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THE RELATION OF "DUCTION" TO DYNAMIC STEREOACUITY

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9013D.02

Released by:

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SUBMARINE MEDICAL RESEARCH LABORATORY

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SUMMARY PAGE

THE PROBLEM

To determine whether the size and direction of the error an observer makes in judging the relative distance of two objects (stereoacuity) can be predicted from a standard optometric examination.

FINDINGS

Subjects who tended to judge the target to be at the same distance as the standard when the target was actually closer to them were generally men whose eyes tended to converge when at rest, who wore spectacles with high negative corrections, and who could withstand a relatively large amount of diverging prism-power.

APPLICATION

The information presented in this report should be of interest to ophthalmologists and optometrists as well as to those individuals concerned with detection and localization of targets.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9013D — Optimization of Visual Performance in Submarines. The present report is No. 2 on this Work Unit. It was approved for publication on 8 April 1969 and designated as Submarine Medical Research Laboratory Report No. 575.

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ABSTRACT

The relation between duction break-recovery (B/R) ratios and localization error in a test of dynamic stereoacuity was examined in 73 young men. Positive (near) localization errors, esophoria, high negative spherical correction, high adductive and low abductive B/R ratios were found to be related. Positive errors were associated with high adductive and low abductive B/R midpoints for esophores, but the relationship for exophores was not clear. The difference between adductive and abductive B/R ratios increased with increasing positive error. The difference between adductive and abductive B/R midpoints was greater for esophores than exophores and increased with increasing positive error. The magnitude of error was related to the magnitude of the spherical correction which the subject wore during the experiment. The direction and magnitude of the localization errors were not much more predictable from the duction measures than from the phorias.

THE RELATION OF "DUCTION" TO DYNAMIC STEREOACUITY

INTRODUCTION

Stereoscopic depth perception (stereoacuity) deteriorates as viewing conditions get worse. When an observer tries to set a variable target at the same distance as a standard, not only does the precision with which he makes the setting decrease, but, in addition, the error of the final setting increases. Furthermore, this increase in the localization error is not random; the errors for a given observer get larger in a given direction: the variable target is set either increasingly closer to, or farther away from, the observer. Different observers, of course, make errors in different directions.[1,2]

The results of a previous study appeared to indicate a relationship between direction of error and lateral phoria: nearly all observers with esophoria set the variable rod in the Howard-Dolman type apparatus nearer than the standard rod, and nearly all observers with exophoria set the variable rod farther than the comparison.[2] This was similar to Ogle's report[3] of the relation between phoria and fixation disparity. It was clear, however, that other factors must be involved, because (1) many observers exhibited opposite localization errors for stationary and moving thresholds, (2) the crossover point varied between individuals, and (3) there was no marked relation between the magnitude of the phoria and the size of the localization error.

It seemed likely that another contributing factor might be an observer's ability to maintain fusion of the binocular images of a stimulus — his duction ability. This report deals with a study of the direction of the localization error in dynamic stereoacuity as a function of several variables, but with emphasis on the relation to duction.

APPARATUS AND PROCEDURE

Dynamic stereoacuity was tested with a Howard-Dolman type apparatus which could be rotated around the observer's head; that is, two vertical parallel rods separated by a fixed 3° visual angle, were rotated in tandem, and he followed them while they were in his 55° visual angle field of view. The apparatus has been described in detail elsewhere.[1]

Thresholds were measured with the method of constant stimuli while the rods were rotating at 90° per second, the lowest speed of rotation at which the direction of the localization error was previously found to be the same as at all higher speeds. The variable rod was put at a given setting and after a warning signal, the apparatus was rotated once. The subject judged whether the variable rod was nearer or farther than the standard; another setting of the variable was made and the process was repeated, and so on.

Abduction and adduction were measured with a Risley prism, and phorias were measured with a Maddox rod while the subject fixated a 24 cm rod, 9 mm in diameter, set at 137 cm from his eyes — the same distance as the standard rod in the Howard-Dolman apparatus.

SUBJECT

The subjects were 73* Navy enlisted men who either wore spectacle corrections or did not have unaided 20/20 acuity in both eyes, and had been sent to the Submarine Medical Center for final visual evaluation before being admitted to the Submarine School. All turned out to be myopes. Each subject wore his spectacle correction, if any.

*The numbers do not always add to 73 in the various Tables and Figures because of the failure to obtain a complete set of data from each subject. For example, a stereo threshold could not be obtained for two men because their localization error exceeded the limits of the apparatus. The direction of their error was quite clear, however, and they were included in those analyses in which only direction and not magnitude of error figured. Further, it was noted too late that the spherical error of one man and the phoria of another man had not been noted, and in two cases, the duction measures were lost. The information obtained with these subjects was used, however, whenever possible.

RESULTS

The subjects were classified according to both their phoria and the direction of their localization error. The average duction break-recovery (B/R) ranges for the resulting groups are given in Table I. The table shows, for example, that as the eyes were forced to converge, those subjects who had previously been found to place the variable rod in the Howard-Dolman apparatus farther than the standard (negative error), lost fusion when the power of the prism reached 21.8 prism diopters base out on the average; they recovered fusion when the power was decreased to 16.2 diopters. When the eyes were forced to diverge, those subjects making negative errors lost fusion when the power of the prism reached an average of 9.6 diopters and recovered fusion when the power was subsequently reduced to 5.7 diopters.

Range.— There is very little change in the abductive B/R ranges for the four groups; whether they make positive or negative errors, both exo- and esophores have abductive B/R ranges of around 3.7 diopters. Since all subsequent analyses involving abductive measures for the **total sample** of subjects similarly showed relatively little change from one condition to another, the analysis of the data for the total sample centers around the adductive measures. These underwent a marked change. The adductive B/R ranges are appreciably higher for the subjects making near (positive) errors than for those making far (negative) errors. For both exo- and esophores making far (negative) errors, the adductive B/R range is about 5.4 diopters; but for the subjects making positive errors, it increased to about 8.4 diopters.

Localization error is plotted as a function of adductive B/R range in Fig. 1. A negatively sloping regression line is apparent, indicating that a low B/R range is associated with a negative error irrespective of phoria.

TABLE I. Average Adductive and Abductive Break-Recovery Ratios.

	Negative (Far) Localization Error			
	Exophores (N=15)		Esophores (N=22)	
	Adduction	Abduction	Adduction	Abduction
Ratio	21.8/16.2	9.6/5.7	22.7/17.6	8.3/4.7
Range	5.6	3.9	5.1	3.6
Midpoint	19.0	7.6	20.2	6.5
Ratio of Midpoints	2.5		3.1	
Difference between Ranges	1.7		1.5	
Spherical Correction (Right/Left eye)	1.33/1.15		1.26/1.32	
	Positive (Near) Localization Error			
	Exophores (N=7)		**Esophores (N=25)**	
Ratio	20.2/11.9	10.1/6.5	27.1/18.6	8.4/4.7
Range	8.3	3.6	8.5	3.7
Midpoint	16.0	8.3	22.8	6.5
Ratio of Midpoints	2.2		3.5	
Difference between Ranges	4.7		4.8	
Spherical Correction (Right/Left Eye)	1.71/2.03		1.55/1.30	

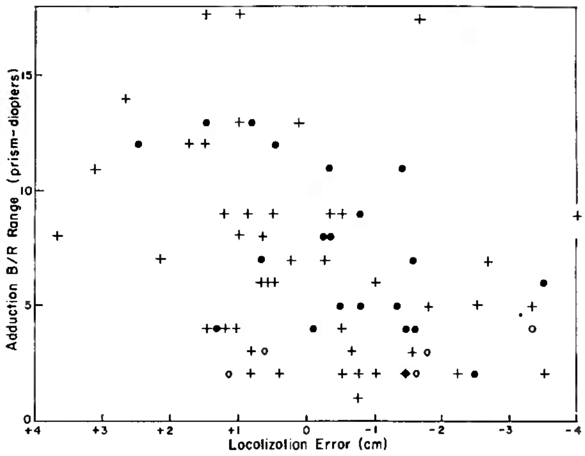

Fig. 1. **The relation between localization error and adductive B/R range. (Esophores ●; exophores +; orthophores o).**

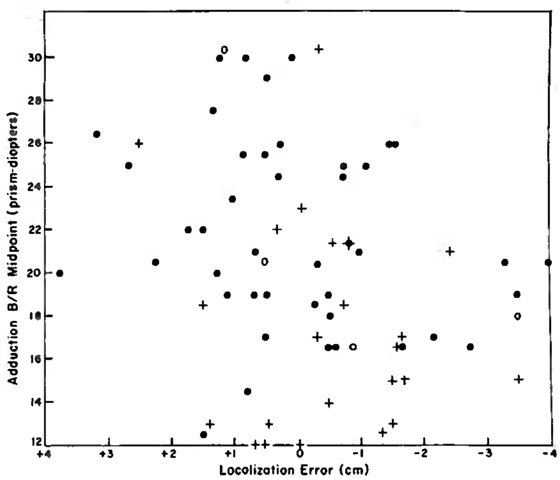

Fig. 2. **The relation between localization error and adductive B/R midpoint. (Esophores ●; exophores +; orthophores o).**

The product-moment correlation is -.49 ($p < .05$). This relationship is also shown in Table III, which gives the average error as a function of B/R range when the median range is computed and the subjects divided according to whether their range is above or below the median. The average negative error is twice as great for subjects with a low range, while the positive error is greater for subjects with a high range. There is virtually no difference in these averages when they are computed separately for exo- and esophores.

TABLE II. **Average Localization Error as a Function of Magnitude of Adductive Break-Recovery Range.**

Negative (Far) Error	
High Range	Low Range
0.78	1.48
Positive (Near) Error	
1.35	0.74

Midpoint.— Table I also shows that the ratio of the midpoints — that is, the amount of adductive to abductive prism-power which the subject can withstand — is somewhat greater for esophores than for exophores.

When errors are plotted against B/R midpoint (Fig. 2), the same picture emerges for the esophores, but the relationship is unclear for the exophores. The product-moment correlation for the two groups combined is -.35 ($p < .05$).

Phoria.— The relationship between phoria and error for this sample is small; the correlation is .14, but it is in the same direction as the previous findings.[1]

Spherical correction.— There is an increase in the mean spherical correction of those subjects making positive localization errors compared to that of the subjects making negative localization errors. The increase is greater for exophores than for esophores. The relationship is shown in Fig. 3. The correlation is -.35 ($p < .05$).

Small vs Large Localization Errors.— The data can be analyzed also by dividing the subjects according to whether they made small (below the median) or large (above the median) localization errors, as shown in Table III. Here we see further evidence of the relationship between esophoria and positive errors. Of the subjects making large negative errors only 6 of the 18 (33%) are esophores; of those making small negative errors, 11 out of 19 (58%) are esophores. Of those making small and large positive errors, the percentage of esophores is 61 and 65, respectively. The adduction B/R midpoint and range both increase with decreasing negative error or increasing positive error, although again the adduction measures are not consistent.

The differences between adductive and abductive B/R ranges increase with increasing positive error, as the ratios of adductive to abductive prism-power (midpoint) tend to do also.

Finally, it can now be seen more clearly

TABLE III. Comparison of the Average Results for Subjects making Small vs Large Errors.

	Adduction	Abduction	Adduction	Abduction
	Large Negative Error		Small Negative Error	
Ratio	22.3/17.3	9.6/5.3	22.9/17.4	8.4/4.9
Midpoint	19.8	7.4	20.2	6.6
Range	5.0	4.3	5.5	3.5
Ratio of Midpoints	2.7		3.06	
Difference between Ranges	0.7		2.0	
Phoria	5 EXO 6 ESO 7 ORTHO		6 EXO 11 ESO 2 ORTHO	
Rx: Right	1.28		1.30	
Left	1.19		1.30	
	Large Positive Error		Small Positive Error	
Ratio	26.7/17.6	9.3/5.2	24.2/17.0	8.6/5.1
Midpoint	22.2	7.2	20.6	6.8
Range	9.1	4.1	7.2	3.5
Ratio of Midpoints	3.08		3.03	
Difference between Ranges	5.0		3.7	
Phoria	2 EXO 11 ESO 4 ORTHO		2 EXO 11 ESO 5 ORTHO	
Rx: Right	1.81		1.47	
Left	1.66		1.48	

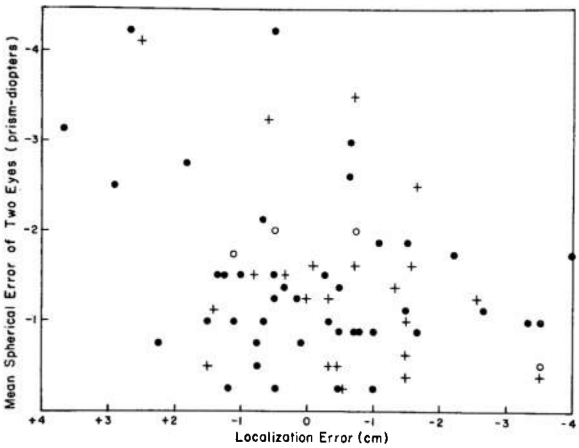

Fig. 3. **Localization error as a function of spherical correction. (Esophores ●; exophores +; orthophores o).**

that increasing spherical correction is associated with increasing positive error. The correction increases quite regularly from about 1.2 diopters for subjects making large negative errors to around 1.7 diopters for those making large positive errors.

Subjects with Low Refractive Errors.— The present data differ from those obtained by Luria and Weissman[1] in one major respect: the relationship between phoria and localization error previously found — exophores made negative errors and esophores made positive errors — was quite small in the present sample. Although the division between positive and negative errors was quite even, the distribution of phorias in the present sample was grossly skewed; 47 of the subjects were esophores and only 22 were exophores.

It seemed likely that the relationship was being obscured by the fact that the present sample was unrepresentative, being composed entirely of myopes. Indeed, when only those subjects with less than one diopter of spherical refractive error were considered, the previous much more pronounced relationship emerged: Of 8 subjects making negative localization errors, 6 were exophores, and of 8 subjects making positive errors, 7 were esophores. An analysis of the results of this sub-sample showed that, as expected, increasing positive error was associated with increasing esophoria (Fig. 4, r=.45), with increasing adductive B/R midpoint (Fig. 5, r = -.49), and with increasing adductive B/R range (Fig. 6, r = -.29).

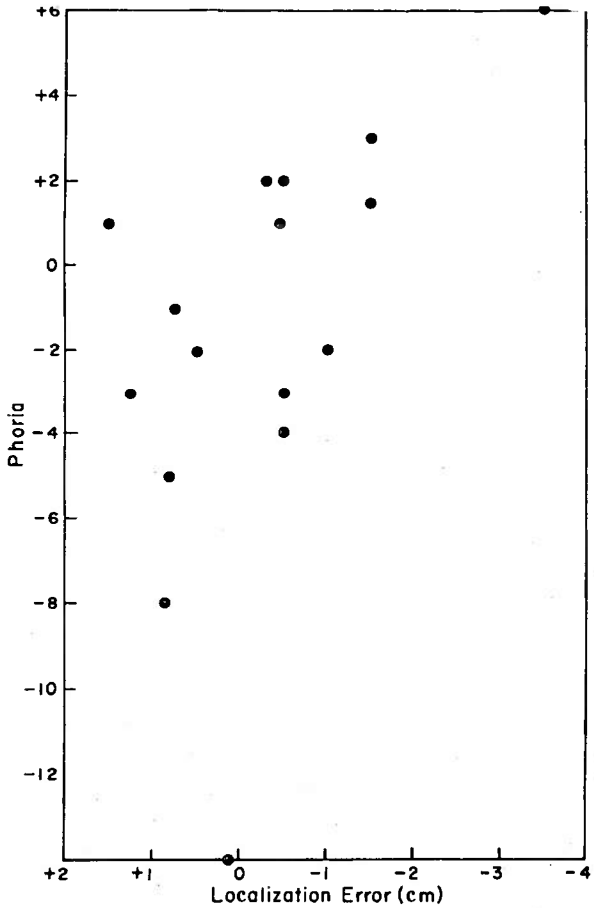

Fig. 4. Localization error as a function of phoria for the subjects with less than one diopter of spherical refractive error.

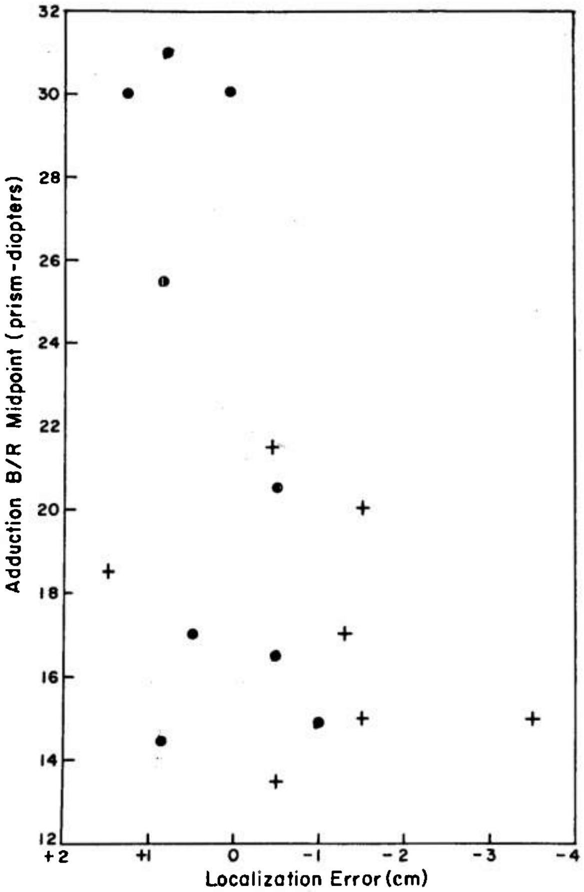

Fig. 5. Localization error as a function of adductive B/R midpoint for the subjects with less than one diopter of sperical refractive error. (Esophores ●; exophores +).

No analyses involving abductive measures have been presented so far because, as noted above, of the relative invariance of these measures for the total sample. It is noteworthy, therefore, that for the sample of subjects with small refractive error, relationships between abductive measures and the other variables appear. It is now apparent that low abductive B/R ranges are associated with positive errors (Fig. 7, r = .30) — the opposite of adductive B/R ranges (Figs. 1 and 6) — while Fig. 8 shows that increasing abductive B/R midpoint is associated with negative errors (r = .90), also the opposite of the adductive relationship (Figs. 2 and 5).

Quality of the Visual System.— It seems reasonable to suppose that a good visual system is characterized by a high adductive B/R midpoint and a low range, while the combination of a low midpoint and a high range would indicate a poor visual system. We would predict, accordingly, that subjects in the former category would have the smallest localization errors and standard deviations. Table IV shows, however, that the results do not support our hypothesis. The results were not improved by analyzing only the results of those subjects with low refractive error, or by separating the localization-errors according to direction.

TABLE IV. Average Errors (without regard to direction) and Standard Deviations as a Function of the Magnitude of Adductive Midpoint and Range.

		Midpoint	
		Low	High
Range	Low	1.24±.58	1.15±.54
	High	1.10±.69	1.24±.71

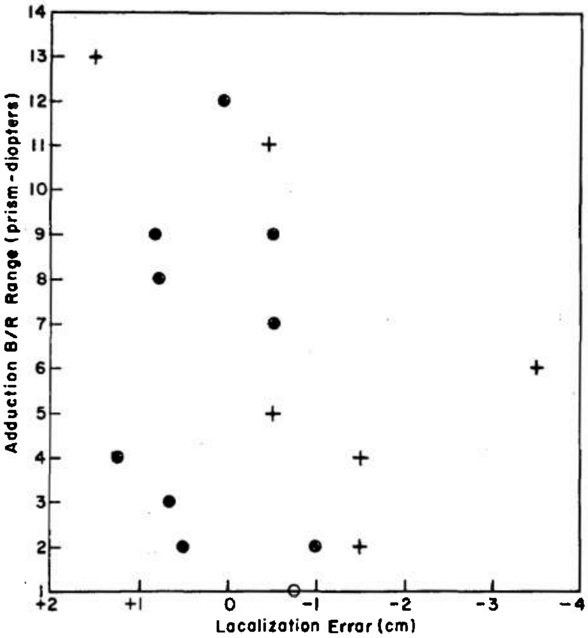

Fig. 6. Localization error as a function of adductive B/R range for the subjects with less than one diopter of spherical refractive error. (Esophores ●; exophores +).

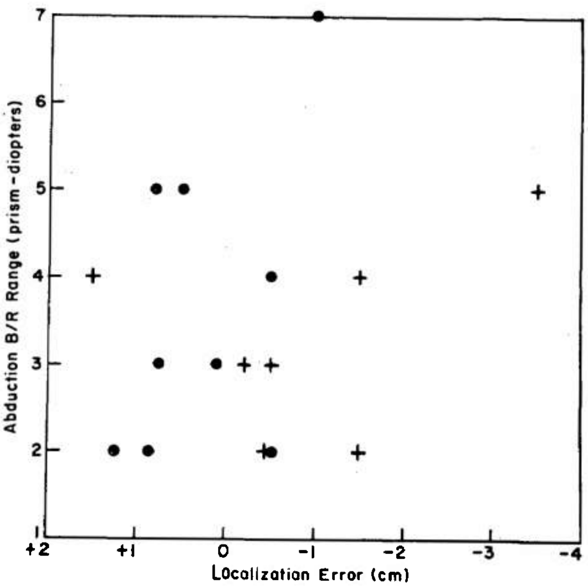

Fig. 7. Localization error as a function of abductive B/R range for the subjects with less than one diopter of spherical refractive error. (Esophores ●; exophores +).

DISCUSSION

Previous work has shown that the reliability of tests of phoria range from a poor .43 to a moderate .73, and the correlations between the tests average only about .50.[4] Despite this inherent variability, the present study has revealed several relationships involving ductions and phorias. The main results can be summarized briefly.

Positive (near) localization errors tend to be associated with esophoria (Table 3, Fig. 4), **high adductive and low abductive B/R ranges** (Figs. 1, 6, 7), **high adductive and low abductive B/R midpoints** (Figs. 2, 5 8), **and high negative spherical correction** (Table 3, Fig. 3). It must be noted that these relationships (except of course the last one) are usually much clearer for the group of subjects who exhibited very small refractive errors. The relationship between localization error and phoria is seen only after these myopes of more than one diopter are removed from the sample; however, this relationship has been noted before,[2] and corresponds to Ogle's[3] finding of the relation between error and fixation-disparity, as noted above.

The ratio of adductive to abductive B/R midpoints, and the difference between the abductive and adductive B/R ranges both increase with increasing positive error (Table 3). Esophores have an advantage over exophores in the range of prism-power which they can withstand. Since esophoria is associated with positive errors, there will be an increasing proportion of esophores with increasing positive error, resulting in an average increase in the ratio of adductive to abductive midpoints.

The increase in the difference between the abductive and adductive ranges is due to the fact that the adductive — but not the abductive — ranges increase with positive error.

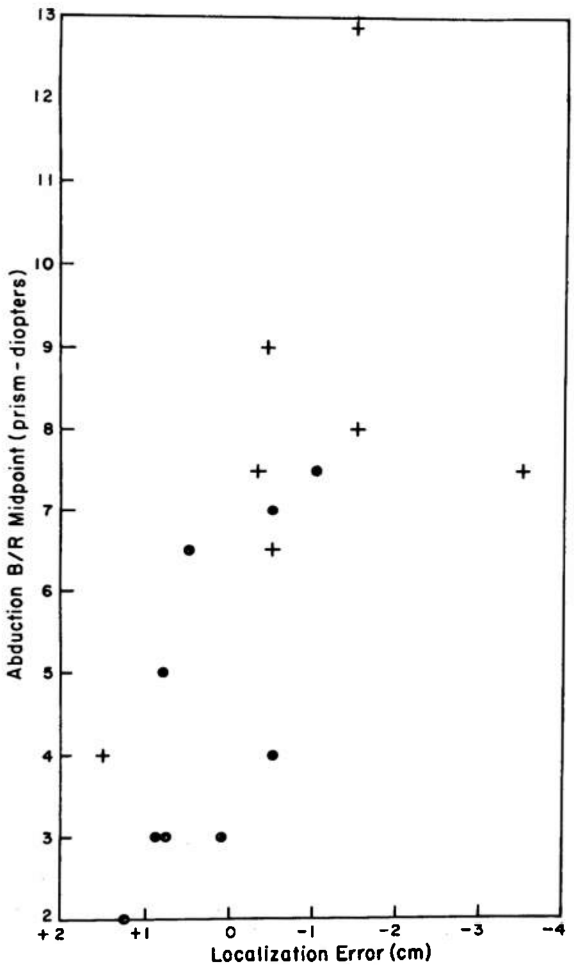

Fig. 8. Localization error as a function of adductive B/R midpoint for the subjects with less than one diopter of spherical refractive error. (Esophores ●; exophores +).

Perhaps the most interesting finding is the relation between spherical refractive error and localization error — that is, that an increasing refractive error is associated with increasing positive error. This is true for both exo- and esophores, but it appears to be more pronounced for the exophores. It is particularly interesting in view of the fact that the subjects wore their spectacle corrections while observing and thus refractive error should presumably be irrelevant. It is not certain what the explanation is.

It is also not clear to what extent localization error is better predicted from duction than from phoria. For the total sample, the correlation between phoria and error was only .14, but the correlation between error and adductive midpoint was .49 and it was .29 between error and adductive range. Both of the latter are considerable improvements, yet for the sub-sample of subjects with low refractive errors, there was no such difference. The correlations between error and phoria and between error and adductive midpoint were both nearly .50.

We are forced to conclude that localization error was not well predicted from the variables in the present study, that even the sample of subjects with low refractive error did not yield the expected results concerning the quality of the visual system, and that other factors, which we have not dealt with, play a part.

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13. ABSTRACT

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