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A comparison of fixation disparity in real and simulated environment

Luis A. Ortiz
Pacific University

Steven E. Lally
Pacific University

Guity Sohrab
Pacific University

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A comparison of fixation disparity in real and simulated environment

Abstract
A comparison of fixation disparity in real and simulated environment

Degree Type
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Master of Science in Vision Science

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A COMPARISON OF FIXATION DISPARITY

IN REAL AND SIMULATED ENVIRONMENT

A Fifth Year Project Presented to
the Faculty of the College of Optometry at
Pacific University, in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Optometry

by

Luis A. Ortiz

Steven E. Lally

Guity Sohrab

ACKNOWLEDGMENT

We wish to express our sincere appreciation for the cooperation rendered by the persons who served as subjects in this study. We are particularly indebted to Dr. Colin Pitblado, Ph.D., whose guidance and assistance enabled this project to be carried to its completion.

TABLE OF CONTENTS

INTRODUCTION AND HISTORY

When corresponding points of the retina are stimulated, ordinarily a single point in space is perceived. So it is commonly assumed that during binocular fixation the visual axes must intersect at one point being in the plane of the object. However, experimental evidence indicates that in spite of the tendency of the visual system to register the dioptric images of the two eyes to correspond as nearly as possible, there occurs an actual small deviation of the visual axes although fusion is still maintained. The reason that fusion is thus maintained is that the deviation of corresponding points is of such a small amount that it falls within the so-called Panum fusional area. (see figure 1) It is this fusional area which prevents physiological diplopia resulting from all those objects in space which do not fall on corresponding points in the retina.

If identical target patterns are presented on the two sides of a stereoscope slide these will appear under normal conditions single. If dissimilar (non-fusable) small targets are now placed in the center of the fused target, it will be observed that the central targets will appear displaced relative to each other. This displacement is more pronounced when heterophoria is present or if the convergence and accomadative system is altered by means of lenses or prisms. This phenomenon has been labeled fixation disparity, or retinal slip, and is a common observation among users of the stereoscope.

Fixation disparity was first described and interpreted by Lau in 1921. He used targets like the ones illustrated in figure two.

Figure 1:*

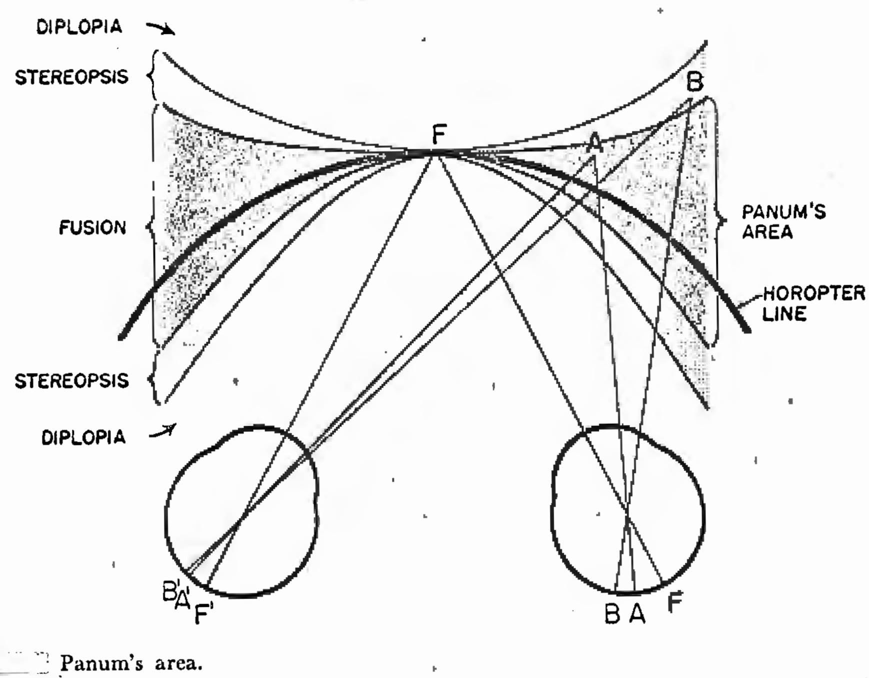
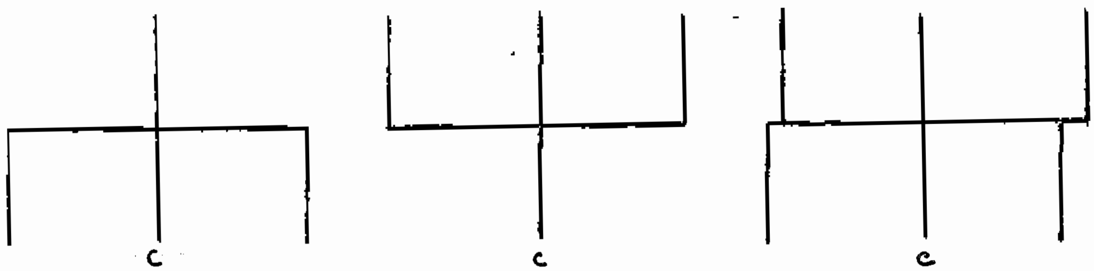


Diagram from Adler, Physiology of the Eye, p.847.

*Note: There is disagreement regarding the actual shape of Panum's area. Mitchell and others believe them to be circular rather than oval in shape.

Figure 2:



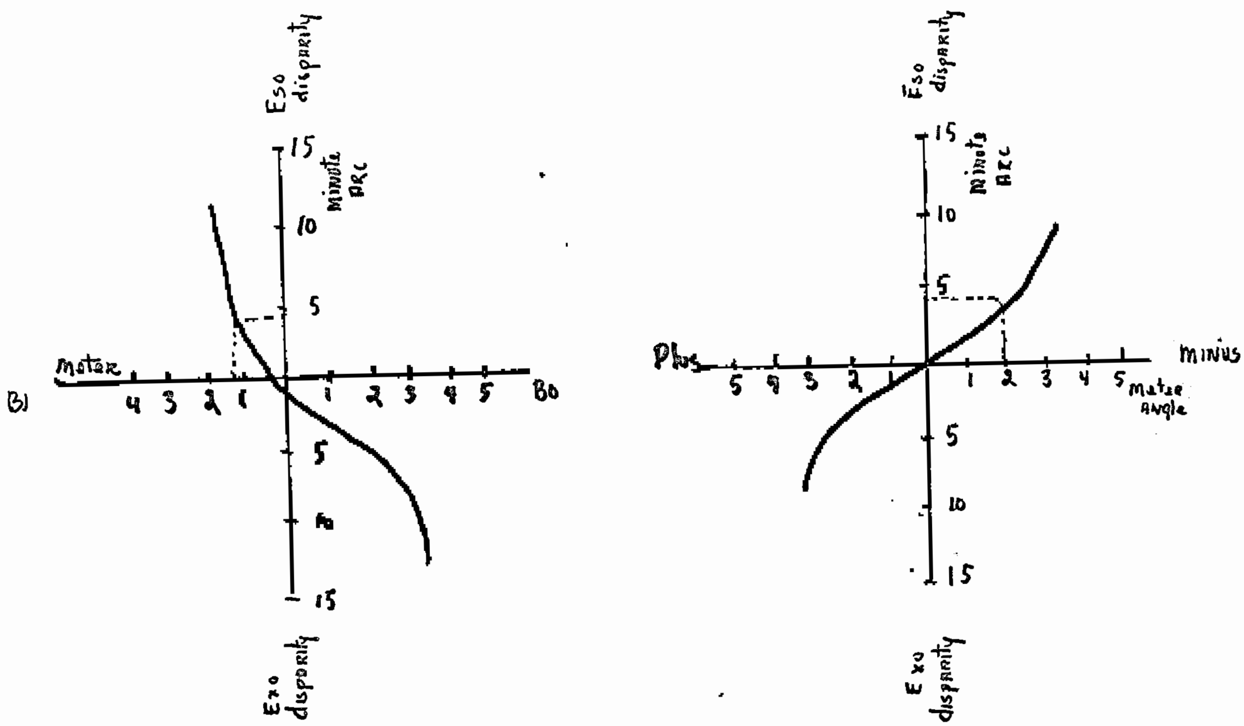
(Target diagrams taken from Ogle and Prangen, American Journal of Ophthalmology, Vol. 32, p. 1071)

The center (c) line was observed on the two sides of the stereoscope fused. The adjacent parallel lines, top or bottom, were seen by each eye respectively. Lau discovered that both lines (top or bottom) had to be displaced in the same direction before they could be seen as three straight parallel lines. The magnitude of the displacement increased if the movable arms of the haploscope were rotated. He deduced from this that the visual axes in his observation were slightly behind the position of the central fused line. Today this concept has been expanded to state that the visual axes may to a limited extent intersect before or behind the visual plane without disruption of singular binocular vision.

Similar observations were reported by Hofmann and Lewin and Sakuma, but it was not until 1928 under the designation of retinal slip that Ames and Glidden reported on the relationship that exists between fixation disparity and phoria. They found a fair correlation between the direction of displacement of the fixation disparity and the phoria. This observation was further pursued by Jampolsky, Flom, and Fried, who found that for distance fixation large values of esophoria are associated with large values of convergent fixation disparity, but that there is little or no relationship between degree of exophoria and fixation disparity. The same idea is held by Ogle, Mussey, and Prangen , who believe it to be by and large in the same direction but not correlated quantitatively, probably because the phoria is a phenomenon of dissociation of the eyes.

Ogle has made the most comprehensive study of the effect on fixation disparity of fusional stress produced by prism. He found in his studies that the amount of the fixation disparity increased in the same direction as the fusional stress. The same effect was observed if the accomadative system was stimulated or imhibited. The data obtained from this have been used in order to calculate the A.C./A. by determining first the amount of fixation disparity produced by certain lenses. This fixation disparity is then plotted on a prism-fixation disparity graph where a prism value is obtained, as illustrated by the following example: a minus two diopter lens is found to produce a fixation disparity of four minutes of arc. It is found that four minutes of arc is produced if 7.5 prism diopters B.I. is used in the graph. We can say then that the A.C./A. for this subject is 3.7 prism diopters for every diopter of stimulus. (see figure 3)

Figure 3:



(Graphs taken from Martens and Ogle, American Journal of Ophthalmology, Vol. 47, p.458.)

Using the same apparatus, Ogle also studied the fixation disparity in the vertical meridian. He found results similar to those in the horizontal meridian except that the data were linear rather than a sigmoid curve. He also found that the eye adapted to the vertical prism. This adaptation resulted in a gradual return of the fixation disparity induced by the prism to the pre-prism value. Once the adaptation had occurred, removal of the prism produced fixation disparity in the opposite direction to that originally produced by the prism.

Mitchell and Ellerbrock made studies similar to Ogle's on the adaptation that occurs in fixation disparity during forced convergence. Ogle demonstrated that this existed in the vertical meridian, while Mitchell and Ellerbrock showed the same phenomenon in the horizontal meridian. This they found to be true for forced divergence. No compensation was demonstrated for forced convergence. It seems that the mechanism which maintains fusion is unique in this respect.

Ogle noticed in his experiment that an increase in target size brought about an increase in fixation disparity. Shepherd studied this observation more carefully using targets varying in size from one to eighteen degrees, and found that the actual correlation using the product-moment method was minus .26. He concluded that no relationship existed between target size and fixation disparity.

The existence of fixation disparity has been challenged by Verhoeff, who believed that experiments previously carried out had not actually demonstrated the presence of fixation disparity because alignment of the lines seen by each eye requires strong attention, and therefore attention must be withdrawn from the object of fixation. He also criticized Jampolsky's data, since many of the subjects used in his experiments had evidenced strabismus earlier in life. Although Verhoeff's point of view seems reasonable, studies where fixation disparity is measured using flashing techniques do not support his argument.

The work which has heretofore been done in this field is primarily oriented toward the relationship between the fusional processes and fixation disparity. Our research has turned up no published study of fixation disparity in a real environment in comparison with a simulated environment. It is our intention then to investigate that area, using similar techniques to those of previous experiments, but with variations which will be included under the discussion of procedure.

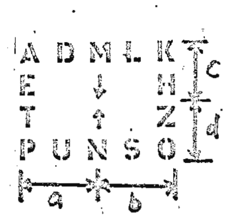
METHOD

In our project, we used polaroid controls to represent the "real environment", and a telebinocular to represent the "simulated environment". These two apparatuses will be described in detail later. If the telebinocular does truly simulate the real environment, two like experiments--one done with polaroid control, the other done with the aid of a telebinocular--should yield two like sets of data. The difference between these two sets of data should be zero. Therefore, the null hypothesis of our project is: "$\bar{X}_R = \bar{X}_S$, where R = "real environment" and S = stereoscope." In order to test this null hypothesis, it was necessary to obtain two different sets of measures, with other stimulus dimensions held constant.

APPARATUS:

The target for this project was constructed on white construction paper with black ink (figure 4).

Figure 4:



It was constructed so that a = b and c = d. Then three different photographs (35 mm. slides) were taken of this with different parts blacked out, leaving the following:

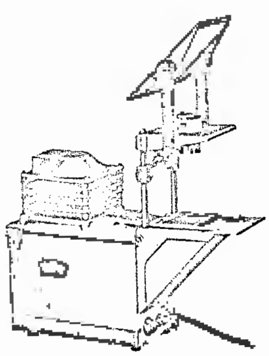
Figure 5:

A D M L K
E H
T Z
P U N S O

A B C

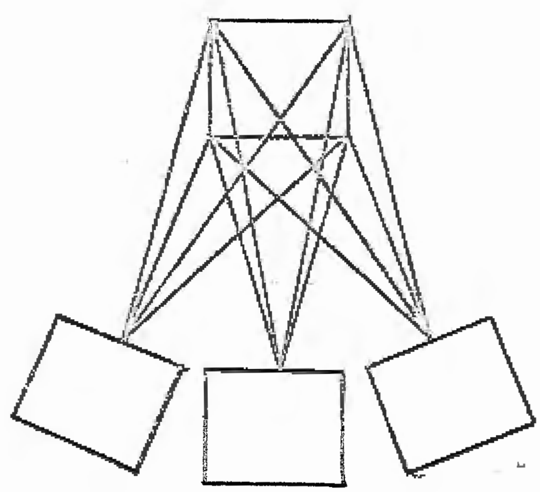
The polaroid apparatus was arranged so that A of figure 5 was presented to both eyes, B of figure 5 was presented to the right eye only, and C of figure 5 was presented to the left eye only. This was accomplished with three overhead projectors, arranged as shown in figure 6 (B).

Figure 6:



Keystone Overhead Projector.

A



B

The target, figure 5 (A), was projected without the use of polaroid. The Snellen visual acuity demand of the letters was 20/50. The arrow in figure 5 (B) was projected by a second overhead projector with a polaroid filter whose plane of polarization was parallel to that in the right lens of conventional polaroid viewing spectacles. The other arrow, figure 5 (C), was projected by a third overhead projector with a polaroid filter polarized at right angles to the first. The arrow in figure 5 (C) was projected to a fixed position in the geometric center of the target containing the letters. The arrow in figure 5 (B) was mounted on a clear glass slide that fit into a movable carrier (figure 7) so that the arrow could be moved laterally, left or right (figure 8).

Figure 7:

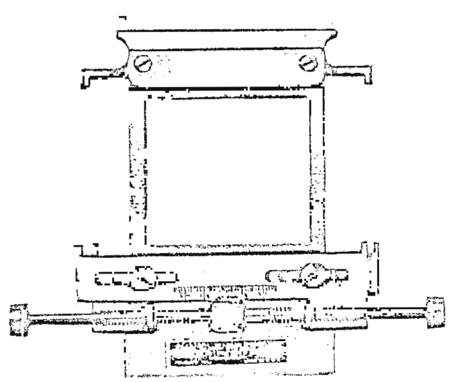
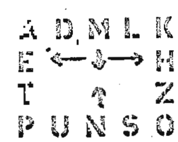


Figure 8:



The same target was used in the telebinocular apparatus, with one difference. Two reference lines were added to the original construction paper target. The reason for the addition of these two lines will be explained later. The original target, with the added reference lines, was then photographed. Different parts of the negative were covered to obtain the three separate pictures shown in figure 9.

Figure 9:

A B C

The pictures were made into transparencies so that the letters, arrows, and reference lines were all that were visible. The size of the telebinocular target was determined by projecting the "real environment" target onto the screen and setting the telebinocular in the position that was to be occupied by the observer so that the light from the screen projected a real image of the target through the telebinocular lenses and onto the telebinocular stage. The stage was adjusted so that the image was clear. Once this setting was determined, the size could be calculated (assuming accurate optics of the telebinocular) or it could simply be measured. Also, the separation between the two images formed on the stage could be measured. The setting of the stage was 18.5 cm. from the lenses. The size of the target was measured to be 1 cm., and the separation between the two images formed was 95 mm. This gave like angular sizes and dioptric vergences of the targets in the two different apparatuses.

The telebinocular apparatus was set with a special viewing stage constructed for the experiment, "Displacement of Half Images During

Binocular Viewing", done by Dr. Colin Pitblado. The following is part of the description of the stage, taken from Dr. Pitblado's write-up of the above mentioned experiment. "The stereoscopic stimuli were viewed on a special viewing stage constructed to meet the specifications of the experiments. This stage, which is pictured in (figure 10) contained two independently movable half-fields, one for the right eye and one for the left. These half-fields consisted of aluminum blocks which could be moved horizontally in the frontoparallel plane fo the Telebinocular along aluminum tracks. The stimulus drawings were pressed against the blocks at top and bottom by flat steel springs.

It will be observed in figure 10 that the steel retaining springs for the right half-field are on the tracks rather than on the moving block. This arrangement was designed to allow the stimulus picture for the right eye to be held stationary while the block on which the (arrow) was drawn was free to move back and forth across that half-field."

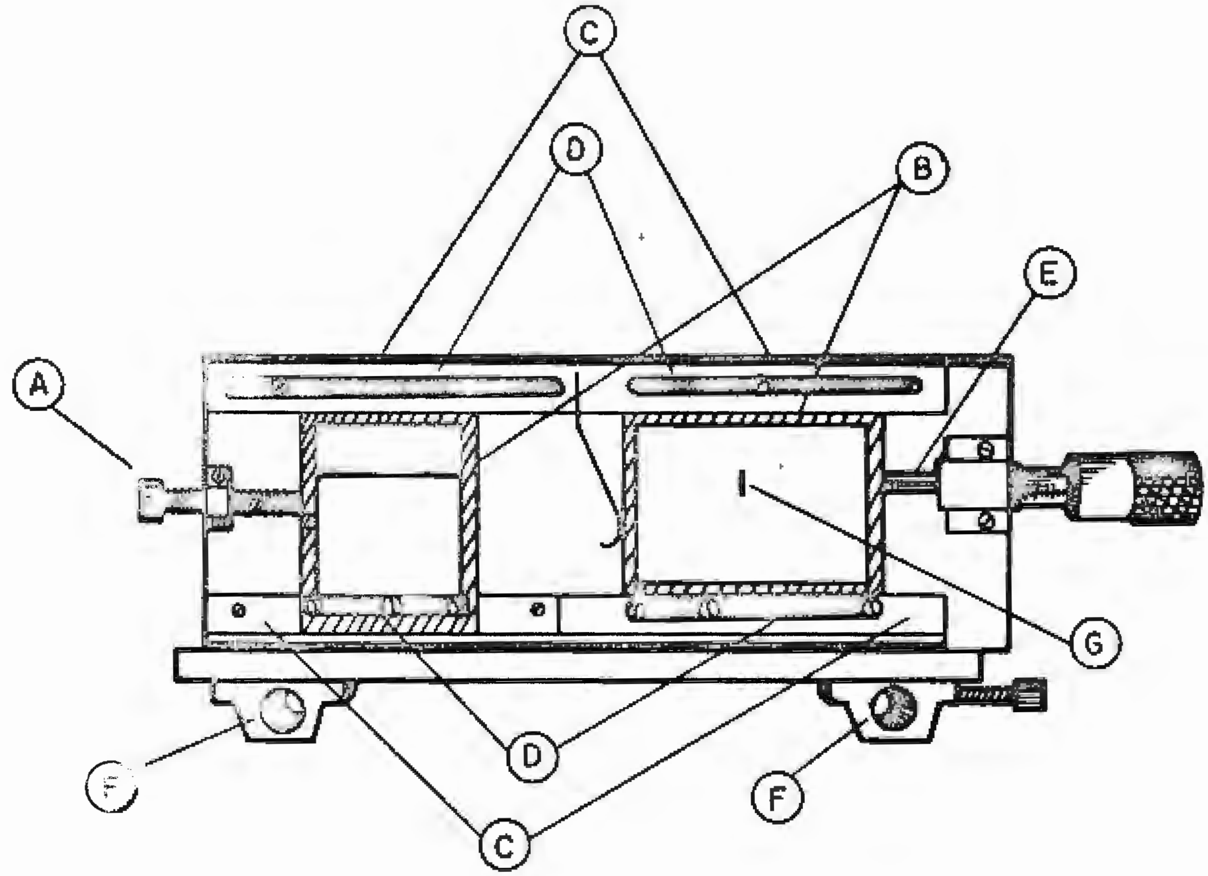


FIG. 10 Special viewing stage for the Telebinocular: (A) lead screw, (B) movable half-fields, covered with paper, as in the experiment, (C) tracks in which the half-fields move, (D) spring steel retaining clips for stereo pictures, (E) micrometer-driven plunger, (F) slides on which stage moves along the runners of the Telebinocular.

Figure 10 (B) shows the left half-field only partially covered. In our experiment, each half-field was covered completely with white paper which was used for a background. The target in figure 9 (A) was mounted directly onto the background of the left half-field. This was glued in place to prevent it from being moved accidentally. The targets in figure 9 (B and C) were mounted on the right side of the stage. The top arrow was mounted directly on the white background of the right half-field. The target in figure 9 (B) was set in the steel retaining spring for the right half-field. As mentioned in the above description of the stage, these springs are on the tracks of the stage rather than on the movable half-field. This allows the target in figure 9 (B) to be held stationary while the right half-field on which the top arrow is mounted is free to move back and forth. Since all the targets were transparencies, the top arrow was visible behind figure 9 (B). The right half-field was moved by turning the micrometer dial on the far right of figure 10. This has a four place micrometer scale making it possible to measure lateral displacements of the top arrow correct to 1/10,000 of an inch or within 0'1" of visual angle. The left half-field can be moved laterally by turning the lead-screw (figure 10 (A)). The separation between the two half-views, figure 9 (A and B), as mentioned earlier, was determined by measurement. This separation, 95 mm., could easily be set with the lead-screw.

The target was constructed so that the arrow in figure 9 (A) was equidistant from the two reference lines. The distance between the two reference lines was determined by occluding the left eye-piece of the telebinocular and lining up the arrow of the right side first with the left reference line and then with the right reference line. The difference between the two readings equals the distance between the two lines. Several readings of this distance were taken. The values were then averaged and divided by two, yielding a constant, K = .1065 inch. This constant equals the distance from either reference line to the objective midpoint or bottom arrow. The constant, K, was rechecked by placing the left target (figure 9 (A)) in the steel retaining spring of the right half-field. The top arrow (figure 9 (C)) was aligned with the left vertical line and then with the bottom arrow. The difference between these two settings should equal the previous constant, K. The difference obtained was .1064" as compared with .1065", confirming the accuracy of the above method. A base reading of the left line was determined by each subject. This reading was taken in case the position of the half-view, figure 9 (B), was different with different subjects. This was necessary because all the subjects were not run at one time, and the apparatus had to be dismantled when not in use. Also, since the arrow was in a slightly different plane than the half-view, figure 9 (B), the position of the subject's head, due to parallax, determined the exact base reading. The different lateral positions of the subjects' heads in the telebinocular resulted in a slightly different base reading for all subjects. For this reason, once the subjects started this experiment, they were instructed to try to avoid moving their head in any direction.

PROCEDURE:

The same procedure was used with each subject. First, the subject's far point visual acuity was determined. His far point phoria was determined by the cover test, Von Graefe method, and stereoscope lateral phoria test. (It was arbitrarily decided that all data from subjects with less than 20/20 far point visual acuity, with correction, would be rejected. Also, only subjects with binocular vision were accepted.) The subject was asked to sit in front of the telebinocular, move his head forward until his forehead touched the headrest, and look into the telebinocular. The left eye-piece was occluded, and the subject's attention was directed to the left vertical line with a pointer. He was then asked to turn the micrometer dial until the top arrow appeared in alignment with this left vertical line. The micrometer reading of this position was recorded as the base line. The occluder was then removed from the left eye-piece, and the subject was asked how many targets he could see. If he saw two, he was instructed to move his head slowly away from the instrument until the two targets appeared to merge into one. If he was unable to make the two targets into one, he was eliminated from the experiment. If he was able to make the two targets into one, he was then instructed to move forward until his forehead touched the headrest again. If the target doubled again when he moved his head forward this second time, he was eliminated from the experiment. Of the thirty-six subjects tested, eight saw two targets when the occluder was removed. With the above method, five subjects were able to keep the two targets one when they moved their head forward the second time. Two of the other three were able to make the two targets into one with their head away from the instrument, but they were not able to keep the targets united when they moved their heads forward the second time. These two were also eliminated from the experiment. One subject was unable to make the two targets into one even with the above method; therefore, he was also eliminated. For those five subjects who were able to keep the half-views united when they moved forward the second time, it was necessary to retake the base reading at the conclusion of the disparity readings to take into account the new positions of their heads.

Once in position, the subject was instructed to move the top arrow slowly to the right until it appeared in alignment with the bottom arrow. He was not to move the top arrow back and forth, but in one direction only. A reading was then obtained. For the next trial, the arrow was moved to a position near the right reference line. The subject was again instructed to move the top arrow in one direction only (this time to the left) until it appeared directly above the bottom arrow. Five readings were taken. The first was taken approaching the bottom arrow from the left, the second from the right, the third from the left, and the fourth from the right. On the fifth reading, the subject was allowed to move the top arrow back and forth until he felt he had the best possible alignment.

A very similar procedure was followed in the "real environment" (polaroid) experiment. The top arrow was moved by the adjustment screw of the movable carrier (figure 8). This was turned by the experimenter, and the subject was instructed to say "now" when the top arrow appeared directly above the bottom arrow. The subject was told that the arrow would be moved in one direction only for each of the first four readings. On the fifth reading, he could tell the experimenter to move the arrow back and forth until the best possible alignment was reached.

RESULTS

The data obtained are represented on the tables included. In the appendix are the raw data for each of the five measurements in the telebinocular and in the polaroid condition. The readings have been converted to prism diopters. Eso disparity is designated by a plus sign and exo disparity by a minus sign.

The method in which prism units were obtained in the telebinocular was as follows. After the base reading was obtained for each subject, the constant, K=.1065, was added to it. This gave the position of the immovable arrow for the individual. This center was used to determine the amount of lateral displacement in each trial, which was obtained in inches and then converted into centimeters by multiplying by 2.54. The telebinocular stage distance, 18.5 centimeters, when converted to meters and divided into the displacement in centimeters, yields prism diopters. Since the telebinocular distance and 2.54 are constant numbers, these could be combined into one constant, 13.7. This constant could be multiplied by each lateral displacement to obtain prism diopters.

Illustration of Subject # 1:

B = Base reading
K = .1065
R = Alignment of arrow
L = Lateral displacement

R = .3020"
B = .2108"
$L = R - (B + K)$
$L = .3020 - (.2108 + .1065)$
L = .0153" eso displacement

Conversion to Prism Diopters
d = distance of stage, .185 meters
L'= lateral displacement in centimeters
$L' = 2.54 \times L$
Prism diopters = L'/d

Prism diopters = $L \times 2.54/.185 = L \times 13.7$
$= .0153 \times 13.7 = .21\Delta$ eso disparity

The polaroid displacement was measured by tracing the projected arrows on the recording sheets with a #2 pencil. The separation between the lines traced was then measured using a micrometer which read directly in centimeters. This displacement was then divided by six meters (6 meters ≅ 20 feet) and prism diopters were obtained.

The table on the following page contains the mean for each subject under both conditions. The "x" column contains the difference between the two means (telebinocular minus polaroid). The mean of the obtained differences was .1785 with a standard deviation of .2343.

The null hypothesis of our project requires that there be no difference between fixation disparity in real and simulated environments, i.e., $\bar{d} = 0$. This hypothesis was tested by means of students' t test for significance of difference between correlated observations. With d.f. = n-1 = 32, the obtained $t = 4.38$ ($p < .005$). On this basis our null hypothesis is rejected.

SUBJECT Number	MEAN FIXATION DISPARITY Polaroid	Telebinocular	Difference (X)	X-M	$(X-M)^2$
1	+.0859	+.299	+.1031	-.0754	.0057
2	-.044	+.648	+.692	+.5135	.2631
3	+.016	+.617	+.601	+.4225	.1785
4	+.005	+.1209	+.1159	-.0626	.0039
5	+.0304	+.1149	+.0845	-.0940	.0088
6	-.031	-.0577	+.0247	-.1538	.0236
7	+.0061	+.0803	+.0742	-.1043	.0109
8	-.0374	+.3357	+.3731	+.1946	.0379
9	-.009	-.195	-.186	-.3645	.1328
10	-.007	+.1375	+.1445	-.0340	.0012
11	-.0306	+.0474	+.0780	-.1005	.0101
12	-.0136	+.1021	+.1157	-.0628	.0039
13	-.027	+.7816	+.8086	+.6301	.3970
14	-.0218	-.0313	-.0105	-.1890	.0357
15	-.049	-.1047	-.0957	-.2742	.0752
16	-.0102	+.2057	+.2159	+.0374	.0012
17	-.008	+.799	+.807	+.6285	.3950
18	+.014	+.1328	+.1188	-.0597	.0036
19	-.0448	+.067	+.1118	-.0667	.0045
20	-.015	+.0525	+.0675	-.1110	.0123
21	+.007	+.295	+.288	+.1095	.0112
22	+.0106	-.0054	-.0160	-.1945	.0378
23	+.0609	+.1496	+.0887	-.0898	.0081
24	+.0022	+.0319	+.0297	-.1488	.0221
25	+.0106	+.169	+.1584	-.0201	.0004
26	+.034	-.0234	-.0574	-.2359	.0556
27	-.009	+.194	+.200	+.0215	.0005
28	-.016	+.0618	+.0778	-.1007	.0101
29	-.0734	+.1182	+.1916	+.0131	.0002
30	-.0674	+.106	+.1734	-.0051	.00003
31	-.0266	+.1461	+.1727	-.0058	.00003
32	+.0002	+.1188	+.1186	-.0599	.0036
33	+.0321	+.253	+.2209	+.0424	.0018
SUM		33)	5.8905		1.7563
M		=	.1785		

$$S = \sqrt{\frac{1.7563}{32}}$$

$$= .2343$$

DISCUSSION

Before carrying out the foregoing experiment it had been anticipated that if there were to be a difference its direction should be determined by a mechanism such as proximal convergence (the effect of a subject's awareness that the target is actually within arm's reach rather than at the distance simulated). One would expect more eso fixation disparity (or less exo fixation disparity) in the stereoscope, and the findings supported this expectation. All but five of the subjects showed considerably more eso fixation disparity in the telebinocular than in the "real environment".

The fixation disparity measured in the telebinocular was of significantly greater magnitude than that found in the "real environment". This would suggest that in a clinical situation, if the fixation disparity exhibited by a patient as measured in a telebinocular is small, it is probably insignificant in a real environment. Therefore it is unrealistic to make a judgment about fixation disparity from what may be measured in a telebinocular, without considering proximal convergence.

In this project we have developed a possible method of measuring and quantifying the effect of proximal convergence on the fixation disparity. This involves the assumption that the mean proximal convergence is equal to the mean of the obtained differences (see page 19). This was found to be .1785, as previously stated. (This also assumes that other factors are not significantly involved.)

The question remains as to whether similar results will be obtained at distances of less than twenty feet. This is a potential subject for further study by others interested in fixation disparity.

APPENDIX

A. Raw Data Table

B. Statistical Calculations

A.

FIXATION DISPARITY IN PRISM DIOPTERS

SUBJECT NUMBER	POLAROID AT 20 Feet					TELEBINOCULAR, SIMULATED 20 Feet				
1	+ .067	+ .126	+ .0886	+ .1123	+ .0356	+ .59	+ .1788	+ .424	+ .108	+ .1935
2	- .086	+ .016	- .076	+ .015	- .091	+ .825	+ .53	+ .73	+ .465	+ .7
3	+ .079	- .034	+ .033	0	0	+ .75	+ .56	+ .565	+ .569	+ .621
4	- .052	+ .048	- .009	+ .030	0	+ .21	- .0288	+ .1645	+ .107	+ .127
5	- .037	- .051	- .010	- .024	- .030	+ .144	+ .074	+ .127	+ .127	+ .1025
6	- .007	- .042	0	- .059	- .047	+ .026	- .0945	- .112	- .10	- .0082
7	+ .014	- .014	+ .017	- .001	+ .023	+ .1055	+ .0494	+ .148	- .0535	+ .152
8	+ .004	- .057	- .020	- .060	- .054	+ .171	+ .115	+ .123	+ .123	+ .0398
9	+ .017	- .08	+ .021	- .037	- .033	- .122	- .382	- .137	- .181	- .151
10	+ .019	- .018	+ .009	+ .031	- .007	+ .22	+ .0985	+ .155	+ .118	+ .096
11	+ .008	- .069	- .028	- .042	- .022	+ .0905	- .0465	+ .0452	+ .0658	+ .0822
12	- .041	0	- .057	+.017	+ .013	+ .159	+ .147	+ .119	+ .0507	+ .0356
13	- .052	+ .009	- .052	- .011	- .032	+ 1.032	+ .53	+ .86	+ .625	+ .861
14	- .042	- .011	0	- .01	- .046	- .0316	- .0439	-.0246	- .0507	- .059
15	- .086	- .021	- .062	- .014	- .062	- .11	- .171	-.0274	- .134	- .081
16	+ .099	- .079	+ .072	- .041	- 0	+ .393	+.0398	+ .356	+ .089	+ .1505
17	+ .082	- .097	+ .085	- .067	+ .047	+ .704	+.009	+ .628	+ .57	+ 1.084
18	+ .078	0	+ .034	- .053	- .011	+ .127	+ .059	+ .1865	+ .101	+ .1905
19	- .077	- .039	- .054	- .031	.023	+ .0617	+ .0617	+ .074	+ .0892	+ .0494
20	+ .037	- .057	- .016	- .041	0	+ .119	+ .0027	+ .0864	- .0137	+ .0685
21	+ .038	- .008	+ .035	- .031	0	+ .354	+ .288	+ .274	+ .286	+ .273
22	+ .0412	+ .005	+ .0176	- .0466	+ .0359	- .0031	- .0061	- .0061	- .0023	- .0097
23	+ .165	+ .0155	+ .0771	- .0313	+ .785	+ .197	+ .153	+ .1001	+ .166	+ .131
24	+ .014	- .024	- .018	+ .021	+ .0233	+ .147	- .0356	+ .0178	- .0108	+ .041
25	+ .066	- .082	+ .032	- .037	- .026	+ .178	+ .127	+ .151	+ .213	+ .178
26	+ .028	+ .081	± .027	+ .055	+ .053	+ .053	- .0465	- .0194	- .0221	± .082
27	+ .042	- .105	+ .075	- .046	- .012	+ .294	+ .137	+ .23	+ .085	+ .226
28	+ .066	- .082	+ .069	- .110	- .024	+ .0675	- .0189	+ .0785	+ .073	+ .073
29	- .108	- .005	- .068	- .084	- .102	+ .264	- .0108	+ .1285	+ .0507	+ .137
30	- .006	- .104	- .045	- .127	- .055	+ .1495	+ .059	+ .117	+ .081	+ .1235
31	+ .043	- .139	+ .031	- .044	- .024	+ .22	+ .122	+ .143	+ .1015	+ .144
32	- .053	- .006	+ .091	- .054	+ .023	- .137	- .23	- .155	- .04	- .032
33	+ .169	- .0606	+ .063	- .064	+ .053	+ .505	+ .0454	+ .233	+ .172	+ .313

B. STATISTICAL CALCULATIONS

The formula for standard deviation is $S = \sqrt{\frac{\Sigma(x-m)^2}{N-1}}$ where S = standard deviation, Σ means "the sum of", x - m = deviation about the mean, and N = number of cases.

$$\Sigma(x-m)^2 = 1.7563. \quad N = 33. \quad S = \sqrt{\frac{1.7563}{33-1}} = \sqrt{.0549} = .2343.$$

This is the standard deviation around the mean of the difference between the two experimental conditions.

The formula for the Standard Error of the mean difference is $S_{\bar{d}} = \frac{S}{\sqrt{N}}$ where $S_{\bar{d}}$ = the standard error of the mean difference.

$$S_{\bar{d}} = \frac{.2343}{\sqrt{33}} = \frac{.2343}{5.75} = .0407.$$

The formula for the t distribution is $t = \frac{\bar{d}}{S_{\bar{d}}}$, where $\bar{d}$ = sample mean difference $\left(\frac{\Sigma d}{N}\right)$, and $S_{\bar{d}}$ = standard error of the mean difference.

For the purpose of this experiment, the degrees of freedom, df, = N-1. Since data from thirty-three subjects were used, df = 32. The table of t values indicates that if d = 0, the probability of t = 2.75, or greater, will occur by chance only one percent of the time. Since we obtained a value of t = 4.3857, the null hypothesis is rejected.

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7. Pitblado, C., Displacement of Half Images during Binocular Viewing, unpublished Ph.D. dissertation, Boston Univ., 1966. Also issued as Sperry Rand Research Center Report # SRRC RR-66-34.

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1. Adler, F.H., Physiology of the Eye. C.V. Mosby Co., St. Louis, 1965.

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4. Martens, T. and Ogle, K., "Observations on accomodative convergence", Am.J.Ophth. 47:455, 1959.

5. Ogle, K.N., "Fixation disparity", Am.Orthopt.J. 4:35, 1959.

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7. Pitblado, C., Displacement of Half Images during Binocular Viewing, unpublished Ph.D. dissertation, Boston Univ., 1966. Also issued as Sperry Rand Research Center Report # SRRC RR-66-34.

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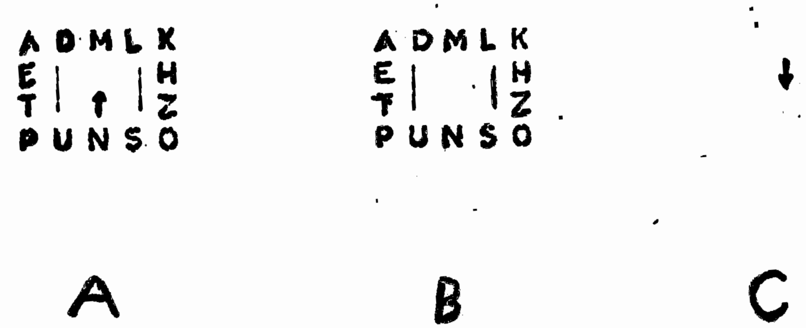
9. Verhoeff, F., "Fixation disparity", Am.J.Ophth.48:339, 1959.

was then photographed. Different parts of the negative were covered to obtain the three separate pictures shown in figure 9.

Figure 9:

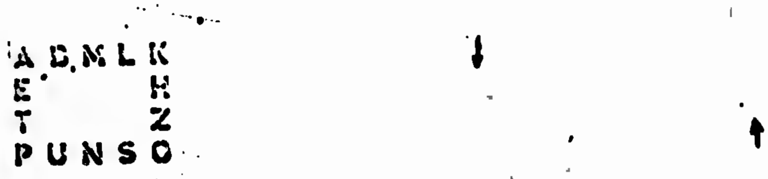


SUBJECT Number	MEAN FIXATION DISPARITY Polaroid	Telebinocular	Difference (X)	X-M	$(X-M)^2$
1	+.0859	+.299	+.1031	-.0754	.0057
2	-.044	+.648	+.692	+.5135	.2631
3	+.016	+.617	+.601	+.4225	.1785
4	+.005	+.1209	+.1159	-.0626	.0039
5	+.0304	+.1149	+.0845	-.0940	.0088
6	-.031	-.0577	+.0247	-.1538	.0236
7	+.0061	+.0803	+.0742	-.1043	.0109
8	-.0374	+.3357	+.3731	+.1946	.0379
9	-.009	-.195	-.186	-.3645	.1328
10	-.007	+.1375	+.1445	-.0340	.0012
11	-.0306	+.0474	+.0780	-.1005	.0101
12	-.0136	+.1021	+.1157	-.0628	.0039
13	-.027	+.7816	+.8086	+.6301	.3970
14	-.0218	-.0313	-.0105	-.1890	.0357
15	-.049	-.1047	-.0957	-.2742	.0752
16	-.0102	+.2057	+.2159	+.0374	.0012
17	-.008	+.799	+.807	+.6285	.3950
18	+.014	+.1328	+.1188	-.0597	.0036
19	-.0443	+.067	+.1113	-.0667	.0045
20	-.015	+.0525	+.0675	-.1110	.0123
21	+.007	+.295	+.288	+.1095	.0112
22	+.0106	-.0054	-.0160	-.1945	.0378
23	+.0609	+.1496	+.0887	-.0898	.0081
24	+.0022	+.0319	+.0297	-.1488	.0221
25	+.0106	+.169	+.1584	-.0201	.0004
26	+.034	-.0234	-.0574	-.2359	.0556
27	-.009	+.194	+.200	+.0215	.0005
28	-.016	+.0618	+.0778	-.1007	.0101
29	-.0734	+.1182	+.1916	+.0131	.0002
30	-.0674	+.106	+.1734	-.0051	.00003
31	-.0266	+.1461	+.1727	-.0058	.00003
32	+.0002	+.1188	+.1186	-.0599	.0036
33	+.0321	+.253	+.2209	+.0424	.0018
SUM		33)	5.8905		1.7563
M		=	.1785		

$$S = \sqrt{\frac{1.7563}{32}} = .2343$$

It was constructed so that a = b and c = d. Then three different photographs (35 mm. slides) were taken of this with different parts blacked out, leaving the following:

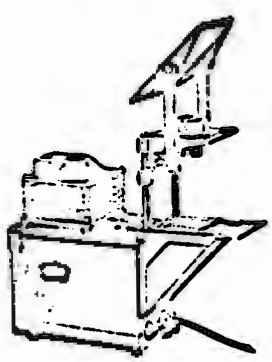
Figure 5:



A B C

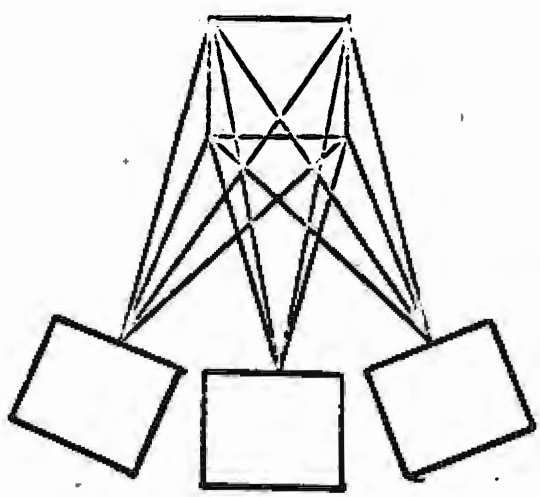
The polaroid apparatus was arranged so that A of figure 5 was presented to both eyes, B of figure 5 was presented to the right eye only, and C of figure 5 was presented to the left eye only. This was accomplished with three overhead projectors, arranged as shown in figure 6 (B).

Figure 6:



Keystone Overhead Projector.

A



B