Original Article

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Ophthalmology Section

Correlation Between Stereoacuity and Experimentally Induced Graded Monocular and Binocular Astigmatism

VARSHA KULKARNI[1], NEELAM PUTHRAN[2], BHAVNA GAGAL[3]

ABSTRACT

Introduction: Stereopsis, the highest grade of binocular single vision, is affected by various factors, such as mis-alignment of visual axes, refractive errors especially anisometropia and astigmatism, both of which may result in amblyopia. There are very few studies in literature regarding the relationship between stereoacuity and refractive errors, especially astigmatism.

Aim: The present study was conducted to determine the correlation between stereoacuity and experimentally induced graded astigmatism in emmetropes.

Materials and Methods: A randomized study was conducted on 2000 individuals of either gender, between the ages of 8-35 years, at tertiary care centre attached to a medical college during the period of August 2012 to August 2014, All subjects were emmetropic with normal binocular single vision. Participants were randomly divided into four groups of 500 individuals each. Two groups were subjected to induced myopic astigmatism, either uni-ocularly or binocularly, using + 1.0 D and + 2.0 D cylinders at varying axes i.e., 45^0, 90^0 and 180^0. Similarily, the remaining two groups were subjected to induced hypermetropic astigmatism, using - 1.0 D and - 2.0D cylinders at varying axes i.e. 45^0, 90^0 and 180^0. Near stereoacuity was determined by the Titmus Fly Stereo Test, both before and after induction of astigmatism. Statistical analysis was done using paired t-test and ANOVA.

Results: The mean stereoacuity in emmetropes was 28.81±4.97 seconds of arc. There was a decrease in stereoacuity with increase in dioptric power of astigmatism (p<0.001). Oblique astigmatism reduced the stereoacuity maximally, while stereoacuity was least affected at 180° axis. Hypermetropic astigmatism caused more deterioration in stereoacuity than myopic astigmatism. A gross reduction in stereoacuity was noted in induced monocular astigmatism as against binocular astigmatism.

Conclusion: This study suggests that stereoacuity is significantly affected by even minor degrees of monocular or binocular astigmatism.

Keywords: Anisometropia, Amblyopia, Refractive errors, Stereopsis

INTRODUCTION

Precise judgments of depth are essential for daily activities. Indeed, a high grade of depth perception is a necessary requirement in many professions. Depth perception is termed as Stereopsis, a word derived from the Greek language wherein στερεο- *stereo-* means "solid", and ὄψις *opsis*, means "sight". In ophthalmology, stereopsis is defined as the relative ordering of visual objects in depth, and represents the highest grade of binocular single vision, wherein two dissimilar images of the same object are formed simultaneously, on the retinae of the two eyes [1]. These images are then processed in the visual cortex to produce a single fused image, whose location in space can be perceived. Gross stereopsis for distant vision may be possible uniocularly, because of monocular cues like linear perspective, motion parallax, inter position, relative sizes of objects etc.

The minimal disparity of images detectable by an individual is termed as stereoacuity. Stereoacuity may be quantitatively assessed by means of a stereoscope. The first stereoscope was invented by Wheatstone in 1838 [1]. He proved that horizontal disparities of the images, rather than vertical disparities, were of greater relevance for the perception of depth.

Stereoacuity is affected by various factors, such as mis-alignment of visual axes, refractive errors, anisometropia, and amblyopia. Of the refractive errors, astigmatism, in children, is important due to its fairly high prevalence, being between 6.33% to 36.9% [2,3]. Astigmatism may be induced in elderly patients after cataract surgery, pterygium excision, and even after refractive surgeries following which stereopsis may worsen.

A search of the literature revealed that little information existed regarding the relationship between stereoacuity and refractive errors, especially astigmatism [4,5].

AIM

This study was conducted with the aim to determine the change in stereoacuity after experimentally inducing graded monocular and binocular astigmatism at various axes.

MATERIALS AND METHODS

A randomized study was carried out in a tertiary health care centre attached to a medical college, from August 2012 to August 2014. Institutional Ethics Committee approval was obtained prior to commencing the study. This study was performed on 2000 emmetropic individuals, between the ages of 8-35 years (mean age 20.8 years) having normal binocular single vision. Individuals having squint, amblyopia or any other ocular disease were excluded. Individuals were enrolled in the study after taking a due informed consent for both, participation in the study, as well as for any subsequent publication of data from the study. A chit method of randomization was used to allot the participants to one of the four groups. All individuals were tested in the same room between 10AM-1PM under common illumination conditions. Baseline stereoacuity for near was recorded using Titmus Fly Stereo Test before inducing astigmatism.

Astigmatism was induced in each group so as to produce either a binocular myopic astigmatism, binocular hypermetropic astigmatism, monocular myopic astigmatism or monocular hypermetropic astigmatism.

In Group A, binocular myopic astigmatism was induced using +1 D cylinder and +2 D cylinder at 45⁰, 90⁰ and 180⁰ in front of both eyes. The order of cylinder power and axes was randomised. Stereoacuity was recorded 5 minutes after induction of astigmatism allowing participant to adjust with the cylinders. A 5 minute interval was maintained between tests to avoid fatigue.

Similarly, in Group B, binocular hypermetropic astigmatism was induced using -1 D cylinder and -2 D cylinder at 45⁰, 90⁰ and 180⁰. In Group C, monocular myopic astigmatism was induced using +1 D cylinder and +2 D cylinder at 45⁰, 90⁰ and 180⁰ in front of right eye, regardless of dominance. In Group D, monocular hypermetropic astigmatism was induced using -1 D cylinder and -2 D cylinder at 45⁰, 90⁰ and 180⁰ in front of right eye.

Data was captured on a standardized proforma. Results were tabulated and statistically analysed using paired t-test and ANOVA. A p-value <0.05 was considered significant.

RESULTS

This hospital-based study was conducted on 2000 individuals. Out of all the 2000 participants, 1012 were males and 988 were females. Mean baseline stereoacuity was 28.81±4.97 seconds of arc (range 20-40 seconds of arc).

In Group A, binocular induced myopic astigmatism with both +1 D cylinder and +2 D cylinder stereoacuity was affected maximally at 45⁰ and least affected at 180⁰, (p<0.001) [Table/Fig-1].

A similar impact was noted in Group B with both -1 D cylinder and -2 D cylinder binocular induced hypermetropic astigmatism (p<0.001) [Table/Fig-2].

In Group C, monocularly induced myopic astigmatism with +1 D cylinder, the mean stereoacuity was 55.90 ± 7.47 arc seconds (p<0.001) at 180⁰, 58.74±7.32 arc seconds (p<0.001) at 90⁰ and 76.49 ± 8.61 arc seconds (p <0.001) at 45⁰ axes. With +2 D cylinder there was gross reduction of stereoacuity to 110.68 ± 22.97 (p<0.001) at 180⁰, 119.80 ± 28.24 (p<0.001) at 90⁰ and 153.36 ± 34.01 (p<0.001) at 45⁰ axes [Table/Fig-3].

In Group D, the findings with both -1 D cylinder and-2 D cylinder monocularly induced hypermetropic astigmatism were similar [Table/Fig-4]. In monocularly induced hypermetropic astigmatism with-1 D cylinder, the mean stereoacuity was 56.94 ± 6.49 arc seconds (p<0.001) at 180⁰, 61.19 ± 11.30 arc seconds (p<0.001) at 90⁰ and 80.50±18.74 arc seconds (p<0.001) at 45⁰ axes. With -2 D cylinder there was gross reduction of stereoacuity to 113.68 ± 25.20 arc seconds (p<0.001) at 180⁰, 123.08 ± 31.47 arc seconds (p<0.001) at 90⁰ and 156.16±33.97 arc seconds (p<0.001) at 45⁰ axes.

Binocularly induced hypermetropic astigmatism caused more deterioration of stereoacuity than binocularly induced myopic astigmatism [Table/Fig-5]. Stereoacuity was grossly affected in both monocular myopic and hypermetropic astigmatism [Table/Fig-6].

DISCUSSION

Binocular Single Vision, Grade III, or Stereopsis, is usually fully developed by six years of age. Stereopsis requires normal functioning of both eyes and is adversely affected by refractive errors, anisometropia, aniseikonia, squint and amblyopia from any cause. Binocular depth perception is present only up till six metres distance. Thereafter, a gross estimation of depth perception becomes possible due to monocular clues such as motion parallax, linear perspective, overlay of contours, distribution of highlights and shadows, size of known objects and aerial perspective etc., [1].

	Mean Stereoacuity in binocular Induced Myopic Astigmatism with +1.00 D cyl	Mean Stereoacuity in binocular Induced Myopic Astigmatism with +2.00 D cyl	p-value
Baseline (sec of arc)	28.81 ± 4.97	28.81 ± 4.97	
180⁰	32.42 ± 4.98	55.15 ± 7.37	<0.001
90⁰	36.21± 7.28	58.97 ± 9.11	<0.001
45⁰	44.12 ± 8.64	79.25 ± 9.51	<0.001

[Table/Fig-1]: Stereoacuity in binocularly induced myopic astigmatism.

	Mean Stereoacuity in binocular Induced Hypermetropic Astigmatism with -1.00 D cyl	Mean Stereoacuity in binocular Induced Hypermetropic Astigmatism with -2.00 D cyl	p-value
Baseline (sec of arc)	28.81 ± 4.97	28.81 ± 4.97	
180⁰	38.51 ± 8.50	68.56 ± 7.33	<0.001
90⁰	43.41± 8.97	88.97 ± 8.87	<0.001
45⁰	52.34± 9.19	116.09 ± 13.62	<0.001

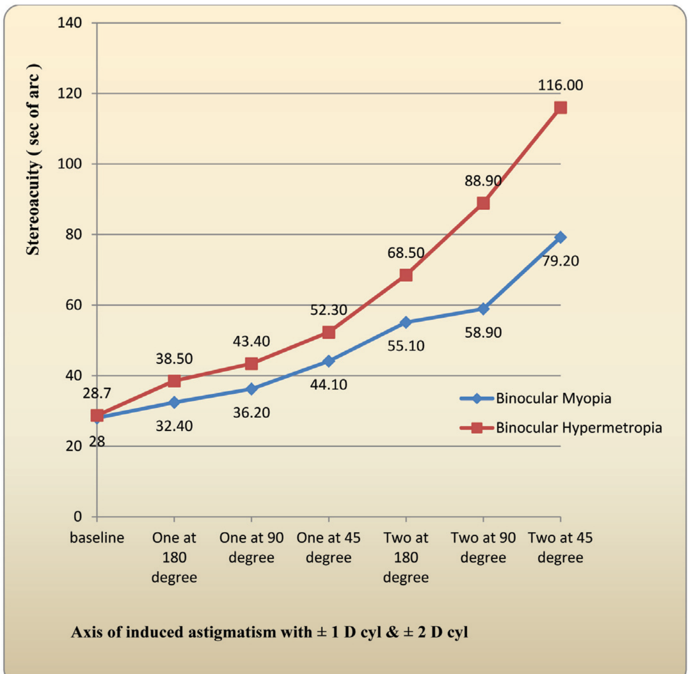
[Table/Fig-2]: Stereoacuity in binocularly induced hypermetropic astigmatism.

	Mean Stereoacuity in monocular Induced Myopic Astigmatism with +1.00 D cyl	Mean Stereoacuity in monocular Induced Myopic Astigmatism with +2.00 D cyl	p-value
Baseline (sec of arc)	28.81 ± 4.97	28.81 ± 4.97	
180⁰	55.90 ± 7.47	110.68 ± 22.97	<0.001
90⁰	58.74 ± 7.32	119.80 ± 28.24	<0.001
45⁰	76.49 ± 8.61	153.36 ± 34.01	<0.001

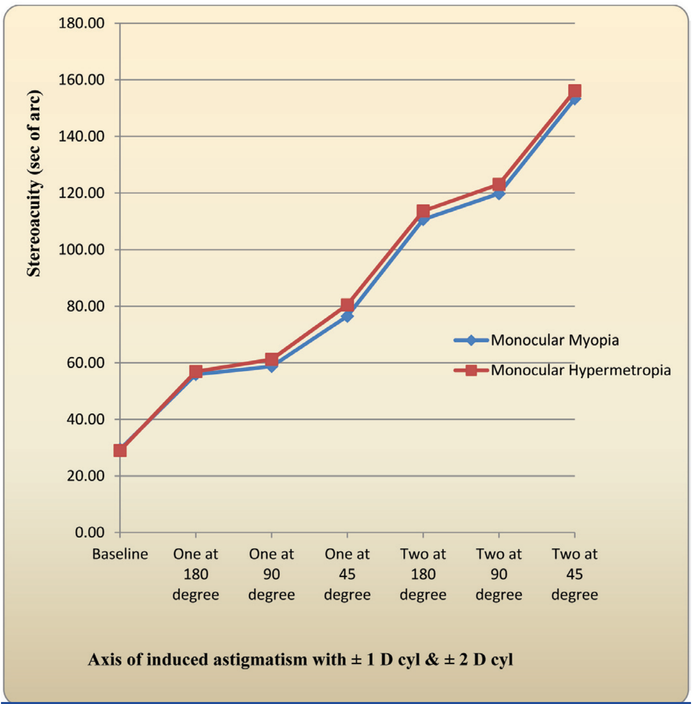
[Table/Fig-3]: Stereoacuity in monocularly induced myopic astigmatism.

	Mean Stereoacuity in moncular Induced Hypermetropic Astigmatism with -1.00 Dcyl	Mean Stereoacuity in monocular Induced Hypermetropic Astigmatism with -2.00 Dcyl	p-value
Baseline (sec of arc)	28.81 ± 4.97	28.81 ± 4.97	
180⁰	56.94 ± 6.49	113.68 ± 25.20	<0.001
90⁰	61.19 ± 11.30	123.08 ± 31.47	<0.001
45⁰	80.50 ± 18.74	156.16 ± 33.97	<0.001

[Table/Fig-4]: Stereoacuity in monocularly induced hypermetropic astigmatism.



[Table/Fig-5]: Comparison between stereoacuity in binocularly induced myopic and hypermetropic astigmatism.



[Table/Fig-6]: Comparison between stereoacuity in monocularly induced myopic and hypermetropic astigmatism.

Bonita P et al., have compared the distant and near stereoacuity in young adults with normal binocular vision and found no significant difference between distance-habitual and near-habitual viewing [6]. In the present study, determinations of only near stereoacuity were done.

Dadeya S et al., studied effect of anisometropia on binocular visual function [7]. They have reported that induced anisometropia causes suppression scotoma on worth four dot test because of uniocular defocus but fusion could be demonstrated by Bagolini's striated glasses in all subjects. Fusion testing was not considered as a factor in this study as the subjects already possessed stereopsis even after inducing astigmatism.

Under ideal experimental conditions, stereoacuity thresholds may reach 2-3 seconds of arc, but in clinical practice, stereoacuities of 30-40 seconds are considered normal. Heravian Shandiz J et al., reported a mean stereopsis of 40.83 ± 2.78 seconds of arc with Titmus Fly Stereo Testing [4]. In our study, the baseline mean stereoacuity in emmetropes was 28.81 ± 4.97 seconds of arc.

Astigmatism induces image blur which causes deterioration of stereoacuity. The image blur is proportional to the diopteric power of astigmatism and thus the stereoacuity deteriorates with increase in diopteric power of astigmatism irrespective of myopia or hypermetropia. As anticipated, the presence of astigmatism caused a significant adverse impact on stereopsis. Binocularly induced hypermetropic astigmatism caused a greater deterioration in near stereoacuity than binocularly induced myopic astigmatism which may be because of better near vision. The deterioration was found to be proportional to the increase in diopters of astigmatism.

Dadeya S et al., have reported that one dioptre of spherical anisometropia reduces the stereoacuity to an average of 92 arcs of second [7]. However, 33% of their subjects maintained 40 arc seconds of stereopsis with this level of spherical anisometropia. In the present study the spherical amount of anisometropia was not part of the methodology.

Regardless of the type of astigmatism, the axis of astigmatism was also seen to significantly influence the deterioration in stereopsis. Dadeya S et al., found that one dioptre of cylindrical anisometropia reduced the stereoacuity to an average of 60 seconds for ATR and 55 seconds for with the rule astigmatism [7]. Chen, et al., reported that the reduction in depth discrimination was dependent on the axis of the induced astigmatism (p<0.01) [5]. The maximum effect occurred with orthogonal-oblique orientations (x45 left; x135 right), followed by against the rule astigmatism. With the rule astigmatism had the least effect (p<0.001). Shinichiro Nakano et al., also reported similar results with maximum reduction of stereoacuity at oblique axes [8]. The present study also reveals a maximum deterioration at 45^0 axes in both myopic and hypermetropic astigmatism, while stereoacuity was least affected at 180^0. Stereoacuity was significantly affected in hypermetropic astigmatism as compared with the myopic group.

In addition to image blur caused by astigmatism, binocular disparity of retinal images also plays a role in reduction of stereoacuity. There was minimal difference between monocular myopic and monocular hypermetropic astigmatism because both cause similar image blur and image disparity between retinal images. We noted that there was a significant difference in monocularly induced astigmatism as compare to binocularly induced astigmatism of same degree. The reduction in stereoacuity in monocular induced astigmatism was greater than that in binocular induced astigmatism, irrespective of the type. However, the correlation with degree of astigmatism and its axis was similar to the binocular induced astigmatism group.

	Mean stereoacuity with -1 D cylinder		Mean stereoacuity with -2 D cylinder	
	Present study	Jethani et al., [9]	Present study	Jethani et al., [9]
180^0	56.94 ± 6.49	130.90 ± 35.2	113.68 ± 25.20	372 ± 173.8
90^0	61.19 ± 11.30	84 ± 39.5	123.08 ± 31.47	294 ± 170.8
45^0	80.50 ± 18.74	84 ± 35.1	156.16 ± 33.97	318 ± 179

[Table/Fig-7]: Comparison of results with study by Jethani et al.

J Jethani et al., studied induced monocular asnisometropia in 10 subjects and reported a reduction in stereoacuity [9]. In their study maximum reduction was observed in oblique astigmatism. Reduction was more in induced against the rule astigmatism than in with the rule astigmatism [Table/Fig-7]. The stereoacuity reduction was gross in their study which may be attributed to the fact that some of their subjects had pre-existing refractive errors and consequently had differing base line stereoacuities.

The findings in this group are consistent with the results seen by 0uguz et al., who reported that stereoacuity levels were reduced in proportion to the degree of anisometropia [10]. A 1D of cylindrical anisometropia reduced stereoacuity to an average 51-56 arc seconds. A 3D of anisometropia, regardless of type, produced a marked reduction of stereoacuity in all patients. Similar results were found by Heravian J et al., [4]. They reported that there was significant reduction in stereopsis level with respect to the degree and types of meridional anisometropia (p<0.001). Maximum reduction of stereopsis occurred with 4D myopic and hypermetropic astigmatic anisometropia in oblique axis (773.33 ± 101/4 and 693.33 ± 179.9 second of arc for Titmus stereotest). However, in this study, comparison between mean stereopsis in myopic and hypermetropic astigmatic anisometropia, showed that there was a significant reduction in all three axes, horizontal, vertical and oblique (p<0.001) and not restricted to any particular axis.

LIMITATION

Our study was conducted on emmetropic individuals with normal binocular function. They were not adapted to the image blur and disparity; hence, there was gross reduction in stereoacutiy after inducing astigmatism. It is possible that the effect on stereoacuity might be different in individuals who have astigmatism in early childhood, which is the critical period of binocular vision development. Therefore, further investigation in this regard needs to be done.

CONCLUSION

There was a proportionate decrease in stereo acuity with increase in dioptric power of astigmatism. Hypermetropic astigmatism causes more deterioration in stereoacuity than myopic astigmatism. Stereoacuity was most affected with oblique astigmatism (45). The reduction in stereoacuity in induced monocular astigmatism was more severe than in binocular astigmatism. This study suggests that stereoacuity is significantly affected by even a small degree of monocular or binocular astigmatism and therefore should be corrected before amblyopia sets in.

REFERENCES

[1] Von Noorden GK. Binocular vision and ocular motility: theory and management of strabismus, 4th ed. St Louis: CV Mosby, 1990:8-40.

[2] Wen G, Tarczy-Hornoch K, McKean Cowdin R, Cotter SA, Borchert M, Lin J, et al. Prevalence of myopia, hyperopia, and astigmatism in non-hispanic white and Asian children: Multi-ethnic pediatric eye disease study. *Ophthalmology*. 2013;120(10): 2109-16.

[3] Kleinstein RN, Jones LA, Hullett S, et al. Refractive error and ethnicity in children. *Arch Opthalmol*. 2003;121(8):1141-47.

[4] Heravian J. The effect of unilateral induced astigmatism on stereopsis. *Medical Journal of Mashhad University of Medical Sciences*. 2010;53(2):97-90.

[5] Chen SI, Hove M, McCloskey CL, Kaye SB. The effect of monocularly and binocularly induced astigmatic blur on depth discrimination is orientation dependent. *Optometry and Vision Science*. 2005;82(2):101-13.

[6] Wong BPH, Woods RL, Peli E, et al. Stereoacuity at distance and near. *Optometry Vision Science*. 2002;79(12):771-78.

[7] Dadeya S, Kamlesh, Shibal F, et al. The effect of anisometropia on binocular visual function. *Indian J Ophthalmol*. 2001;49:261.

[8] Nakano S, Hiraoka T, Hasegawa Y, et al. Effect of monocularly and binocularly induced astigmatic blur on stereopsis. *Ophthalmol Vis Sci*. 2012;53.

[9] Jethani J, Shah K, Kellaiya A, Patel N. The effect of experimentally induced anisometropia on binocularity and bifoveal fixation. *Gujarat Medical Journal*. 2015;70 (1):52-58.

[10] Oguz H, Oguz V. The effects of experimentally induced anisometropia on stereopsis. *J Pediatr Ophthalmol Strabismus*. 2000;37(4):214-18.

PARTICULARS OF CONTRIBUTORS:

1. Professor, Department of Ophthalmology, Bharati Vidyapeeth Medical College, Pune, Maharashtra, India.
2. Professor, Department of Ophthalmology, Bharati Vidyapeeth Medical College, Pune, Maharashtra, India.
3. Senior Resident, Department of Ophthalmology, Bharati Vidyapeeth Medical College, Pune, Maharashtra, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Varsha Kulkarni,
Professor, Department of Ophthalmology, Bharati Vidyapeeth Medical College, Pune-411043, Maharashtra, India.
E-mail: dr.varsha@rediffmail.com

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