plotting.

The study produced definite recommendations for refractive examination and correction for stereocompilers and for environmental conditions under which they work. Some changes in equipment design were also suggested.

IN 1959 the Topographic Division of the U. S. Geological Survey negotiated a research contract with Dr. Wendell E. Bryan to study the problem of eye fatigue in stereoplotting operations at their Rocky Mountain Area headquarters in Denver. This "pilot study" dealt with 10 stereocompilers for a period of 6 months.

Some previous work had been done by Salzman[1] and Anson[2] and the results of the pilot study were reported by Dwyer.[3]

The findings of this study prompted the Geological Survey in August 1961 to initiate an expanded research contract with Dr. Bryan. In this study the base was enlarged to 60 photogrammetrists for a period of 18 months, in order to provide a better statistical base. An environmental study was carried on in conjunction with this work, and a psychological survey was conducted as one means of evaluating the results from the various elements to be discussed later.

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In this discussion, most of the attention will be directed to the eye-fatigue and vision problems encountered with the anaglyphic double-projecting type of plotter. Corrected vision is equally important to the operation of the non-anaglyphic type of plotter; however, viewing filters and the low level of illumination of the stereomodel usually associated with double-projecting instruments develop the more interesting results.

[1] Salzman, M. H., "The Place for Vision Testing in Photogrammetry," PHOTOGRAMMETRIC ENGINEERING, Vol. XVI, No. 1, pp. 82–94.

[2] Anson, A., "Significant Findings of a Stereoscopic Acuity Study," PHOTOGRAMMETRIC ENGINEERING, Vol. XXV, No. 4, pp. 607–611.

[3] Dwyer, R. F., "Visual Factors in Stereoscopic Plotting," PHOTOGRAMMETRIC ENGINEERING, Vol. XXVI, No. 4, pp. 557–564.

* Publication authorized by the Director, U. S. Geological Survey. Presented at the 29th Annual Meeting, American Society of Photogrammetry, Washington, D. C., March 19, 1964.

Selection of Personnel

From a group of over 100 volunteers, 54 stereocompilers and 6 supervisors were selected so as to provide a base in (1) age and experience level, (2) supervisory evaluation of performance, and (3) a frequency of visual complaints which was representative of the whole group of photogrammetric employees at this headquarters.

Clinical Optometric Examination

The selected personnel were given a complete optometric examination, which included an examination of the lids and the external portions of the eye (external ocular) and the internal eye (ophthalmoscopy), examination and measurement of the anterior surface of the cornea (ophthalmometry), examination and neutralization of the ocular system with a light source (retinoscopy), tests for balance of the external ocular muscles (phoria test), a complete examination of the cornea and iris under high magnification (biomicroscope), and determination of refraction.

Prior to active work in the program, all the test subjects were given a medical examination, including tonometry and ophthalmoscopy of the eye, as an additional check to assure that no active internal eye pathology existed. This was given by the U. S. Public Health Service.

Each compiler in the research test group was furnished prescription-ground anaglyphic glasses calibrated for his individual preference for compiling or "model-viewing" work distance. All but eight of the group were furnished regular prescription glasses for normal-activity use. Complete reexaminations were conducted for the entire group at regularly spaced intervals—four times during the 18-month study. On-the-job consultations were conducted weekly with supervisors and test subjects to quickly resolve any visual difficulties.

Scribing

The widespread indications of visual fatigue resulting from scribing operations resulted in the design and manufacture of a special slip-on binocular loupe. Early in the program, each test subject was equipped with this new loupe which is illustrated in Figure 1. The new loupe is adjustable for individual interpupillary distance. By varying the lens power (four to six diopters), and by moving the frame forward or back, the loupe can be adjusted to the preferred magnification and the individual working-distance preference.

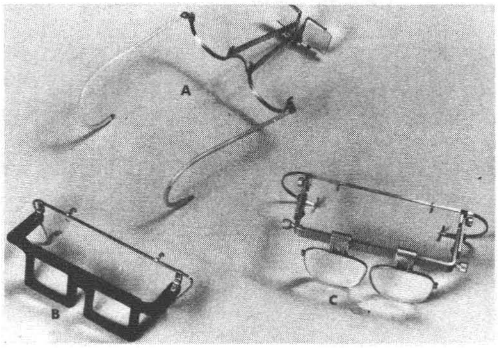


Fig. 1. The new binocular loupe (C) and earlier designs: the A. O. binocular (A) and Telesight (B).

Lenses can be either glass or plastic, as individually preferred. Convergence prism power in the lenses substantially reduces muscle tension, which is the major contributor to eye fatigue in scribing. Therefore, early in the research program, all test personnel were given effective ophthalmic equipment. This assured that the group as a whole had been brought to a high level of operational visual ability. Of equal importance, a program to insure maintenance of this operational visual level was established.

Stereoplotting Environment

In addition to isolating individual visual problems, the Geological Survey pilot study of 1959 strongly suggested that changes in stereoplotting environment could be a powerful influence in increasing efficiency and reducing fatigue. Figure 2 illustrates the experi-

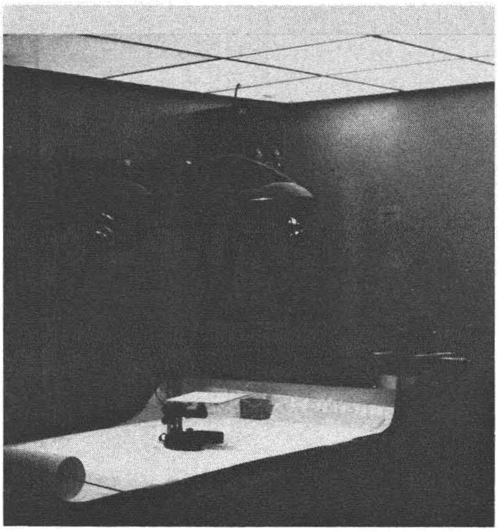


Fig. 2. Experimental individual stereoplotting room.

mental stereoplotting room used during the pilot study. Production experience with this room resulted in two basic conclusions. First, a higher level of ambient light during stereoplotting operations creates a more desirable and comfortable visual atmosphere without any loss of plotting accuracy. Second, the highly desirable condition of eliminating the visual shocks of abrupt changes in light levels can be attained without reducing operational efficiency.

These findings, combined with the guidance of Dr. Oscar Richards of Southbridge, Mass., resulted in the design and construction of a large stereoplotting room in the Geological Survey building at the Denver Federal Center. A portion of this experimental room, capable of accommodating 17 ER-55 plotting units, is illustrated in Figure 3.

held to 22 degrees (Figure 4). The remaining area had a cutoff angle of 45 degrees, making necessary looking almost directly up to see any unshielded light source. Under these conditions, with the projectors on, the light level at the tracing table platen is 1.5 foot-candles; in the immediate ambient area it is 1.2 foot-candles; and in the remaining areas of the room it is 2.5 foot-candles. The additional illumination necessary for examination of photographs and for scribing operations has been designed to eliminate direct unshielded light reaching the stereocompilers.

All personnel in the test group were assigned to this room for a period of not less than 3 months.

Methods of Analyzing the Program

There were three elements or bases on

Fig. 3. A portion of experimental room containing 17 ER-55 stereoplotting instruments.

which the results of the research program were evaluated: 1—opinions and reactions of the personnel in the test group; 2—effects on operational production; 3—optometric clinical findings.

Two major conditions established by Dr. Richards were considered in both the design and the operational use of the room. These were: (1) during stereoplotting operations, the light level of the immediate ambient area should be 90 per cent of the light level at the tracing table platen; and (2) direct, unshielded light reaching the stereo compiler reduces his visual efficiency.

The first condition was attained by a variable-transformer dimming system coupled with a diffusing ceiling or "false sky" to control the general light level of the entire room. The ceiling directly over the stereomodel plotting surface was baffled with an opaque material and the cutoff angle of the diffusing material immediately surrounding this was

1. Opinions and Reactions of the Test Group.—The 1959 pilot study had indicated that some systematic method of evaluating individual reaction to, and opinions of, experimental changes was necessary in order to establish a realistic analysis. One of the professional consultants, Henry W. Hofstetter, O.D., Ph.D., Dean of the Division of Optometry, Indiana University designed a questionnaire to accomplish this purpose. Dr. Hofstetter is nationally known for his work in physiological optics and environmental psychology.

Space does not permit reproduction of the questionnaire in its entirety; however, it was similar to standard industrial psychological examinations. That is, key questions (the answers to which would be affected by experimental visual and environmental changes) were embedded among unrelated, or loosely related questions. The answers to these questions probably would not be affected by experimental changes, but would provide a measure of the consistency of the individual's opinion. The questionnaire was executed by each member of the test group at three different stages during the progress of the study period: first, in August 1961, before any examinations or experimental changes, to establish basic opinions; second, in May 1962, after the test group had been furnished ophthalmic equipment; and, third, in January 1963, after environmental changes had been introduced. Dr. Hofstetter also conducted a personal interview with the majority of the test group in March 1963, near the end of the research period.

Dr. Hofstetter stated in his report, "Certain of the questions were expected to be totally unrelated to either one or both of the major experimental changes introduced and were, therefore, expected to produce constant results. The virtually complete absence of unanticipated changes gave strong indication of high reliability."

2. Effects on Operational Production.—As a measure of the effectiveness of the experimental changes, production records were studied for all personnel involved. A *prestudy* percentage-effectiveness figure was computed for each stereocompiler in the program based on his production record for the previous years as compared with the average production record of the Rocky Mountain Area as a whole. Thus, if test subject 5 showed a 10-hours-per-square-mile production rate on Project A and the total average production rate on this project was 12 hours per square mile, the resultant indication is that test subject 5 was 20 per cent more productive than the Area norm during his work on Project A. This was done for all projects and the results averaged to give a production-effectiveness figure for each individual. The same method was used to record performance during the research period except that individual and group records were computed bimonthly.

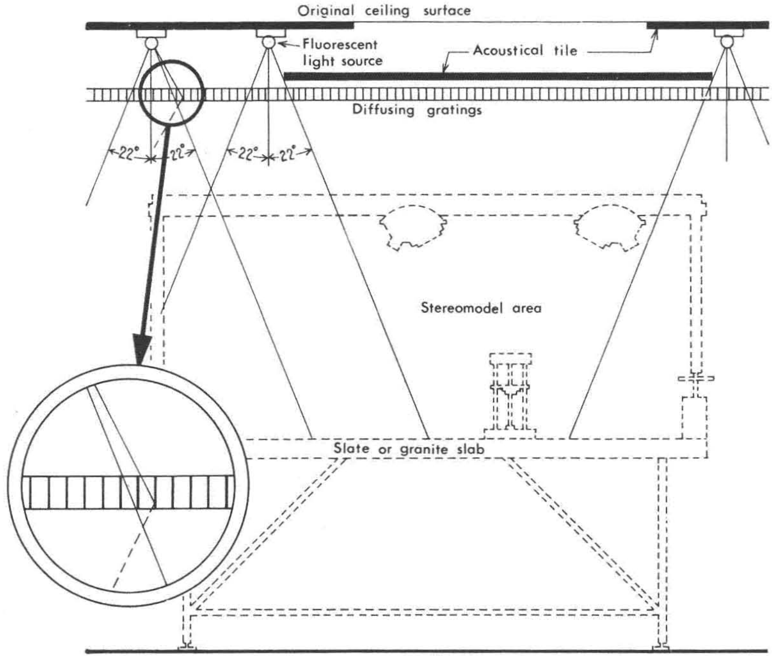


Fig. 4. Lighting arrangement over the stereoplotting instruments. The depth and spacing of the louvers in the diffusing gratings, and their distance from the light source, fix the cutoff angle at 22°.

Before discussing the results of these computations, it should be emphasized that, because of the difficulty variables inherent in quadrangle mapping, these results should be

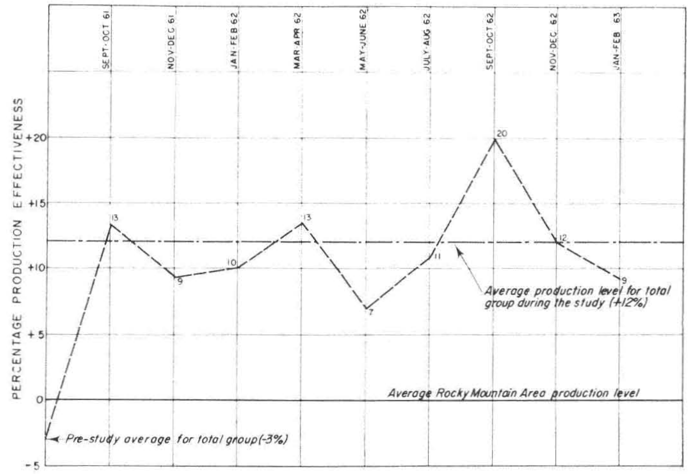


FIG. 5. Variation in production effectiveness of test group during the 18-month research period.

interpreted as *indications* rather than factual statements. It is not stated that if you will take similar steps with your organization, your production will increase by such-and-such per cent. Instead if you take similar action, your personnel are almost certain to become more productive.

Figure 5 indicates the production record of the test group during the 18-month research period. Notice that the selected group pre-study level was 3 per cent less productive than the Area norm, and that immediately after introduction of the research project, group production jumped to 12.5 per cent more productive than the Area norm—a total increase of 15.5 per cent. This level was roughly maintained throughout the remainder of the 18 months, with only minor changes until the surge in September-October 1962, which will be discussed later.

Another method of showing individual performance changes is illustrated in Figure 6. This is striking if the left side of the graph is covered and there is noted the number of dots representing prestudy above-average producers. Now, cover the lower half of the graph and note the concentration of post-study above-average producers.

3. OPTOMETRIC CLINICAL FINDINGS.—As suggested in the pilot study, this group demonstrated remarkable consistency in several of these optometric tests (refractive error, habitual vertical phoria, binocular fusion, and visual acuity), indicating that people who have spent several years in stereocompilation work have undergone a severe visual screening. On initial examination, 49 subjects were found to need new prescriptions for regular glasses; 15 of these had never had a previous prescription for glasses. Eight subjects were found with no significant refractive error requiring the wearing of regular glasses. Three subjects required no change in their current prescription for regular glasses.

Within the above total of 60 subjects, there was found 4 with red-green color deficiency, no active internal eye pathology in any of the test subjects, and vertical muscle imbalance on 22 subjects, severe lateral muscle imbalances on 11 subjects. One subject was found with minor visual deficiency.

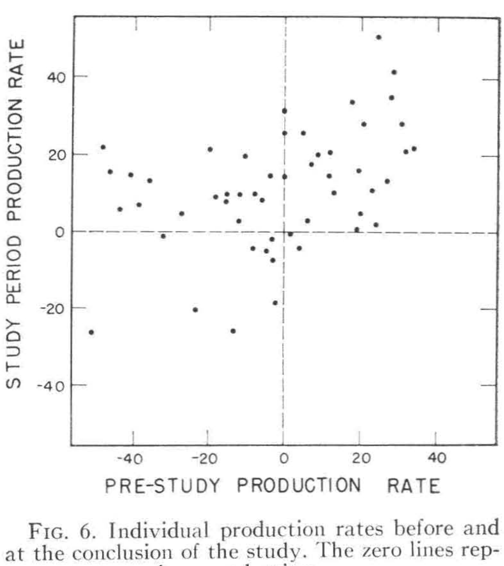


FIG. 6. Individual production rates before and at the conclusion of the study. The zero lines represent average Area production.

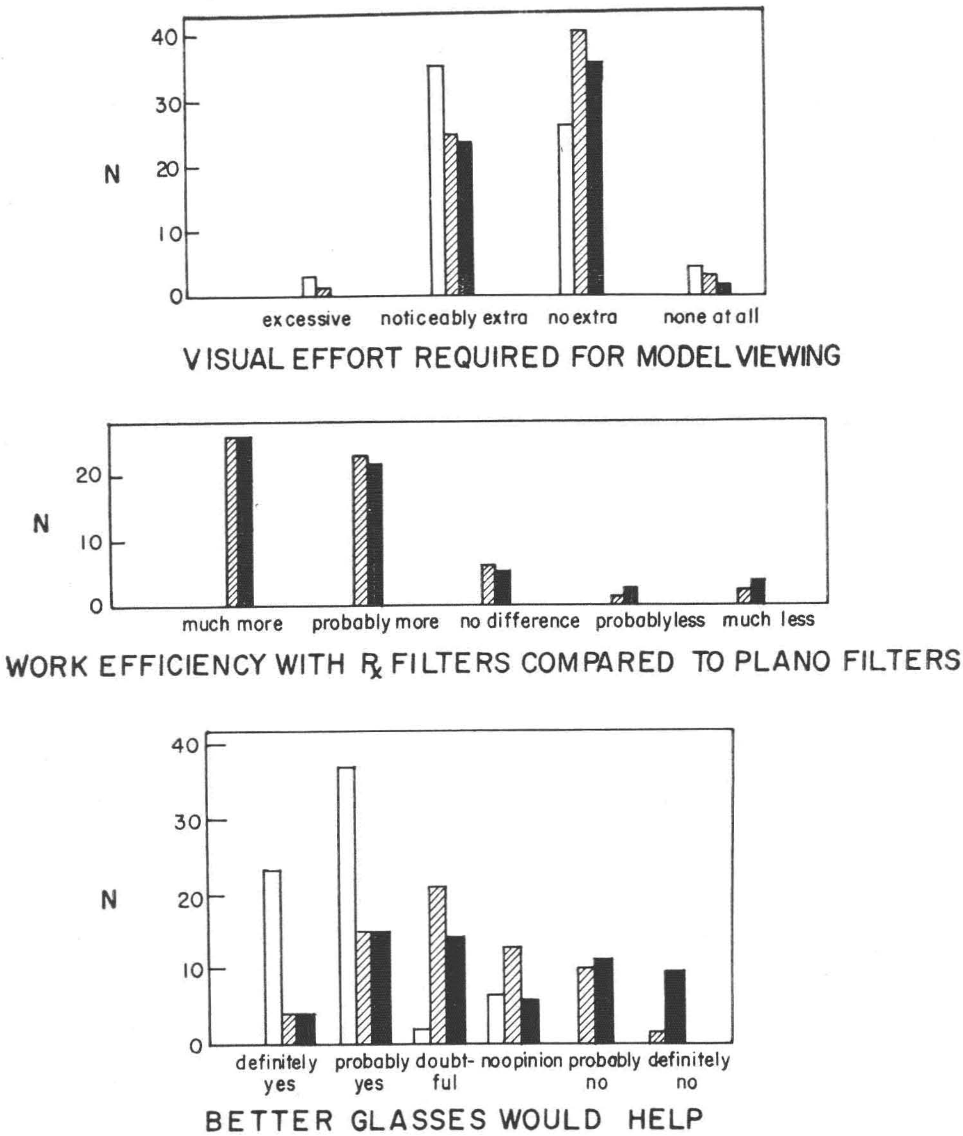


FIG. 7. Opinions of the test participants concerning experimental changes in stereoplotting environment and ophthalmic equipment. The upper graph gives reactions as to effort required in model viewing under all the conditions existing at the times of the three questionnaires, as represented by the open, cross-hatched, and solid bars, respectively. The middle graph presents opinions as to changes in efficiency brought about by the use of prescription anaglyphic glasses. The lower graph summarizes the opinions regarding the helpfulness of better glasses.

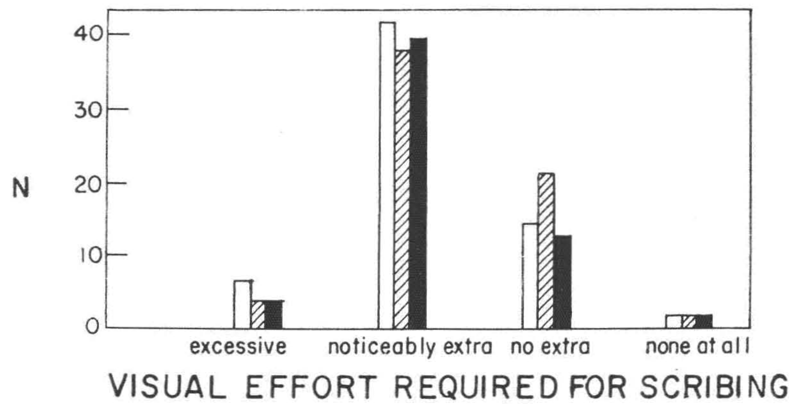
CONCLUSION AND RESULTS

To illustrate Dr. Hofstetter's analysis of the test reaction of the group to prescription glasses for regular wear and anaglyphic glasses calibrated to the individual's working distance, Figure 7 indicates a strong preference for prescription filters.

Figure 8 shows the reaction to the individually-fitted scribing loupe and indicates preference for the new loupe.

Figure 9 indicates a reduction in fatigue in both model-viewing and scribing.

Two separate measures of the experimental room's effectiveness were available. One was the information from Dr. Hofstetter which indicated a substantial individual preference in



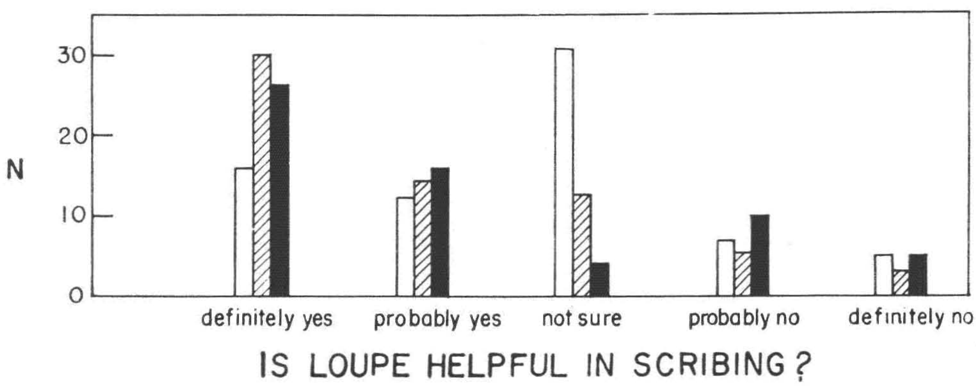


FIG. 8. Opinions of the participants with regard to the new scribing loupes. The three types of bars—open, cross-hatched, and solid—represent the three successive questionnaires, respectively.

favor of the large stereoplotting room. That is, prior to experience in the experimental room, 95 per cent of the test subjects preferred traditional isolated rooms. This is understandable since the test subjects had an average of eight years stereoplotting experience in single room environments. After production experience in the large room, only 15 per cent maintained preference for the isolated plotting room, with 65 per cent definitely favoring the large room, and 20 per cent having no distinct preference. Figure 10 illustrates the considerable shift in stereocompilers' opinions found by Dr. Hofstetter.

Separate production records were maintained for each stereocompiler during his assignment in the experimental room. Production levels for the experimental room are compared against production for isolated stereoplotting rooms in Figure 11. A production-effectiveness level some 20 per cent above Area norms is shown. This is an increase of about 5 per cent over previous production gains by the test group and explains the production surge mentioned previously.

It is our opinion that this research program has proved the importance of the human engineering factor in stereoscopic plotting. Considerable research and development has been done on instrumentation to improve work efficiency and accuracy but the human factor has been neglected. Many of the operators of these extremely delicate instruments were at a disadvantage as far as meeting the visual demands were concerned.

In no other type of work was there such a continual demand upon stereoscopic vision, particularly at such very low levels of illumination. Because stereopsis is the most delicate achievement of binocular vision, and the most difficult for the human visual system to constantly maintain, the visual demands on the operators were, at times, exhausting in terms of nervous energy.

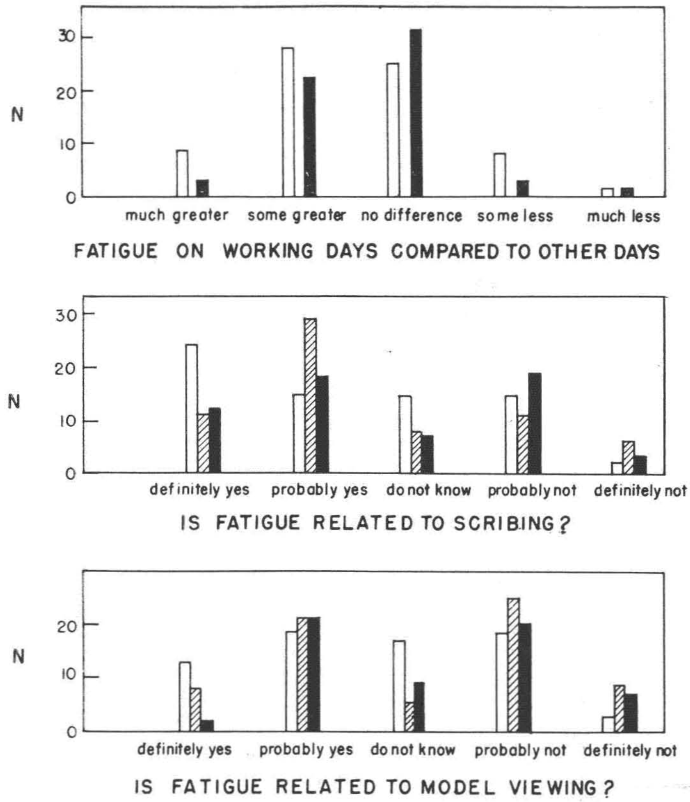


FIG. 9. Summary of participants' responses to questions regarding fatigue. The open, cross-hatched, and solid bars designate the first, second, and third questionnaires, respectively.

The information gained by the research leaves no doubt that the type of visual care applied in this program should be expanded to cover all personnel doing stereocompilation and that the cost of such care would be justifiable on a production basis alone, quite independent from factors of increased accuracy and morale.

In addition to screening tests, applicants for stereoplotting positions should meet the conditions listed below. Individuals who are short of these requirements may perform satisfactorily now and for the near term of their employment. However, it is believed that management should consider the whole career, if possible, when selecting new employees.

We should continue to avail ourselves of the Ortho-Rater Screening Instrument, the Titmus Optical Screening Instrument, or a similar device, so that a graphic record of the subject's visual skills can be maintained. The screening-instrument findings must be augmented with clinical findings in order to be of any value. A complete optometric examination and analysis, using the following criteria, should be obtained before the applicant is accepted for this type of work.

1. The full-spectacle correction for distance vision should not exceed 6 diopters for nearsightedness (myopia), 2 diopters for farsightedness (hyperopia), and 3 diopters for astigmatism and/or anisometropia (a condition where the size of image formed by one eye is different from that formed by the other).
2. The visual acuity must be correctable to 20/20 or better in *each* eye.
3. Normal binocular fusion must be demonstrable at distance and near.
4. Distance vertical-heterophoria (one eye sees an image higher than the other) should not exceed one prism diopter.
5. Binocular stereopsis must be demonstrable.
6. Nominal color deficiency is acceptable, though colorblind people should be given special attention for balancing ap-

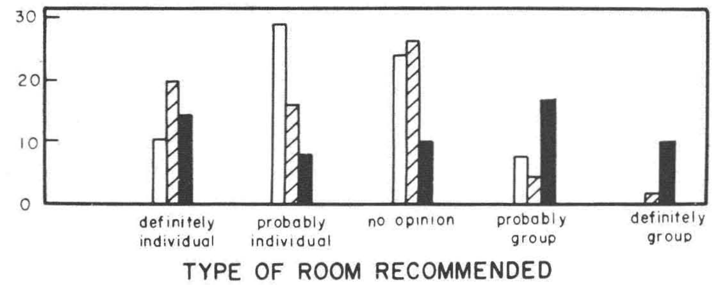


FIG. 10. Participants' preferences concerning room size. The three types of bars—open, cross-hatched, and solid—represent the three questionnaires, respectively.

parent light transmission of the anaglyphic prescription filters.

7. Nominal peripheral visual field deficiencies may be acceptable.
8. For experienced stereoplotting personnel, the following additional conditions should be fulfilled:
   (a) Refractive errors must be corrected generally and for all working distances. Spectacle lenses must correct for ametropia (refractive error), anisometropia, astigmatism, presbyopia (condition associated with older eyes—bifocal treatment is needed), and vertical imbalance, whether of myologic (muscular), or refractive origin.
   (b) Dioptic allowance must be made in the prescription anaglyphic filters for the chromatic anisometropia induced by the anaglyphic system.
   (c) Contact lenses may be acceptable for the correction of the basic refractive error.
9. Professional service should include a virtually continuous program of optometric surveillance for ophthalmic needs as indicated by reports of discomfort, visual complaints, periodic tests, and interviews. Preferably, one optometric consultant should be completely responsible for the program in any given area. He should also be in charge of the visual screening of prospective employees. It should be pointed out here that the seven stereocompilers in the test group who made striking gains in production (40 to 63 per cent) exhibited definite need for optometric care, but their needs were of such a limited magnitude as to invite neglect. This would indicate that compilers who would be helped most by this type of program would not have been eliminated by conventional screening criteria.

Another very important consideration is brought out in this research study. It is generally agreed that the natural visual attrition associated with increasing age cannot be avoided. The results here obtained indicate that proper optometric fitting can make the older operator very nearly as visually capable at his working distance as he was in his early years. The real value here involved is the effective utilization of the older person's invaluable experience and background knowledge in his specialized skill.

With regard to stereoplotting environment, it is recommended that serious consideration be given to eliminating the traditional isolated stereoplotting room. It was found that, in addition to the more comfortable and visually efficient conditions created by the ex-

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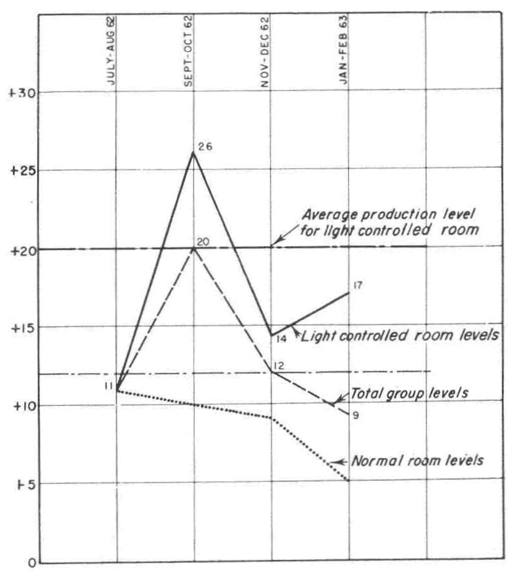

FIG. 11. Comparison of productivity in light-controlled room with that in a normal room.

the pre-cooling system of the illumination optics. This flows first through a small heat exchanger behind the dichroic mirror, where it picks up heat generated by the absorption of infra-red passing through the mirror. It then flows through the lamp housing, and also collects heat produced by the absorption of ultra-violet which has passed through the quartz reflector.

The flow rate is chosen to accommodate more than the 5,000 watt (280 BTU/min.) lamp output, most of which converts to heat in the illumination optics. This type of Freon vaporizes at 117°F., so it must be kept below this temperature throughout the entire loop. A flow of 8 gal./min. can carry off 320 BTU/min. with a temperature rise of 15° over the tank temperature, which is close to ambient, or about 75°F. The heated Freon from this loop goes through an air-cooled heat exchanger, where its temperature is reduced to less than 80°F., and then mixes with the film-cooling Freon in the tank.

The applications of this cooling method extend from simple viewers to high-precision measurement. Experience with the prototype system indicates that the Freon-cooled film viewer will be stable enough to place on a high accuracy measuring machine, where it could give the photointerpreter very wide intensity variation on a machine which can also measure and record film coordinates.

References

1. Stott, John G., *et al.* "Printing of Motion Picture Film, Immersed in a Liquid; Contact Printing and Optical Printing." *Journal of the Society of Motion Picture and Television Engineers*, Vol. 66, pp. 607–615. (October 1957).
2. Eastman Kodak Co. *Manual of Physical Properties of Kodak Aerial and Special Sensitized Materials*. Kodak Publication, Rochester, N. Y. (November 1962).
3. Pirane, Henri. *The Sensations*. Yale University Press. Conn. (1952).
4. LeGrande, Yves. *Light Color and Vision*, Vol. 2. John Wiley. (1957)
5. Alder, Francis H. *Textbook of Opthalmology*. W. B. Saunders, Philadelphia, Pa. (1962).

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perimental room, as evidenced by the production increase, other equally important advantages exist. These include the ease of supervision (from the standpoints of both the supervisor and the compiler), the generation of a strong cohesive or "team" feeling, and the possibilities of more efficient utilization of available space. The Rocky Mountain Area of the Geological Survey will utilize this design when additional space is available in the near future.

It is recommended that the number of plotting units in this type of environment be reduced to 12 instruments per room. This is about the size of one supervisory unit and lends itself to an effective positioning of plotting instruments. Through the research study it was found that lighting conditions, closely approaching those created in the experimental room which produced our best results, can be attained by properly spaced and baffled light sources without resorting to expensive dimming equipment.

Summary

The results of this research are of serious concern to the professions of photogrammetry and optometry. There are additional areas for study that could not be compressed into this research project.

Photogrammetry must continuously study the visual abilities of stereocompilers, particularly those engaged in making precise measurements at extremely low light levels. Environmental conditions, particularly in regard to ambient light, should be carefully controlled. Group stereoplotting rooms appear to have definite advantages over isolated units.

Optometrists must be thoroughly educated to appreciate the stringent visual requirements demanded by stereocompilation operations. This is being accomplished by seminars and work groups conducted by the professional societies.

1965 Convention: March 28—April 3. See page 1052.