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Vision Training and Stereophotogrammetry

In two of three tests, stereoscopic acuity was shown to improve after seven weeks of vision training.

Abstract: *Ten stereophotogrammetry students and three graduate photogrammetrists were given seven weeks of vision training. The visual systems of these 13 experimental subjects were matched to those of 13 control subjects. Stereoscopic acuities were determined before and after the training period on both groups using a Wild Autograph A-7 stereoplotter, a Howard-Dolman apparatus, and the Keystone Multi-Stereo Test. Stereoscopic acuities as determined on the stereoplotter and the Howard-Dolman apparatus were improved at better than a 0.05 significance level as computed on the Wilcoxon Signed Ranks test and Student's t test for the difference between two dependent means.*

Introduction

Stereophotogrammetry is a branch of cartography which requires stereoscopic vision to discriminate small changes in elevation from stereoscopically viewed aerial photographs. The stereo observer (or stereoplotter operator) is limited by his own stereoscopic ability to perceive the elevation differences, the speed at which he makes the judgment, and the period of time over which he can operate at a high efficiency level. This investigation tested the concept that the training of a broad range of vision skills would improve the stereoplotter operator's capability in all three areas of limitation.

Wittenberg *et al.* (1969) reported on previous efforts to show the effect of training on stereoscopic acuity and offered original evidence that showed stereoscopic acuity could be improved by directly training the subject's sensitivity to retinal disparity. They used the Aviator's Unit of the Keystone Diagnostic Series as the stereoscopic test, employed an experimental and control group, and trained the experimental group on a Bausch and Lomb M-2 trainer. The training task was to repeatedly set a balloon at the same height as an airplane when the only clue to the relative height of the balloon with respect to that of the airplane was retinal disparity (differential angular parallax (Collins, 1981) taken at the retina). Foley and Richards (1974) reported that a stereoanomalous subject, who had been involved in a series of experiments requiring a judgement of retinal disparity, showed a definite improvement in his ability to interpret relative depth from the disparity clue. After some 1000 trials, the subject had an improved ability to discriminate large disparities. Both in the Wittenberg *et al.* and in the Foley and Richards reports, improvement in stereoscopic ability was made by training the interpretation of retinal disparity directly. In this project, no attempt was made to train the interpretation of retinal disparity, but instead an effort was made to make the binocular vision systems of the subjects operate as efficiently as possible. Therefore, monocular and binocular fixation ability, and accommodative and convergence interaction skills were trained with an especial attempt at removing all possible tendencies toward suppression. This approach was desired because the usual task of the stereoplotter operator is very similar to the training task employed by Wittenberg *et al.* It was apparent that the photogram-

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metrists could, to a certain extent, train themselves. Here, the more applicable question was, "Could vision training, in general, improve stereoscopic acuity?" If it could, beginning stereoplotter operators would profit by such a program and, presumably, would be able to achieve competence more quickly, and perhaps, ultimately exhibit a higher degree of stereoscopic precision because their binocular systems were operating at a high level of efficiency.

METHOD

Twenty-six subjects were used in this study. The group of thirteen experimental subjects was composed of ten undergraduate (age 20 to 27 years) photogrammetry students who had never used a stereoplotter before this research project and who had performed no stereoscopic tasks on the stereoplotter during the project period and three graduate subjects (ages 26 to 41 years) who had considerable experience on the stereoplotter. Thirteen control subjects were chosen from the students, faculty, and staff of the Ferris State College of Optometry to match the binocular systems of the experimental subjects. An experienced clinician matched the clinical records of the experimental subjects with those from the files of a subject pool. The pairings were made before any data were gathered and were concealed from the principal investigators while the data were being collected. The two groups were matched such that the control and experimental of a pair had visual systems with similar optical and binocular characteristics. After the first analysis, an additional pairing was made based upon initial stereoscopic acuities as determined in the stereoplotter. All subjects had received a complete vision examination within one year of the study. Clinically significant refractive errors were corrected. There were no gross binocular problems in any of the subjects.

The stereoscopic acuities or thresholds were determined with the Howard-Dolman apparatus, the Keystone Multi-Stereo test, and the stereoplotter. The Howard-Dolman apparatus consists of an elongated box, open at one end, containing two vertical black pegs. The box was placed such that the stationary left peg was three metres from the subject. The right peg could be moved back and forth in a channel six centimetres to the side of the left peg. The subject was told to look at the left peg and to move the right peg by means of a string and pulley arrangement such that the right peg was even with the left peg. Ten settings were made with the experimenter adjusting the right peg to an arbitrary position between settings. The stereoscopic acuity or threshold (η) was taken to be the standard deviation of the settings converted to angular measurement.*

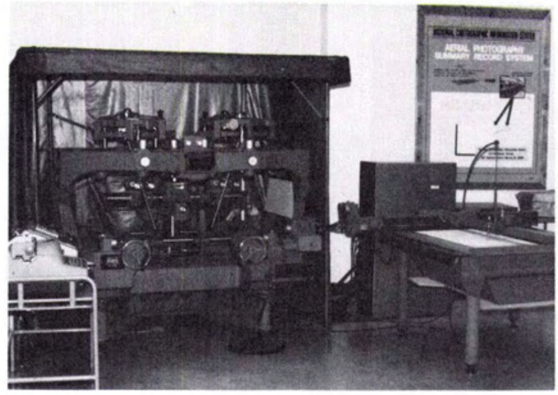

FIG. 1. The Wild A-7 Stereoplotter is shown with the line printer at the left and the plotting table attached to it on the right. The Z-axis control is the horizontal disc at floor level easily reachable by the operator's right foot.

The Keystone Multi-Stereo test consists of three cards containing stereo-pairs viewed in a stereoscope with each card having a row of small black vertical lines. The angular disparity of each successive pair of lines decreases as the subject makes the comparison reading from left to right. The stereoscopic acuity was taken as the target disparity of the last correctly distinguished pair before two incorrect attempts. The viewing distance was optical infinity.

The stereoplotter used was a recently calibrated Wild Autograph A-7 (Figure 1), a high precision plotter of the optical-mechanical type equipped with a Wild EK-5 three-axis digitizer. Exposures used in this experiment were taken two thousand feet above the ground, and absolutely oriented in the instrument.

The primary task of the stereoplotter is to view a stereoscopic rendition of the terrain and to trace out all relevant detail necessary to compile a map. A black floating mark, visible in the center of the field of view, permits the operator to point at detail in the terrain, and by maneuvering this terrain model into optical contact with the floating mark,

* The stereoscopic threshold η was determined by the following formula to convert tangential angle to differential parallax angle:

$$\eta = \frac{\Delta b\ (P.D.)}{(4.8 \times 10^{-6})\ (b^2)}$$

The 4.8×10^{-6} is a conversion factor to change radians to seconds of arc; Δb = one standard deviation of test settings; b = testing distance; $P.D.$ was interpupillary distance.

graphic information can be transmitted to a drawing table for plotting. This task calls for considerable motor skill and a well-developed sense of stereopsis. For the purposes of this research, the subject had only to manipulate the Z axis control (a foot operated wheel at floor level), which moved the terrain vertically up and down with respect to the floating mark.

Written instructions were read to the subject so that all had as similar an initial comprehension as possible. The instrument was adjusted to the subject's interocular distance by direct measurement with a scale and all other controls (except the X, Y, and Z) were held constant throughout the experiment. A specific point was chosen in the stereoscopic scene to be used by all subjects to make the threshold settings for the pre- and post-training data-taking sessions. This point had distinct detail to allow for a strong horizontal disparity clue.

The subject's task was to look in the instrument and bring the scene up to the floating mark (actually perceived as bringing the mark down to the ground) using the foot-operated Z-axis control. The subject was allowed to make the fine adjustment up and down until he was satisfied, but he always had to start with the mark above the ground. The subject was told that the setting was to be timed but, while speed was important, a good placement of the mark on the ground was more important. As soon as the setting was made, the subject operated a hand switch which stopped a timer and turned off the observation lamps in the stereoplotter. The investigator recorded the time and the Z-axis value from the EK-5 digitizer. The investigator then told the subject to adjust the Z-axis foot control in a direction which assured the placement of the marker dot above the ground. The subject then looked into the instrument, turned the light on (and thereby started the timer) and made another setting. Several trial settings were made to assure that the task was understood. Ten such test settings were made.

The subject was then told to visit the other areas of the model while trying to keep the mark on the ground. At the end of each ten-minute period, the subject was asked to return the scene to the test spot and to make ten more settings. The procedure was repeated for an hour to make a total of seven groups of test settings. As with the Howard-Dolman apparatus, the stereoscopic threshold was taken as the standard deviation ($N = 70$) of the settings converted to angular measurement.

The vision training procedures used on the experimental group are listed in Table 1. Each subject was given one hour per week of directly supervised training by the optometrist author or one of the two senior optometry students acting as research assistants. In addition, one hour of home training was assigned each week. Only common ordinary vision training procedures were used and the subjects were not trained on the test task. The ten photogrammetry students were new to the program and had not progressed to a point where they performed stereoscopic tasks on the stereoplotter. The three graduate photogrammetrists maintained their usual photogrammetry schedule. Precautions were taken to assure that the experimental group did not train their stereoscopic ability on the stereoplotter or any related instrument utilizing a similar task.

TABLE 1. TRAINING SCHEDULE

	Supervised	*Unsupervised*
Week 1	Monocular Rotations Tachistoscopic Presentation	Near-Far Accommodation Pursuit Training
Week 2	Tachistoscopic with Prism Cheiroscope (large figure)	Brock String Diplopia Brock String Convergence ±2.00 Lens Flip Accommodation
Week 3	Haidinger Brush Fixation TV Anaglyphic Anti-Suppression	Cheiroscope (small figure) ±2.00 Lens Flip Accommodation
Week 4	Binocular Rotations with Prism Stereoscope Jump Convergence	TV Anaglyphic Anti-Suppression Cheiroscope (small figure)
Week 5	Polachrome Orthoptor ±2.00 Lens Flip Aperture Rule Trainer	Stereoscope (AN Series)
Week 6	Polachrome Orthoptor ±2.00 Lens Flip	Polachrome Orthoptor
Week 7	Stereoscope (AN Series) Polachrome Orthoptor Aperture Rule Trainer	Polachrome Orthoptor

The experimental subjects were given one hour of supervised training and were assigned one hour of unsupervised training per week for a seven week period. Note that all training procedures are commonly known procedures used for the overall upgrading of monocular and binocular abilities.

RESULTS

Table 2 presents the stereoscopic thresholds of all the subjects before and after training in the case of the 13 experimental subjects and in the first and second threshold determination sessions in the case of the 13 control subjects. The number of the experimental subject and the paired control subject is indicated in the left-hand column followed by the Multi-Stereo data, Howard-Dolman data, and stereoplotter data. The stereoplotter threshold is computed from 70 trials over a one-hour period, the Howard-Dolman threshold from ten trials over a five-minute period, and the Multi-Stereo test from recording the stereoscopic angle of the correct discrimination before two consecutive errors.

TABLE 2. STEREOSCOPIC THRESHOLDS (SECONDS OF ARC)

Subject-Pair Control Experi-mental	*Multi-Stereo* Pre	Post	*Howard-Dolman* Pre	Post	*Stereoplotter* Pre	Post
1	11.04	9.02	7.55	6.56	6.76	7.25
1*	7.21	7.21	21.20	10.93	2.58	1.14
2	7.21	7.21	18.08	20.62	4.94	4.56
2	3.60	5.52	7.08	7.08	4.64	3.88
3	5.52	22.08	7.86	9.41	3.27	2.36
3	18.04	11.04	23.84	9.82	5.55	6.38
4	7.21	7.21	3.39	5.24	6.31	8.21
4	7.21	9.02	8.09	8.24	2.96	1.29
5	11.04	5.52	7.59	7.86	3.34	3.65
5	11.04	5.52	11.73	11.73	4.48	2.58
6	5.52	7.21	2.57	8.85	6.31	4.64
6*	3.60	7.21	14.76	7.03	3.95	1.29
7	3.60	5.52	2.90	7.17	6.23	5.09
7	7.21	5.52	6.52	7.68	5.47	7.30
8	7.21	7.21	6.80	7.87	1.14	1.29
8	18.04	7.21	9.54	16.13	3.95	5.17
9	7.21	9.02	6.41	11.69	5.17	5.70
9	3.60	3.60	4.99	5.13	14.90	2.13
10	7.21	11.04	14.44	7.85	4.70	4.10
10	22.08	33.12	34.78	37.44	10.18	8.21
11	7.21	18.04	7.82	10.43	12.31	13.60
11	7.21	7.21	8.80	4.53	2.13	0.61
12	3.60	3.60	5.44	4.12	2.81	2.36
12	5.52	7.21	7.72	11.59	6.16	3.04
13	5.52	5.52	11.65	13.74	3.27	4.10
13*	7.21	5.52	9.55	6.27	5.55	1.52

* The stereoscopic acuities in seconds of arc are given for the first and second data taking sessions. The data for the control member of a pair is given above the data for the experimental member. The asterisks indicate the data of the graduate photogrammetrists. The gain scores necessary for the Wilcoxon Signed Ranks test and Student's t test, for the difference between two dependent means was determined in each case by subtracting the threshold determined in the first (pre) data taking session from that determined in the second (post) session.

THE STEREOPLOTTER DATA

Stereoscopic acuity. The threshold change ($\Delta\eta$) as measured on the stereoplotter is significant at the 0.05 level (one-tail) using the Wilcoxon Signed Ranks Test and Student's t test for the difference between two dependent means (Minium, 1978). For both the Wilcoxon and Student's t tests, pairings (the establishment of dependence) must be made. The initial pairing was done matching binocular systems with the principal investigators kept "in the blind." The Wilcoxon is ideally suited for this study because it assumes no distribution (is non-parametric) and recognizes the difference between the acuity gain attained by the experimental subjects but does not give overdue importance to the amount of the difference. The Student's t test, however, assumed a normal distribution of the data and recognizes not only the rank order of the data, but also the amount of the differences between the before and after training acuities. A frequency distribution plot of both the experimental group and the control group suggested that the normalcy assumption is fairly appropriate. The null hypothesis was that there was no difference between the threshold changes of the two groups or that the experimental group's performance increased. Because it is very improbable that the stereoscopic threshold would increase with training, the one-tailed interpretation was thought to be the more correct.

After the initial pairing matching the binocular systems along the usual clinical parameters, an additional pairing was made which matched the experimental to control who had a similar pretraining period stereoplotter acuity. Once again, the null hypothesis was rejected at the 0.05 level on the Wilcoxon and the Student's t test.

Speed factor. The time needed for each threshold setting was recorded. These times were averaged for the first session (pre-training for the experimental group) and for the second session. The first average was subtracted from the second to give each subject a "change in average speed of setting" value. The "change in average speed of setting" value of the experimental subject of a pair was subtracted from the value of the control subject of that pair. While there was some evidence to support the hypothesis that the experimental group was somewhat faster in its settings, the null hypothesis must be accepted even at the 0.10 level of significance (one-tailed or two-tailed) using the Wilcoxon Signed Ranks Test.

Fatigue Effect. The effect of fatigue on stereoscopic performance was investigated by having the subject make seven threshold determinations over an hour-long period. Fatigue would have been demonstrated if the threshold of stereopsis had grown numerically larger or if the average time taken to make a setting had increased over the hour-long period.

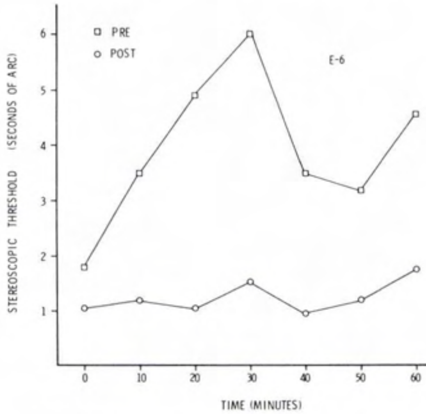

FIG. 2. The stereoscopic thresholds were determined at 10-minute intervals over a 60-minute time period. Fatigue would have been demonstrated by an increase in stereoscopic threshold over time. The stereoplotter data for one of the experimental subjects is shown with the pre-training data indicated by squares and the post-training data by circles.

The data were plotted with the time of threshold determination on the abscissa and with either stereoscopic threshold or average speed of setting on the ordinate (an example is given in Figure 2). While there was a definite effect and improvement after training in two experimental subjects, no trend was evident. In 17 of 26 subjects, no effect of fatigue was demonstrated. We conclude that the hour-long period over which the visual system was stressed was not long enough to show a definite fatigue factor. Further research using another method or a longer time period to stress the binocular system is indicated.

THE HOWARD-DOLMAN DATA

The changes in acuity were computed by subtracting the pre- and post-training period scores for the control and experimental group. The experimental group showed an increase in stereoscopic acuity at the 0.07 significance level on the Wilcoxon Signed Ranks Test and Student's t test. A glance down Table 1 will show that the correlation between the Howard-Dolman scores and the stereoplotter scores is surprisingly low. Some of the experimental subjects who made a large change in stereoplotter threshold did not show a comparable change on the Howard-Dolman and the reverse is also true. This will be mentioned in the discussion section.

KEYSTONE MULTI-STEREO DATA

The stereoscopic acuity decrease after training in the experimental group was not significantly different from that of the control group even at the 0.10 significance level on the Wilcoxon Signed Ranks test or the Student's t test. The results were not surprising in that the Multi-stereo test was not as sensitive as the other two threshold determination methods because it required the test administrator to choose between thresholds that were on the order of 2 seconds of arc disparity apart. Finer changes could not be discriminated.

DISCUSSION

The difference in the performance changes of the subjects when measured in the Howard-Dolman apparatus or the stereoplotter seems, at first observation, to be inconsistent. One would not expect a perfect correlation because of physiological variation and the fact that two different instruments were used, but one would expect better than that shown in Table 2. In an effort to further analyze our results, we determined a Pearson Coefficient of Correlation between the Howard-Dolman and the stereoplotter data for the following four cases:

- Control group-Before training period, r = −0.10
- Control group-After training period, r = 0.04
- Experimental group-Before training, r = +0.10
- Experimental group-After training, r = +0.63

The only significant correlation between the Howard-Dolman data and the stereoplotter data occurred in the only one of the four named categories whose occupants had undergone vision training. It is basic in the study of stereoscopic acuity to understand that the concepts of quality and quantity apply. For instance, the Multi-Stereo test should be a better (relative to the Howard-Dolman) measure of quantity rather than quality of stereopsis. If at some split second all of the myriad of factors controlling oculomotor balance come into equilibrium, then the subject could make his discrimination and report the correct answer even though while he is reporting he can no longer discriminate the nearer of the two rods. Given time, such a person can score very well on the Multi-Stereo test or any similar test. This same subject, however, will have a handicap on the Howard-Dolman because his instantaneous streaks of stereoscopic excellence come only rarely, and he must recognize them among all the other imaginings going on in his mind. There is a large task difference between the Multi-Stereo and the Howard-Dolman. The Howard-Dolman task requires a more sustained high level of stereoscopic acuity. It is this ability to sustain a high level over time and under various conditions that composes stereoscopic quality. If the quality of stereopsis is good, the subject will be able to perform well and consistently well on any stereoscopic test. If the quality is poor, but the ability is present, then the subject will perform well on tests which are not quality dependent such as the Multi-Stereo test.

We maintain that the experimental subjects demonstrated a relatively high correlation between Howard-Dolman and stereoplotter after-training acuities because both stereoscopic acuity tests require a similar task and because a well balanced binocular system with good quality will tend to score well on any stereoscopic test under a broad range of conditions. The vision training procedures to which the experimental group were subjected should have produced better balanced binocular systems in that group.

In summary, ten naive photogrammetry students and three graduate photogrammetrists were paired to thirteen control subjects. The pairing was done by comparing binocular systems and by initial stereoplotter stereoscopic acuities. The thirteen photogrammetry personnel were given at least seven hours of non-specific vision training. The stereoscopic thresholds as determined on the stereoplotter decreased in the experimental group as compared to that of the control group at a significance level of 0.05 in the Wilcoxon Signed Ranks test and Student's t test for the difference between two dependent means. If determined on the Howard-Dolman apparatus, the stereoscopic threshold also decreased but at the 0.07 significance level on the same two statistical tests. There was no threshold change discernible even at 0.10 significance level on the Multi-Stereo test. No significant change in the speed of the threshold setting was observed. With respect to the fatigue factor, it was concluded that the one-hour period over which the binocular systems were stressed was too brief to show a definite fatigue effect.

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