Assessment of stereopsis in pediatric and adolescent spectacle-corrected refractive error – A cross-sectional study

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**Purpose:** To assess the level of stereopsis in school children with spectacle-corrected refractive errors using Titmus fly and Randot stereo tests, evaluate the factors associated with the level of stereopsis, and determine the level of agreement between the two tests. **Methods:** A cross-sectional study was done on 5- to 18-year-old school-children wearing spectacles for at least 1-month duration. Visual acuity was assessed using Snellen's visual acuity chart, and their spectacle correction being used currently was measured using an auto lensmeter. The level of stereopsis was assessed using Randot and Titmus fly stereo tests. Data were entered using Microsoft Excel and analyzed using IBM-SPSS version 20, Chicago, IL. The associations between stereopsis and type of refractive error, visual acuity, age, and gender were analyzed. An agreement between Randot and Titmus fly test was done using Kappa statistics. **Results:** A total of 222 children (101 boys and 121 girls; mean age 13 years) were assessed. Astigmatism was the most prevalent refractive error (60.4%), followed by myopia (24.8%) and hypermetropia (1.4%). Thirty children (13.5%) had anisometropia. All hyperopes had normal stereopsis. Children with spherical myopia had better stereopsis, followed by astigmatism and anisometropia in the same order \( (P = 0.036) \). Children with anisometropia \( \leq 1.5 \) D had better stereopsis than anisometropia more than 1.5 D. Stereopsis was also found to have no correlation with the age and visual acuity at the time of testing or the age at which the child first started wearing spectacles. Stereopsis values obtained from Randot and Titmus fly stereo tests showed moderate agreement with Kappa value 0.581. **Conclusion:** Anisometropia and astigmatism are the most critical factors determining the level of stereopsis in refractive errors.

**Key words:** Randot test, refractive errors, stereopsis, Titmus fly test

Stereopsis or depth perception is the highest level of binocular function, and it is present with orthotropia and good visual acuity in both eyes.\(^1\) It is the binocular estimate of relative depth because of slight image disparity between the two eyes. The development of stereopsis is affected by inadequate or improper stimulation of the visual system. The factors that cause inappropriate development of stereopsis are many; one notable cause being uncorrected refractive errors.\(^2,3\) All types of refractive errors adversely affect stereopsis by inducing visual blur resulting in decreased binocular function with low sensory fusion.\(^4\) Anisometropia may adversely affect stereopsis by producing aniseikonia and reduced fusion.\(^5,6\) Remarkably, stereopsis is not present at birth and develops postpartum with adequate visual system stimulation.\(^7,8\) This development occurs only till the plasticity of the central nervous system is present; therefore, early screening for refractive errors and adequate management of the same during the sensitive, plastic period of the central nervous system may cause regaining of stereopsis. Spectacle-corrected refractive errors can affect stereopsis when there is an incorrect prescription, change in prescription, poor compliance, or amblyopia. Previous studies demonstrated the effect of uncorrected or simulated refractive error on stereopsis.\(^9,10\) In this study, we assess the level of stereopsis among school children with a refractive error corrected with spectacles and also determine the level of agreement between the Titmus fly test and the Randot stereo test, which are the commonly used tests to assess the level of stereopsis.

**Methods**

This cross-sectional study was conducted from April 2018 to October 2019, in a suburban community in South India, after obtaining approval from the Institutional Ethics committee. School Children aged between 5 and 18 years, who were previously diagnosed with refractive error, and using spectacles for at least 1 month were enrolled in the study. The sample size was estimated with an expected proportion of patients with equivocal stereopsis among patients with refractive error as 70\(^%\)\(^{10}\) with an estimated at 5% level of significance and 10% relative precision. Children with a manifest or latent squint, ocular pathologies affecting vision, and poor compliance to instructions were excluded. After obtaining informed consent and assent, the participant details (name, age, sex) were obtained.

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collected, along with the age at which patients first started using spectacles. The monocular visual acuity was assessed using Snellen’s chart, and the spectacle correction used was estimated using an auto lensmeter, Grand Seiko GL 7000, Japan. Stereopsis was tested using the Titmus fly test and Randot stereo acuity test, Stereo Optical Co. Inc., Illinois, in the same order of testing for all children to ensure that the learning effect was distributed fairly. Stereopsis testing was done after asking patients to wear a pair of polarizing glasses over their spectacles. These stereo tests contain sets of three/four circles, among which one is a stereo pair with slight lateral separation of part of the circles. This stereo pair, when viewed through polarizing spectacles, provides a crossed disparity in the images, causing the perception of stereopsis. The amount of disparity in the images is reduced with a subsequent set of circles, providing a mechanism to grade the participant’s stereopsis. The participant was asked to identify the circle, which has a three-dimensional aspect, and the last setup to which he/she identifies correctly is taken as their stereopsis value. Data were entered using Microsoft Excel and analyzed using IBM-SPSS program, version 20 (SPSS, Chicago, IL). Stereopsis measurement was graded into normal: 20–60 s of arc, equivocal: 61–100 s of arc, and subnormal: >100 s of arc. Anisometropia was defined as an interocular difference in spherical power of ≥1 D/cylindrical power of ≥1.5 D.

The distribution of categorical variables such as gender, age at presentation grading, age at first spectacle usage grading, visual acuity grading, type of refractive error, type of anisometropia, and grading of stereopsis was measured as frequency and percentages. The continuous variables such as age, age at first spectacle usage, and stereopsis level were expressed as median with range. The association of level of stereopsis with other variables mentioned was carried out using the Chi-square test and Fischer’s exact test. The refractive errors were converted from the spherocylinder notation to power vector notation by applying the Fourier transformation. A correlation between power vectors (\( J_s \) cross-cylinder set at 90° and 180° meridians, and \( J_s \) cross-cylinder set at 45° and 135°) and stereo values was done using the spearman correlation to determine the effect of the difference in the axis in astigmatic errors. All statistical analyses were carried out at a 5% level of significance, and \( P < 0.05 \) was considered significant. Test of agreement between Randot and Titmus fly test stereopsis grades was done using the Kappa-statistic test.

**Results**

A total of 222 children (101 males and 121 females) with refractive error, using spectacles for more than a month, were included in the study. The median age in the study population was 13 ± 2.71 years. There was no statistically significant difference in stereopsis across age or genders. Astigmatism was the most prevalent refractive error (134, 60.4%), followed by myopia (55, 24.8%) and hypermetropia (31, 14%). The prevalence of anisometropia was 13.5% (30 participants). The median spherical myopia was -1.75 D, spherical hyperopia was +0.50 D, the mean magnitude of astigmatism was -1.84 D, and median anisometropia was -2.00 D. On stereo acuity assessment by Titmus fly testing, 145 (65%) children were found to have normal stereo acuity. 44 (20%) had equivocal, and 33 (15%) children had subnormal stereopsis. On Randot testing, 127 (57%) children were found to have normal stereopsis, 64 (29%) had equivocal, and 31 (14%) children had subnormal stereopsis by the Randot test [Fig. 1]. Among participants having subnormal stereopsis, average myopic power was found to be -2.00 D, average astigmatic power (after converting to spherical equivalent) was found to be -1.75 D, and among anisometropes, average power was found to be -2.00 D.

**Refractive error types and comparison with stereopsis grading**

Out of a total of 55 myopes, 39 (70.9%) had normal stereopsis, 5 (9.1%) had equivocal, and 11 (20%) had subnormal stereopsis by the Titmus fly test. All three (100%) hyperopes had normal stereopsis. One hundred thirty-four astigmatics were evaluated, of whom 88 (65.7%) had normal stereopsis, 32 (23.9%) had equivocal, and 14 (10.4%) had subnormal stereopsis. Of the 30 anisometropes, 15 (50%) had normal stereopsis, 7 (23.3%) had equivocal and 8 (26.7%) had subnormal stereopsis [Fig. 1].

![Figure 1: Chart showing the distribution of stereopsis among different refractive errors using Titmus and Randot stereo testing](image-url)
The Titmus fly stereopsis grading of stereopsis was statistically significant ($P = 0.036$), and children with hyperopia had better stereopsis than myopes, whose stereopsis was, in turn, better than children with astigmatism. Anisometropes $>1.50$ D had the least stereopsis. No statistically significant relationship was found to exist between types of refractive error and Randot stereopsis grading ($P = 0.118$) [Tables 1 and 2].

**Correlation between power vectors and Titmus and Randot stereogram testing**

In the vectorial analysis, the spearman correlation showed a statistically significant minimal positive correlation of the J0 value of LE and RE with Titmus stereo values ($r = 0.196$ and $r = 0.165$) [Table 3]. Titmus and Randot values also showed to be positively correlated with statistical significance.

**Comparison of stereopsis grading with age at first spectacle usage and visual acuity**

Age at first spectacle usage was divided into three groups: Group I – 1–6 years, Group II – 7–12 years, and Group III – 13–18 years. Stereopsis in each of these groups was compared by Titmus fly and Randot stereo tests, and it was found that the age at which spectacle was first used did not affect the level of stereopsis either by Titmus fly or by Randot test ($P < 0.05$).

The monocular spectacle corrected visual acuity of the participants was divided arbitrarily into good visual acuity (6/12 and better) and poor visual acuity (6/18–6/36). One hundred seventy-two children were found to have good visual acuity, and 50 children had low visual acuity. There was no statistically significant difference found between the stereopsis of participants with adequate visual acuity and poor visual acuity ($P < 0.05$).

**Agreement between Titmus fly and Randot stereopsis values**

Distribution of participants according to the grades of stereopsis was studied [Table 4], and agreement of stereopsis values obtained by Randot and Titmus fly tests was done using the Kappa-statistics test. Among the participants classified as having normal stereopsis by Randot stereo test, 91.3% were also classified as having normal stereopsis by Titmus fly test. Among the participants having equivocal stereopsis by Randot, 43.8% were classified as normal by Titmus fly test. Among subnormal stereopsis participants by Randot, 80.6% were classified as subnormal stereopsis by Titmus fly test [Fig. 2]. The Kappa value obtained was 0.581, indicating a moderate agreement between Titmus and Randot stereo tests.

**Discussion**

The prevalence of refractive errors varies between population-based, hospital-based, and school-based screening studies. In our research, astigmatism was the most common refractive error, followed by myopia and hyperopia. The

**Table 1: Median stereopsis value for each type of refractive error**

| Refractive Error (Range) | Total No. of Children | Median Stereopsis Value - Titmus | $P$ | Median Stereopsis Value - Randot | $P$ |
|-------------------------|-----------------------|---------------------------------|-----|----------------------------------|-----|
| Myopia (-0.50 to -6 D)  | 55                    | 40                              | 0.036 | 50                              | 0.118 |
| Hyperopia (0.50-1 D)    | 3                     | 40                              | 0.83  | 20                              | 0.218 |
| Astigmatism (-7.5-4.25 D) | 134                | 50                              | 0.092 | 50                              | 0.576 |
| Astigmatism ≤ 1.5 D    | 57                    | 40                              | 0.015 | 50                              | 0.576 |
| Astigmatism >1.5 D     | 77                    | 50                              | 0.015 | 50                              | 0.576 |
| Anisometropia (-9.00-4.25 D) | 30            | 70                              | 0.075 | 70                              | 0.576 |
| Anisometropia ≤ 1.5 D  | 22                    | 60                              | 0.075 | 70                              | 0.576 |
| Anisometropia >1.5 D   | 8                     | 80                              | 0.075 | 150                             | 0.576 |

**Table 2: Median stereopsis value for each type of anisometropia**

| Refractive Error (Range) | Total No. of Children | Median Stereopsis Value - Titmus | $P$ | Median Stereopsis Value - Randot | $P$ |
|-------------------------|-----------------------|---------------------------------|-----|----------------------------------|-----|
| Spherical Anisometropes (-9.00-4.25 D) | 20                | 80                              | 0.092 | 70                              | 0.015 |
| Cylindrical Anisometropes (-3.25-1.5 D) | 8                 | 55                              | 0.092 | 45                              | 0.015 |
| Mixed Anisometropes (-5.5–1.25 D) | 2                   | 65                              | 0.092 | 85                              | 0.015 |

**Table 3: Correlation between power vectors and Titmus and Randot Stereo testing**

|                  | Correlation coefficient with Titmus Stereo values | $P$  | Correlation coefficient with RANDOT Stereo values | $P$  |
|------------------|--------------------------------------------------|------|--------------------------------------------------|------|
| Right Eye        |                                                  |      |                                                  |      |
| J0               | 0.196                                            | 0.003| 0.83                                             | 0.218|
| J45              | -0.47                                            | 0.489| -0.38                                            | 0.576|
| Left Eye         |                                                  |      |                                                  |      |
| J0               | 0.165                                            | 0.014| 0.022                                            | 0.744|
| J45              | -0.79                                            | 0.239| 0.022                                            | 0.748|
Table 4: Distribution of participants with refractive errors among various grades of stereopsis with Titmus and Randot Stereo testing

| Titmus Stereopsis | Randot Stereopsis | Total |
|-------------------|-------------------|-------|
| Normal            | Normal            | 116   |
|                   | Equivocal         | 28    |
|                   | Subnormal         | 1     |
| Total             |                   | 145   |

Equivocal at their natural focal point, explaining the discrepancy between also increased with age in undercorrected myopes, the near vision focus being explained by myopic astigmatism and anisometropes, in the same order.

A Spanish study stated that there was no difference in stereo acuity of mopes and hyperopes after full refractive correction. Few studies have found stereo acuity of hyperopes to be lower than that of mopes. Previous studies reported that cylindrical refractive errors caused poorer stereopsis as compared to spherical errors, as they are expected to have higher vision blur and generate more difficulty in the fusion of images. The minimal positive correlation between the J0 cross-cylinder set and stereo values indicates that astigmatic errors in the orthogonal meridian (90° and 180°) are associated with poorer stereopsis.

Anisometropes have been found to have binocularity due to aniseikonia and reduced fusion. A South Korean study comparing stereopsis of isometropes and anisometropes found that isometropes have better stereo acuity than anisometropes, with a mean stereopsis of 52.86 arcsec by Titmus fly and 39.20 arcsec by Randot test. Among anisometropes, the mean stereopsis was 77.52 by Titmus fly test and 52.78 by Randot stereo test. A Chinese study also found similar results, where there was a statistically significant difference in stereopsis between emmetropes and anisometropes. The average stereopsis of isometropes in our study was 50 ± 40 (Titmus fly) and 50 ± 45 (Randot test), and anisometropes was 70 ± 100 by both tests. The stereopsis of cylindrical anisometropes was better than spherical anisometropes, which was, in turn, better than the stereopsis of mixed anisometropes. The Kappa-statistics test indicated moderate agreement (0.581) between the stereopsis values obtained by Randot and Titmus fly tests. Most participants with normal and subnormal stereopsis showed similar testing results. The difference occurred only in the equivocal subgroup, where 43.8% of patients classified as equivocal by Randot were classified as normal by the Titmus fly test. This indicates that the Randot test has a lower threshold to identify equivocal stereopsis, who are otherwise graded as normal by the Titmus fly test. Fawcett et al. found this discrepancy across the entire range of stereo values when measured in patients with abnormal binocular vision. This reflects the different underlying mechanisms by the different types of tests. The range of stereo acuity measurable by the Randot circles test is slightly finer (400–40 s) than the range of stereo acuity measurable by the Titmus circles (800–40 s).

The two tests should not be used interchangeably in the same patient to assess stereopsis during the follow-up visits.

Limitations of the study

The prevalence of hyperopia in our study was low and excluded from the analysis. A control group of children with no refractive error was not included. More children with hyperopia can be included if the refractive error is determined by cycloplegic refraction. Also, since the refractive error was determined by lensometry and the participants were not cylorefracted, we do not know the accuracy of the refractions and whether they are up to date. This study did not differentiate amblyopia from an uncorrected refractive error in children with visual acuity less than 6/6. The study also did not identify resolved amblyopes.

very low incidence of hyperopia could be because of the age range 5–18 years with good accommodation and the fact that refractive error was determined by glasses wear and not cycloplegic refraction. The prevalence of anisometropia ranges from 1.57 to 28% among various studies conducted, and in our study population, we had 13.5% of the participants who had anisometropia. The stereopsis testability was 100% by 5 years of age. The level of stereopsis may vary depending on the age group tested, educational status, and test type used. The median stereopsis obtained was 50 ± 40 by the Titmus fly test among 4–18 years old children. In this study, there was no statistically significant difference demonstrated in stereopsis value across different age groups or the age at first spectacle usage. In contrast, in a large population Chinese study, it was found that stereo acuity improved significantly from 4 to 6–7 years and then remained constant. Other studies have also found a gradual improvement in stereo acuity scores with increasing age, and normal stereo acuity of 40 arcsec was discovered at 9 years of age. Although delayed correction of refractive error plays a role in amblyopia and is detrimental to stereopsis, no association was found as the age at first spectacle usage is subject to recall bias and cannot be addressed in this type of study. We did not detect any significant difference in the mean stereopsis among children with visual acuity more than 6/12 and visual acuity between 6/12 and 6/36. Children with lesser visual acuity did not have any decrease in stereopsis. This result could be due to near stereopsis testing in binocular state. Also, in undercorrected myopes, the near vision focus may be at their natural focal point, explaining the discrepancy between good near stereo despite reduced distance vision. Although no significant difference in distance and near stereopsis was elicited by studies comparing, both and few studies have demonstrated improvement in stereo acuity on correcting refractive errors and prescribing new spectacles. Our study results indicated that myopes had better stereopsis, followed by myopic astigmatism, and anisometropes, in the same order.
who could be assumed to have reduced stereopsis. Local stereopsis testing may show falsely overestimate stereo acuity in participants who have poor stereopsis due to monocular cues in the test Wirt circles.

**Conclusion**

Astigmatism is the most common refractive error among our study population, followed by myopia and hyperopia. Spherical refractive errors have better stereo acuity than cylindrical refractive errors, which have better stereo acuity than anisometropes. Age, gender, and monocular corrected visual acuity were not found to affect stereopsis significantly. Compared to the Titmus fly test, the Randot test has a low stereo threshold in detecting participants with equivocal stereopsis.

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**Conflicts of interest**

There are no conflicts of interest.

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