Effect of Induced Heterophoria on Distance Stereoacuity by using the Howard-Dolman Test

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Abstract

Purpose: To evaluate the effect of induced esophoria and exophoria on distance stereoacuity at 6 meters

Methods: Fifty subjects with distance corrected or uncorrected visual acuity of $^6/_6$ and orthophoria without history of amblyopia, strabismus or any ocular pathology were recruited and distance stereoacuity was measured by Howard-dolman test before and after introducing 2, 4, 6 and 8Δ base in and base out to induce esophoria and exophoria, respectively.

Results: Although the decrease in stereoacuity was not significant by introducing 2Δ base in prism (P=0.062), but it was significant statistically by introducing 4 and 6Δ base in (P=0.002, P=0.026, respectively) and 2, 4, 6, 8Δ base out (P=0.042, P<0.001, P<0.001, P<0.001, respectively) prisms compared with orthophoric position. There was no significant difference between stereoacuity in 2Δ and 4Δ induced esophoria with 2Δ and 4Δ induced exophoria (P=0.696, P=0.677, respectively), but 6Δ induced esophoria decreased stereoacuity more than induced exophoria of the same amount (P=0.007).

Conclusion: Induced heterophoria at distance of 6 meters reduced stereoacuity measured by modified Howard-Dolman test. Greater than 4Δ of induced esophoria had statically and clinically adverse effect on distance stereoacuity.

Keywords: Stereoacuity, Heterophoria, Howard-Dolman Test

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Introduction

As is well known, stereopsis is the capacity of the visual system to obtain three-dimensional information from the exterior world by the processing of disparity.[1-3] Although stereopsis is not essential for perception of depth, stereopsis is advantageous in tasks involving complex visual presentations and hand-eye coordination.[1] Functional mechanisms of stereopsis are still not completely understood.[4]

Stereoscopic testing is important in the clinical practice of optometry, as it is a complex task for our visual system and, for accurate execution, requires the precise functioning of the motor and sensory pathways.[5] Patients who have normal stereopsis are highly unlikely to have any serious problems with their refractive or oculomotor systems.[6,7]

The Howard-Dolman stereotest was designed to measure the stereoacuity threshold in distance of 6 meters. This is the standard stereopsis test and serves as the "gold standard" against which all other stereopsis tests are compared.[1] This test is superior to other stereotests as it measures stereoacuity at threshold levels in contrast with suprathreshold measures with other tests. Other studies have used Howard-Dolman tests to measure distant stereoacuity.[8,9] The current study measured the distance stereoacuity threshold using a modified Howard-Dolman three-rod stereotester.

Heterophoria is the relative deviation of visual axes when the eyes are dissociated. Fry and Kent[9] determined that induced phorias bore no predictable relationship to stereoscopic acuity. Looking at naturally occurring phorias, Castren et al[10] found no correlation with observed stereoacuity. On the other hand, in the applied, stereopsis demanding world of stereophotogrammetry, it has long been known that some relationship must exist. Salzman,[11] Dwyer[12] and Moore and Bryan[13] forcefully state that exophores make the best stereocompilers.

Saladin[14] investigated the effect of horizontal heterophoria on Howard-Dolman stereopsis scores in a population of 1,765 stereophtogrammetrists. He concluded that heterophoria had different effects on stereoacuity depending on whether it was in exo, eso or vertical direction and relatively small amounts of esophoria will adversely affect stereopsis, but the ability of the system to overcome the effects of exophoria is considerably more robust. Although he studied a large sample, but all their subjects were stereophotogrammetrists whom their experience of stereophotogrammetry might have some positive effect on Howard-Dolman stereo task and the results might be different from that of general population. On the other hand the stereoacuity threshold was measured at distance of 3 meters in their study and observation distance could affect stereopsis if the visual system uses information, such as accommodation, convergence, and cognitive factors, to estimate the perceived distance and incorporates this information to generate a stereoscopic response.[5,10,15]

In their study, crossed and uncrossed stereoacuity at distance and the effect from heterophoria, Lam et al[16] concluded that orthophores have the best stereoacuity, followed by exophores and esophores; but their study lacked the esophoric subjects compared with orthophores and exophores.

In this study we investigated the effect of induced esophoria and exophoria on distance stereoacuity threshold at 6 meters measured by modified Howard-Dolman test in a sample of general population with normal binocular vision.

Methods

Patients referring for eye examination to optometry clinic of Mashhad University of Medical Sciences during a month were recruited in this study. After a complete optometric examination, orthophoric patients at distance with corrected or uncorrected $^6/_6$ visual acuity (VA) in each eye without amblyopia, strabismus and free from symptomatic binocular problems were included in the study. Fifty patients were included in the study by these criteria.

As mentioned above, stereoacuity was measured at far by modified Howard-Dolman test. The device was similar to the two-rod tester used in previous studies.[8,9] The main difference was the addition of a central movable rod. Figure 1 shows the modified Howard-Dolman apparatus used in this study.
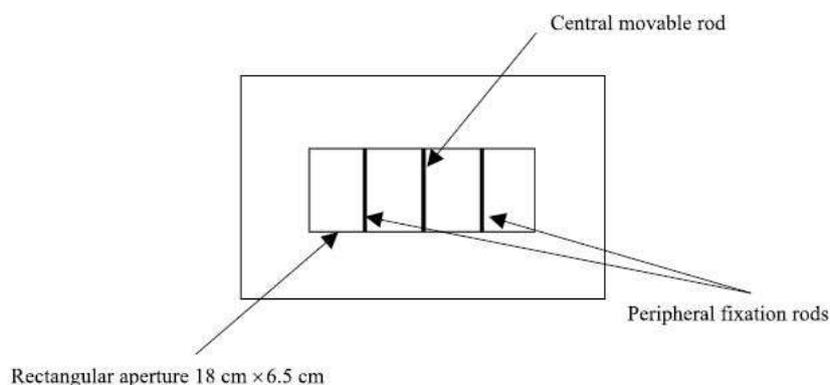
Figure 1. Modified Howard-Dolman apparatus

Therefore, the two peripheral rods were for fixation and the central movable rod was for measuring distant stereothreshold. There was a central rectangular aperture of 18 cm × 6.5 cm at the front surface of the device to block the view of the upper and lower ends of the rods. Each rod was 3 mm in diameter with a separation of 5 cm laterally. The rods were painted black and were seen in silhouette through the aperture against an evenly illuminated white background of luminance around 100 cd/m^2 when viewed at 6 m.[8]

A headrest with a chin cup was used to avoid motion, parallax being used as a cue to depth. The three-rod apparatus was placed at 6 m and at the eye level of the subject. A manual shutter was provided so that the rods could be adjusted without providing the subject with motion cues to depth.[9]

The Howard-Dolman test can be used with either a null task or a just noticeable difference (JND) task. Because the null task requires less decision effort of the observer and is less criterion-dependent, is more stable.[15] We used this method in measuring stereothreshold, therefore. Subjects were instructed to fixate on the reference plane formed by the two fixed rods and to move the middle rod, by means of a string, forward and backward and place it where it seems to be aligned with the two fixed rods. The apparent alignment error between the planes of the movable rod and the two fixed rods was measured in millimeters and averaged after the task was done for 3 times. This task was done first by the best distant correction of the orthophoric subject placed in the trial frame.

Then the 2, 4, 6 and 8Δ base in (induced esophoria) and 2, 4, 6 and 8Δ base out prism (induced exophoria) inserted in the trial frame, respectively. After insertion of the prism the subject was allowed to have 2-3 minutes of binocular visual experience to be completely prism-adapted.[17]

The stereoacuity was calculated by the following formula with the interpupillary distance of each subject measured:

$$\text{Stereoacuity secarc} = 180 \times PD \times d \times 3600/ \, \pi \times (D^2)$$

Where PD is the interpupillary distance, d the disparity between the rods and D the testing distance of 6 m. The data obtained were statically analyzed with SPSS 16 software.

Results

Considering the inclusion criteria, of 80 patients examined, 50 patients with mean age of 27.0 years (range, 10 to 60) were studied.

The mean distance stereoacuity threshold in our orthophoric and visually normal subjects was 4.61±0.52 seconds of arc.

Regarding the effects of induced esophoria on distance stereoacuity threshold compared with orthophoric position (Table 1, Figure 2), results of paired t test showed insignificant increase in distance stereoacuity threshold by introducing 2Δ base in (P=0.062), but a significant increase by introducing 4 and 6Δ base in (P<0.05). Since introducing 8Δ base in prism resulted in 98% occurrence of diplopia and disruption of binocular vision, no stereoacuity threshold could be measured in this condition. On the other hand introducing 4Δ base in showed significant increase in

distant stereothreshold compared with 2Δ base in (P=0.015). Introducing 6Δ base in showed insignificant increase in distant stereothreshold compared with 4Δ base in (P=0.201) considering that this comparison was made only between 22% of subjects due to occurrence of diplopia in 78% of subjects by introducing 6Δ base in prism.

Results of paired t test to assess the effects of induced exophoria on distant stereothreshold compared with orthophoric position showed a significant increase in distant stereoacuity threshold by introducing 2Δ (P=0.042), 4, 6 and 8Δ base out (P<0.001) (Table 1, Figure 2). On the other hand introducing 4Δ base out showed significant

increase in distance stereoacuity threshold compared with 2Δ base out (P=0.001) but an insignificant increase observed in comparison of 6Δ to 4Δ (P=0.174) and 8Δ to 6Δ base out (P=0.701).

Although distance stereoacuity threshold was statically the same by introducing 2Δ base out compared with 2Δ base in (P=0.696) and also 4Δ base out compared with 4Δ base in (P=0.677), but introducing 6Δ base in prism resulted in significantly larger stereoacuity threshold (less stereoacuity) than 6Δ base out (P=0.007) (Table 2). Seventy-eight percent of subjects had diplopia and hence no binocular vision by inducing 6Δ esophoria at far.
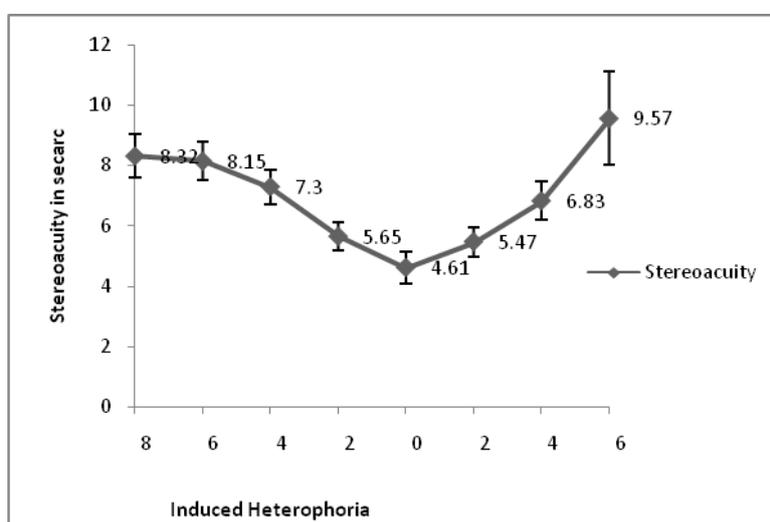

Figure 2. The mean stereoacuity value in seconds of arc for different amounts of induced heterophoria (the error bars represent±standard error of mean)

Table 1. Results of paired t test analysis between orthophoric and induced heterophoric distance stereoacuity scores

		2Δ exo	4Δ exo	6Δ exo	8Δ exo	2Δ eso	4Δ eso	6Δ eso	8Δ eso
	t	-2.086	-4.746	-4.659	-4.277	-1.912	-3.294	-2.604	-
Orthophoria	df	49	49	49	49	49	46	10	0
	P	0.042	<0.001	<0.001	<0.001	0.062	0.002	0.026	-

Table 2. Results of paired t test analysis between stereoacuity scores of the same amounts of induced heterophoria

	95% Confidence Interval of the Difference		t	df	P
	Lower	Upper			
2Δ exo Vs. 2Δ eso	-.78438	1.16518	0.393	49	0.696
4Δ exo Vs. 4Δ eso	-1.17462	1.79164	.419	46	0.677
6Δ exo Vs. 6Δ eso	-6.03915	-1.26631	-3.410	10	0.007

Discussion

The mean distance stereo threshold of our orthophoric subjects was 4.61±0.52 seconds of arc before inducing heterophoria. This finding is in consistence with other studies. Using the null task and a variance value of one standard deviation, Saladin et al[18] believed a result of 14 seconds of arc or better (smaller numeric value) is expected for an adult with a normal binocular system. The mean stereoacuity for orthophoric subjects in Lam et al[16] study was also 5.31±4.38 seconds of arc.

According to the results of this study induced heterophoria negatively affects distance stereothreshold of normal subjects measured with modified Howard-Dolman test. Fry and Kent[9] induced phorias with various amounts of prisms in four subjects and found no particular pattern in changes in stereoacuity. But the variability would be much greater and the relation between heterophoria and stereopsis would be much less distinct in their small number of samples. In 1982, Castren et al[10] were similarly puzzled when they found that the naturally occurring heterophorias of 806 subjects bore no strong correlation with the observed stereoacuity. Visual observation of their data does show, however, that the highest level of stereoscopic error existed in those with the highest amount of esophoria tested (4Δ). Perhaps if they had included subjects with larger esophorias, the statistical significance would have appeared.[14] Similar to our results, the orthophoric subjects of Lam et al[16] study demonstrated better stereoacuity (5.31 sec of arc) than exophoric (6.02 sec of arc) and esophoric subjects (8.91sec of arc). Rutstein et al[19] also concluded that distance stereopsis varies according to the type and magnitude of ocular deviation. They said patients who are orthophoric perform better on distance stereotest than do heterophores and intermittent strabismics. By measuring distance stereoacuity in prism-induced convergence stress, Laired et al[20] concluded that convergence stress induced by base-out prisms on nonstrabismic volunteers affects performance on real world stereotests, such as the FD2 test and is associated with decreased distance stereoacuity.

This study showed that distance stereothreshold increased significantly by introducing base in and base out prisms, but it is observed from the Figure 2 that this increase has steeper slope in the base in part of the stereoacuity curve. Although the increase in stereothreshold was significant by introducing 2Δ base out and insignificant by introducing 2Δ base in compared with orthophoric position, but paired t-test analysis did not show significant difference between stereoacuity of 2Δ and 4Δ induced exophoria with that of 2Δ and 4Δ induced esophoria, respectively. On the other hand induced esophoria greater than 4Δ base in caused significant increase in distance stereothreshold compared with the same amount of induced exophoria. In fact our results showed that the stereoacuity was similar when the induced heterophoria was within 8Δ of exophoria to 4Δ of induced esophoria (Table 1). The mean value of distant stereoacuity was within normal range. The possible explanation lies in the good quality of binocular vision of the observers selected in the present study. They had revealed good maintenance of fusion of the binocular images of a stimulus with good duction ability. Differently, Saladin[14] found a poor stereoacuity (at a distance of 3 m) for subjects with esophoria greater than two prism dioptres. The stereoacuity was similar when the heterophoria was within seven prism dioptres of exophoria to two prism dioptres of esophoria. This difference might be arisen from the different sample population and the test distance of Saladin's study and ours.

The common point between our results and previous studies[4,11-14,16] is that an asymmetry definitely exists between the esophoric and exophoric results of distant stereoacuity. The differing effects of heterophoria on stereopsis can be explained by the relative strength of the separate slow vergence adaptation mechanisms and the relation between fixation disparity and stereopsis.[14]

Conclusion

Induced heterophoria at distance of 6 meters increased stereothreshold (reduced stereoacuity) measured by modified Howard-Dolman test. This increase was statically the same within 8Δ induced exophoria to 4Δ induced esophoria and does not seem to be clinically important in visual healthy

individuals, since the stereoacuity value was within normal range. But greater than 4Δ of induced esophoria had statically and clinically adverse effect on distance stereoacuity.

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