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Improvement in Stereoacuity After Refractive Correction in Astigmatic Children: A Cross-Sectional Study

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ABSTRACT

Uncorrected astigmatism in children is a major cause of visual impairment, often associated with reduced stereopsis and visual symptoms, which may be further exacerbated by prolonged screen exposure. **Objectives:** This study aimed to evaluate the effect of full refractive correction on stereopsis in children with moderate-to-high astigmatism and to examine the association between cylindrical error, screen time, and stereoacuity. **Methods:** A cross-sectional study was conducted among 273 children aged 4–8 years attending the ophthalmology department of KRL hospital, Islamabad. Consecutive sampling was employed. After ethical approval and informed consent, each participant underwent a comprehensive ocular examination, including visual acuity testing with ETDRS charts and stereopsis assessment using vectograph circles. Demographic data, refractive status, screen exposure, and outdoor activity were recorded. Statistical analysis included Spearman's correlation and the Wilcoxon Signed-Rank Test. **Results:** The mean uncorrected stereopsis was 141.5 ± 108.1 arc seconds, improving significantly to 66.8 ± 36.6 arc seconds after optical correction (Z=-14.031, p<0.001). A significant positive correlation was found between cylindrical error in the right eye and baseline stereopsis (Spearman's rho=0.465, p<0.001). Screen time averaged 4.9 ± 1.5 hours/day. Asthenopic symptoms, including frequent blinking (82.4%) and blurred vision (81.0%), were highly prevalent. **Conclusion:** Full refractive correction significantly improves stereopsis in children with high astigmatism. Excessive screen exposure may further compromise binocular function, underscoring the importance of early detection, timely correction, and lifestyle modifications in pediatric populations.

INTRODUCTION

Stereopsis is a key aspect of pediatric vision. It develops postnatally and relies on well-aligned eyes with clear retinal images [1]. Even a slight optical blur or unequal refractive error between the eyes can substantially degrade stereoacuity [1, 2]. In recent years, lifestyle changes, especially increased near work and screen exposure, have been implicated in pediatric refractive problems. Prolonged digital screen time has been linked to various ocular issues, including asthenopic symptoms such as eyestrain, blinking, and blurred vision, and refractive errors in children [3, 4]. Notably, large population studies have shown that extensive early-life screen exposure is associated with a higher risk of developing astigmatism, and the COVID-19 pandemic, with its related lockdowns and screen-centered activities, was accompanied by a marked rise in astigmatism prevalence among schoolchildren [5, 6]. Astigmatism, especially when unequal between eyes, anisometropia, is a potent risk factor for poor stereopsis [7, 8]. However, how optical correction affects stereopsis in astigmatic children with excessive screen use remains

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understudied. Understanding this impact is important because early optical correction can potentially reverse sensory deficits during the critical period of neural plasticity. Despite the high prevalence of refractive errors, particularly astigmatism, there is limited exploration of how cylindrical errors influence depth perception, especially in the context of increased screen time. Given the growing reliance on digital devices from an early age and the lack of emphasis on outdoor activities, this research is crucial for understanding how these factors compound visual impairments. Current study addresses the significant gap in research regarding the impact of uncorrected astigmatism on binocular vision, specifically stereopsis, in children in Pakistan.

Despite increasing recognition of astigmatism as a significant cause of visual impairment in children, its specific impact on binocular vision and stereopsis remains insufficiently explored in the Pakistani pediatric population. While previous studies have linked excessive screen time with refractive errors, limited data exist on how cylindrical error magnitude interacts with digital exposure to influence stereoacuity. Moreover, the extent to which full optical correction can reverse stereopsis deficits in young children during the critical period of visual development is not well documented locally. Therefore, evidence-based evaluation of stereopsis improvement following refractive correction is needed to guide early screening and intervention strategies. This study aims to provide valuable insights into the role of timely visual correction in preventing amblyopia, enhancing binocular function, and mitigating the long-term risk of visual disabilities, particularly in the face of modern digital lifestyles, by focusing on the effects of full refractive correction on stereopsis in children with moderate-to-high astigmatism.

METHODS

This cross-sectional study was conducted on 273 children aged 4–8 years who attended the tertiary pediatric ophthalmology clinic. Ethical approval was obtained from the institutional review board, KRL Hospital, Islamabad (Ref. No. KRL-HI-PUB-ERC/March 23/24), and written informed consent was secured from the parents or guardians of all participants. The study lasted for one year from April 2023 to March 2024. The sample size was estimated using the single proportion formula, based on a presumed prevalence of 14.9%, with a 95% confidence level and a 5% margin of error [9]. This yielded a minimum required sample size of approximately 195 participants. However, it is important to note that this calculation did not account for the design effect (DE), which could be introduced due to factors such as clustering or sampling complexities. To address this, we applied a design effect of 1.5, resulting in an adjusted sample size of 271 children. This adjustment ensures that the sample size is adequate to account for potential bias and variability in the study's design. Consecutive non-probability sampling was applied for participant selection. Children aged 4–8 years with moderate-to-high astigmatism, ≥1.50 D cylinder in at least one eye, who could reliably complete ETDRS visual acuity and vectograph stereopsis testing were included. Exclusion criteria were manifest strabismus, other ocular or systemic diseases affecting vision, history of ocular surgery, severe amblyopia, ongoing occlusion/orthoptic therapy, developmental delay, or incomplete clinical data. Children were referred from the pediatric department with complaints of headaches, after thorough evaluation and exclusion of other medical causes by the pediatrician. Each child subsequently underwent a comprehensive ophthalmic examination. Best-corrected visual acuity (BCVA) was measured with standard ETDRS logMAR charts. Refractive error (spherical and cylindrical) was determined by cycloplegic refraction and refined by subjective methods. Stereoacuity was tested binocularly using vectographic stereograms (Vectograph circles) with appropriate polarizing glasses, yielding results in seconds of arc. History of ocular symptoms, blurring, excessive blinking, family ocular history, daily screen time, and outdoor activity were recorded via the questionnaire. Uncorrected and corrected stereoacuity were both measured. Anisometropia was defined as ≥1.00 D interocular difference in spherical equivalent or cylinder. Data were analyzed using descriptive statistics (mean±SD), Spearman rank correlation for refractive error vs. uncorrected stereo, and the Wilcoxon signed-rank test to compare uncorrected vs. corrected stereopsis (since stereo values are non-normally distributed). A p-value <0.050 was considered significant.

RESULTS

The current study participants (n=273) had a mean age of 5.95 ± 1.26 years, born predominantly at term with normal birth weights. Average daily screen exposure was high (4.94±1.92 hours), and the mean outdoor activity time was less than the recommended time (35.1±21.3 minutes). Common visual symptoms were noted: 82.4% reported frequent blinking, and 81.0% had blurring of vision, symptoms consistent with digital eyestrain. Anisometropia was prevalent in 89.0% of children (CI=1.0727, 1.1471), whereas only 11.0% had essentially equal refraction isoametropia. Astigmatism was most often mixed type (56.4%), followed by compound hyperopic (17.2%) and simple myopic (13.9%) patterns (Table 1).

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Table 1: Frequency Distribution of Ocular Symptoms, Family History, and Refractive Characteristics (N=273)

Variables	Category	Frequency (%)
Unhabitual blinking	Yes	225 (82.4)
	No	48 (17.6)
Blurring of vision	Yes	221 (81.0)
	No	52 (19.0)
Family history of ocular disease	Yes	71 (26.0)
	No	202 (74.0)
Refractive type	Anisometropia	243 (89.0)
	Isoametropia	30 (11.0)
Type of astigmatism (right eye)	SMA	38 (13.9)
	CMA	25 (9.2)
	SHA	9 (3.3)
	CHA	47 (17.2)
	MA	154 (56.4)

Refractive errors revealed significant astigmatism: mean cylindrical error was -2.88±1.00 D (RE) and -2.89±0.99 D (LE), with spherical equivalent hyperopia around +1.7 D in each eye. Visual acuity improved markedly with correction. The mean uncorrected logMAR VA was 0.65±0.14 (approx. 20/90), improving to 0.24±0.12 (20/35) with glasses. This confirms a clinically meaningful gain in clarity after refraction. Screen exposure averaged 4.91 ± 1.45 hours per day, with some children reporting up to 13 hours of daily use. Outdoor activity time was relatively low, with a mean of only 35.1 ± 21.3 minutes per day. Depth perception, measured as stereopsis, showed marked improvement after correction. The median uncorrected stereopsis was 120 ± 40 (IQR: 80-120) arc seconds, which improved to 60 ± 30 (IQR range 50 to 80) arc seconds following optical correction. This highlights the positive effect of refractive correction on binocular visual function (Table 2).

Table 2: Descriptive Statistics of Demographic, Clinical, and Visual Parameters (N = 273)

Variables	Minimum	Maximum	Mean/Median ± SD/IQR)
Age (years)	4.0	8.0	5.95 ± 1.26
Birth weight (kg)	2.0	4.5	3.04 ± 0.36
Gestational period (weeks)	34.0	42.0	37.83 ± 1.36
Visual acuity RE uncorrected (logMAR)	0.30	1.20	0.65 ± 0.14
Visual acuity RE corrected (logMAR)	0.00	0.46	0.24 ± 0.12
Spherical error RE (D)	-4.25	6.00	1.71 ± 1.70
Wet cylinder RE (D)	1.50	6.50	2.88 ± 1.0
Spherical error LE (D)	-4.75	6.50	1.72 ± 1.67
Cylindrical error LE (D)	-6.00	-1.50	-2.89 ± 0.99
Screen time exposure (hours/day)	2.5	13.0	4.91 ± 1.45
Outdoor activity (minutes/day)	15.0	120.0	35.15 ± 21.26
Stereopsis uncorrected (arc sec)	40	800	120 ± 40 (IQR: 80-120)
Stereopsis corrected (arc sec)	40	400	60 ± 30 (IQR range 50 to 80)

In statistical terms, the Wilcoxon test showed a highly significant improvement in stereopsis post-correction (Z=-14.031, <0.001). Out of 273 children, 258 (94.5%) had better stereoacuity with glasses, 14 (5.1%) were unchanged, and only 1 child (0.4%) had slightly worse measured stereo with correction (Table 3).

Table 3: Wilcoxon Signed-Rank Test for Stereopsis Before and After Optical Correction (N=273)

Comparison	Frequency (%)	p-Value	Confidence Interval
Improved stereopsis (Corrected < Uncorrected)	258 (94.5%)	<0.001	CI= 15.9-276.9
No change (Ties)	14 (5.1%)	-	-
Worsened stereopsis (Corrected > Uncorrected)	1 (0.4%)	-	-

Z=-14.031, p<0.001

Spearman correlation confirmed a moderate positive relationship between cylindrical magnitude and baseline stereo threshold (ρ=0.465, p<0.001). The effect size for the Spearman's rho correlation of 0.465 is 0.216, indicating that 21.6% of the variance in stereopsis uncorrected can be explained by the Wet Cylinder. This represents a moderate effect size. In other words, higher uncorrected astigmatism was associated with poorer depth perception before correction. This echoes prior evidence that all forms of refractive error introduce blur that degrades stereoacuity, and that anisometropia/aniseikonia further exacerbate binocular fusion difficulties (Table 4).

Table 4: Correlation Between Wet Cylinder and Uncorrected Stereopsis (Spearman's Rho)

Variables	Wet Cylinder	Stereopsis Uncorrected	Confidence Interval
Wet Cylinder RE	1.000	0.465**	CI=(0.346-0.584)
Stereopsis Uncorrected	0.465**	1.000	-
p-Value (2-tailed)	—	<0.001	-
N	273	273	-

DISCUSSION

The findings of the current study revealed that optical correction produces substantial gains in binocular function in astigmatic children. The high prevalence of astigmatism and anisometropia in this symptomatic cohort, 89% anisometropia, mostly mixed or hyperopic astigmatism, reflects recent trends linking near-focused lifestyles to refractive anomalies [9]. For example, large cohort studies have reported that early and prolonged screen time exposure significantly raises astigmatism risk, and global data now show a post-pandemic surge in astigmatism among children [10, 11]. In our patients, average daily screen time was well above recommended limits, which likely contributed to visual strain, evidenced by high rates of blinking and blur. A study showed similar

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findings that blurred vision and eyestrain are hallmark symptoms of digital eye strain, which increases dramatically in schoolchildren exposed to prolonged screen hours [12]. The current study demonstrated that all children experienced an improvement in stereo acuity after refraction. This aligns with studies showing that providing clear retinal images restores the cues needed for depth perception [13, 14]. It also extends findings from other pediatric studies: for instance, Xiao et al. identified greater astigmatism and anisometropia as independent risk factors for subnormal stereoacuity [8]. The correlation analysis mirrors this, confirming that children with higher magnitude uncorrected cylindrical prescriptions had worse baseline stereo. The dramatic improvement we observed implies that these children had adequate neural plasticity to benefit from correction. Similar findings were shown in studies that highlighted that early intervention can recapture binocular function [15, 16]. The current study highlighted that mixed astigmatism is the common refractive error, followed by hyperopic astigmatism. Mixed astigmatism blurs images along one meridian more than the other, which can induce meridional amblyopia if uncorrected [17, 8]. Although we did not specifically measure amblyopia, the large improvements in visual acuity and stereopsis suggested that even mild binocular suppression was alleviated by symmetric correction. Our results underscore the importance of early refractive screening. Since stereopsis matures in early childhood, prolonged uncorrected blur can have lasting developmental consequences. Given that anisometropia and astigmatism compromise stereopsis, as our data and others showed, routine pediatric eye exams should include stereopsis testing and refraction [19, 20]. Lastly, the limited outdoor time meant 35 minutes/day in our patients was concerning, as lack of sunlight was a known myopia risk factor and may indirectly promote near work [21]. Encouraging outdoor activity and limiting screens could help curb the epidemic of pediatric refractive errors seen globally.

This study has certain limitations, including its cross-sectional design, which precludes causal inference between screen exposure and astigmatism-related stereopsis changes. The use of consecutive non-probability sampling from a single tertiary center may also limit the generalizability of the findings. Additionally, screen time and outdoor activity data were parent-reported and may be subject to recall bias. Future longitudinal and interventional studies are recommended to evaluate long-term stereopsis outcomes after correction and to investigate whether reducing screen time and increasing outdoor exposure can prevent or mitigate astigmatism-related binocular dysfunction in children.

CONCLUSIONS

In conclusion, 4-8-year-old children with significant astigmatism and screen exposure, full spectacle correction produced robust improvement in both visual acuity and stereoacuity. Nearly all patients achieved better depth perception once astigmatic blur was removed. These findings highlight that uncorrected astigmatism is a major impediment to binocular vision, but one that can be largely reversed with timely refractive correction. They reinforce current recommendations for early visual screening in children, especially those with prolonged digital device use, to prevent straining symptoms and preserve stereo function. Future longitudinal studies should explore whether reducing screen time and increasing outdoor play can lessen the development of high astigmatism and its stereopsis consequences.

Authors' Contribution

Conceptualization: AK, NA
Methodology: SAK, MS, AK, MQ
Formal analysis: MS, AV, NA
Writing and Drafting: SAK, MS, AK, AV, MQ, NA
Review and Editing: SAK, MS, AK, AV, MQ, NA

All authors approved the final manuscript and take responsibility for the integrity of the work

Conflicts of Interest

All the authors declare no conflict of interest.

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