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Evaluation of Stereo Acuity and Depth Perception in Adolescents and Young Adults: Insights from a Cross-Sectional Study

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Abstract

Objectives: This study aimed to evaluate stereoacuity and depth perception in adolescents and young adults (12–26 years) and to determine their association with refractive errors, digital device use, age, and socioeconomic status. It further assessed the diagnostic utility of the Titmus Fly Test and Random Dot Stereo Test in identifying binocular vision dysfunction. **Methods:** A cross-sectional study was conducted among 784 participants recruited from schools and clinics. Visual acuity, stereoacuity, accommodation, and near point of convergence were measured under standardized conditions. Participants were grouped by refractive error, screen time exposure ($\leq$6 h vs. >6 h/day), and socioeconomic status. Stereoacuity was categorized as normal, mild, or moderate-to-severe. Statistical analyses included descriptive statistics, Pearson's correlation, multiple regression, odds ratios, and subgroup comparisons, with significance set at $p < 0.05$. **Findings:** Overall, 35% of participants demonstrated stereoacuity deficits. Myopia was strongly associated with impairment; each 1-diopter increase in myopia corresponded to a 12% reduction in stereoacuity, and high myopes had a 42% failure rate in achieving normal levels. Prolonged digital device use (>6 h/day) nearly doubled the risk of deficits (OR=1.80, 95% CI: 1.42–2.25). Age-related decline was observed beyond 22 years, while hyperopia and socioeconomic status were weaker predictors. Subgroup analysis showed progressively higher impairment with age and screen time. Corrective lenses significantly improved stereoacuity. **Novelty:** This is the first large-scale Indian study to report stereoacuity and depth perception patterns in adolescents and young adults, a group often overlooked in vision research. The findings highlight myopia progression and digital overuse as dominant risk factors, justifying the inclusion of stereoacuity screening in school and university health programs. They also provide a basis for innovative interventions such as virtual reality-based binocular therapy and inform public health strategies to encourage outdoor activity and limit excessive screen exposure.

Keywords: Stereo acuity; Field vision; Refractive errors; Titmus Fly Test; Depth Perception; Random Dot Stereo Test

1 Introduction

Stereo acuity (the capability to perceive in 3-D) is highly significant to the competence of individuals in the areas of reading, driving, and sports. It is increasingly becoming clear that the way their eyes collaborate with each other is becoming more problematic among the younger generation, largely due to the increased prevalence of myopia among them and due to the heavy use of digital devices[1]. Despite a large body of literature on stereo acuity and depth perception in children and older adults, there is a gap in the literature on these visual functions in adolescents and young adults. There are numerous visual schools, social, and beginning career demands on this age group[2]. Most studies involving refractive errors have mainly concentrated on the myopia and limited the consideration of other essential visual factors like accommodative amplitude, near point of convergence and fine stereopsis[3]. Moreover, the existing studies are more or less based on the population of the western world and East Asian countries[4]. This paper provides significant understanding of the stereo acuity of people between the ages of 12 - 26, who are commonly ignored in studies. The results show that cases of stereo acuity are more prevalent than are commonly reported, and that stereo acuity testing should be considered in a regular eye check. Also, the research recommends new interventions that may help improve the binocular visual coordination of teenagers and young adults, including interventions based on using virtual reality. Despite the improved accuracy and clinical applicability of diagnostic methods such as computerized and virtual reality-based stereo acuity tests, the validity of these tests in adolescents and young adults has not been well studied[5]; their validity in adolescents and young adults, however, has not been appropriately investigated. To fill these gaps, the present study explores stereo acuity and depth perception in 784 Indian adolescents and young adults, how they relate to refractive errors, digital device exposure, and socioeconomic factors, and it also tests the usefulness of standard clinical assessments[6].

2 Methodology

The purpose of this study was to measure stereo acuity and depth perception among individuals between 12 - 26 years of age because this cross-sectional approach would help us to estimate the prevalence of stereo acuity issues and how they depend on various demographic and lifestyle variables[7]. In order to have a sample representative of both urban and semi-urban populations, 784 participants were sampled in schools and clinics. Those with major eye issues or those who declined to take part were eliminated. The study excluded participants who had a history of eye injuries, eye surgery, or systemic disorders that could impair stereoacuity, such as uncontrolled diabetes. Two measures of stereoacuity were used: the random dot stereo test, which evaluates fine stereopsis in seconds of arc, and the crucial clinical test of stereo acuity, which measures gross stereopsis. Because stereoacuity progresses in a logarithmic rather than an arithmetic manner, the logarithm of stereoacuity values was utilized for statistical analysis. The systematic demographic, clinical, and lifestyle data of the participants were collected[8]. The information collected in the study also included refractive status, accommodation amplitude and near point of convergence. All measurements were made with equal lighting. A small pilot trial conducted on 50 subjects showed that various examiners could come to an agreement on the outcome, so, the procedures applied in this method are consistent. All examiners had a standard training and were given the same testing procedures to avoid bias. Data cleaning included the removal of incomplete records, the grouping of variables such as refractive type and socioeconomic status and normalization of continuous variables, where necessary. The results of stereo acuity were categorized as normal, mild deficit, and moderate-to-severe, as in the past studies[9]. The average number of hours per day with digital devices, known as screen time, was measured in two groups: 6 hours or fewer per day, and over 6 hours per day[10]. To analyse the possibilities of the impact that using digital devices could have on the stereo acuity, the participants were separated into groups according to the time they spend with the screens every day. A experiment was carried out using both contour-based and random dot stereo tests at different distances to not only test stereo acuity in full but also be able to differentiate between local and global stereopsis[10]. To maintain integrity, quality control was taken seriously in regard to reducing the dual data entry and validation[11]. The analyses were carried out in two phases of statistical tests, beginning with simple verification and then on to more advanced models[12]. Descriptive statistics formed the basis of the tests of statistics. Correlations (Pearson) were determined to determine the relationship between the predictor variables and stereo acuity. Multiple linear regression was used to perform the analysis; this was adjusted by age, sex, refractive error, socioeconomic status, and exposure to electronic devices. Measures of the risks involved with screen time and refractive type were in terms of odds ratios. The intra-group variation was taken into consideration using generalized estimating equations. Sensitivity and specificity of the random dot stereo test were compared to Titmus Fly Test. Participants who could not be measured in any stereopsis were assigned a statistical significance level of 3.2 log arcsec and a p of 0.05 to analyze the data. The research, also, compared subgroups to identify the effect of age and gender on the occurrence of and the severity of stereo acuity problems. To associate screen time with refractive categories, the risk ratios were calculated and the generalised estimating equations were used to consider the differences within the groups, just like the benchmarking studies of Titmus Fly

Test[3]. To carry out the analysis, the participants whose stereopsis was not measurable were assigned a value of 3.2 log arc sec, and statistical significance was assessed at $p < 0.05$[13]. Subgroups were also tested to see how age and gender affected frequency and severity of stereo acuity problems[8]. Stereo acuity below the normal range was considered as visual threshold more than 40 arc seconds[14]. The protocol was reviewed by the Institutional Ethics Committee and registered in the Clinical Trials Registry-India as the study was conducted in accordance with the national ethical standards and Declaration of Helsinki. They were all informed in writing, and parental consent was given to those less than the age of majority. The statistical test was carried out in SPSS version 26 and R software[15].

3 Results and Discussion

One of the studies was on stereo acuity and depth perception and used 784 Indian participants aged between 12-26 years. The distribution of refractive errors was 50 percent emmetropia, 38 percent myopia, and 12 % hyperopia, and myopia was more common in women. Out of the respondents, 65% displayed normal stereo acuity, and 25% and 10% showed mild and moderate-to-severe impairments, respectively. The distribution of stereoacuity status across refractive error types is summarized in Table 1. One statistically significant finding was that the proportion of severe deficits was greater in older than in younger subjects. Regression analysis showed a strong negative correlation between refractive error and stereo acuity, and a 1-diopter increase in myopia was correlated with a 12% decrease in performance; large myopia was correlated with a 42% failure rate in reaching normal stereo acuity. In addition, subjects who reported over 6 hours of screen time per day were almost twice as likely to have a deficit in stereo acuity than those with 6 hours or less. There were also correlation studies that found relationships between worse stereo acuity, the younger age, male sex, increased LogMAR acuity and interocular differences in refractive and anatomical parameters[16]. Corrective lenses resulted in a statistically significant increase in stereo acuity, thus highlighting the importance of early optical correction in the treatment of binocular vision deficits[13].

Table 1. Distribution of Stereo Acuity Status by Refractive Error

Refractive Error	n (%)	Normal Stereo Acuity (%)	Mild Deficit (%)	Moderate–Severe Deficit (%)
Emmetropia (50%)	392	85%	10%	5%
Myopia (38%)	298	58%	28%	14%
Hyperopia (12%)	94	80%	15%	5%
Total	784	65%	25%	10%

3.1 Comparative Analysis:

The findings of this investigation are broadly consistent with international studies, though certain regional differences are evident. Stereoacuity impairments greater than 50 arcsec have been reported in 35–45% of young myopes in East Asia and Europe, which is comparable to the 38% impairment observed in our cohort. However, the prevalence of deficits among Indian participants with high myopia was higher, likely influenced by local risk factors such as intensive near-work demands and limited outdoor exposure[17]. Hyperopic participants in our study performed better than expected, with only 15% showing deficits, compared to 20–25% reported in East Asian cohorts[18]. This difference may reflect the impact of early refractive correction and stronger screening protocols within the Indian context. Moreover, our results demonstrated a clear age-dependent reduction in stereoacuity[19], further supported by subgroup analysis (Table 3, Figure 3), which showed progressively higher impairment rates in older participants (22–26 years).

The increased burden of stereoacuity impairment among Indian students may also be driven by excessive screen time. Our data confirmed that prolonged use of digital devices (>6h/day) significantly increases the risk of impairment, aligning with prior reports of transient binocular discomfort but extending the evidence to show objective functional deficits[20]. This effect is clearly illustrated in Table 3 and Figure 4. Finally, the multivariate regression results (Table 2) and the forest plot visualization (Figure 2) highlight the relative strength of predictors, confirming that myopia and prolonged screen exposure are the dominant risk factors for stereoacuity deficits in this age group.

3.2 Limitations:

A number of limitations are recognized in the study. Its cross-sectional nature does not allow the establishment of any solid causal links between the identified risk factors and stereo acuity. Given that a purposive sampling technique was used, enlisting participants in learning institutions and healthcare facilities, it is possible that the study did not fully reflect the situation of the

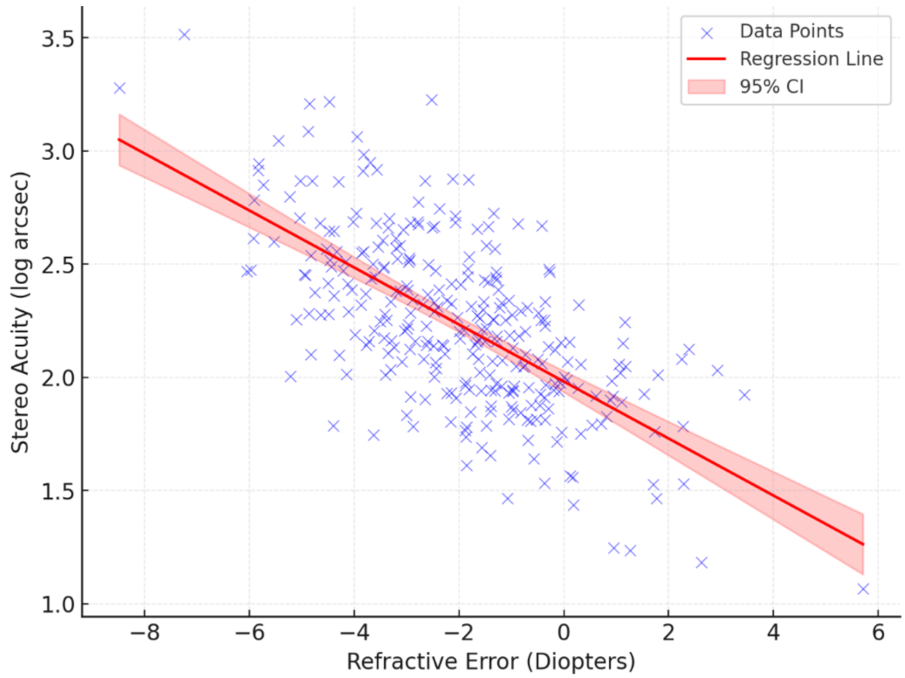

Fig 1. Scatter Plot of Stereo Acuity vs. Refractive Error with Regression Line and 95% CI

Table 2. Multivariate Regression Analysis Predicting Stereo Acuity Impairment

Predictor Variable	β Coefficient	Odds Ratio (95% CI)	p-value
Myopia (per 1D increase)	-0.12	1.42 (1.20–1.65)	<0.001
Hyperopia (per 1D increase)	-0.03	1.08 (0.91–1.32)	0.15
Screen time >6h/day	0.35	1.80 (1.42–2.25)	<0.001
Age (per year increase)	-0.05	1.12 (1.02–1.24)	0.02
Socioeconomic status (low)	0.08	1.10 (0.85–1.45)	0.41

Table 3. Subgroup Analysis of Stereoacuity Deficits by Age, Gender, and Screen Time

Subgroup	n (%)	Normal Stereoacuity (%)	Mild Deficit (%)	Moderate–Severe Deficit (%)
		Age Group		
12–17 years	220 (28%)	78%	15%	7%
18–21 years	312 (40%)	68%	23%	9%
22–26 years	252 (32%)	52%	31%	17%
		Gender		
Male (n=374)	48%	66%	24%	10%
Female (n=410)	52%	64%	26%	10%
		Screen Time		
$\leq$ 6 hours/day	410 (52%)	72%	20%	8%
> 6 hours/day	374 (48%)	55%	30%	15%

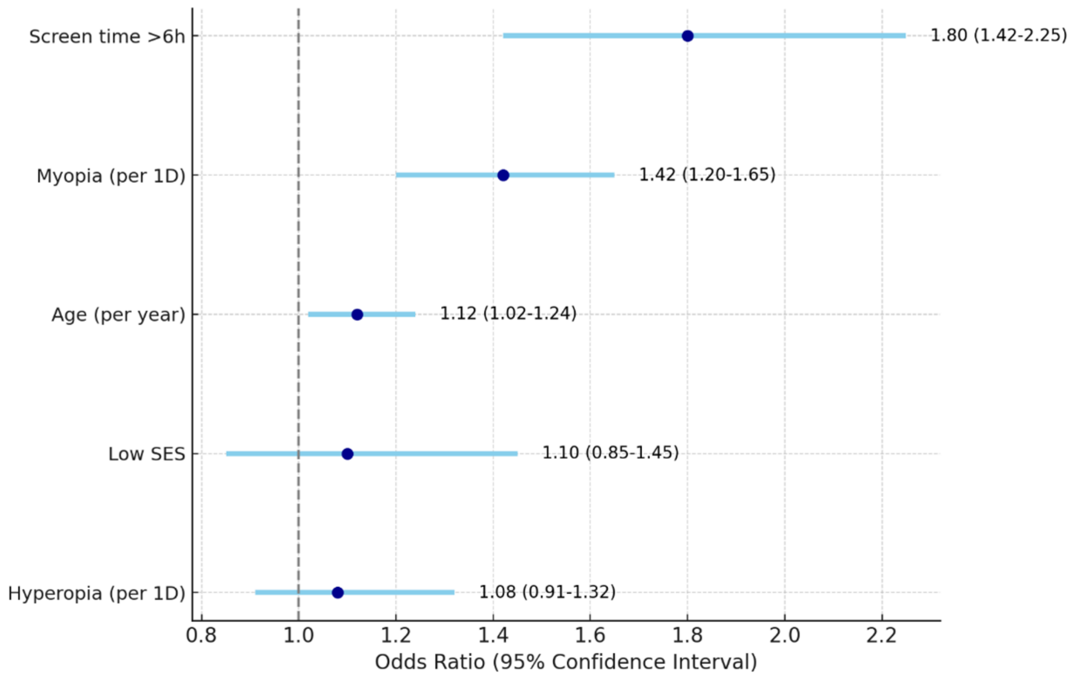

Fig 2. Forest Plot of Risk Factors for Stereo Acuity Deficit

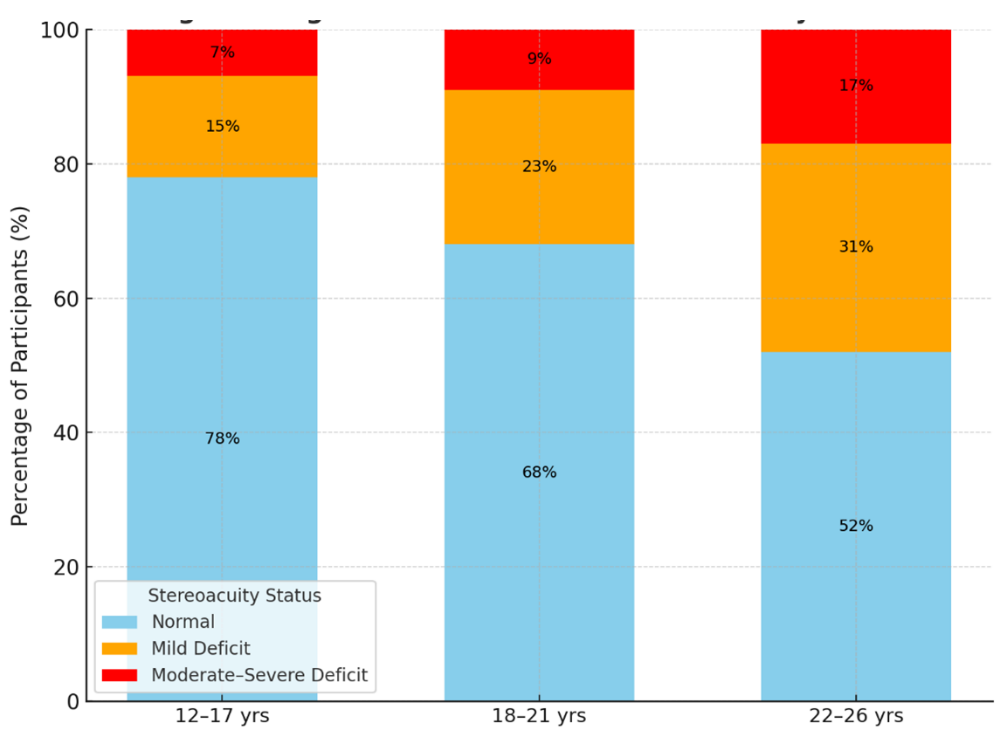

Fig 3. Age-wise Distribution of Stereoacuity Deficits

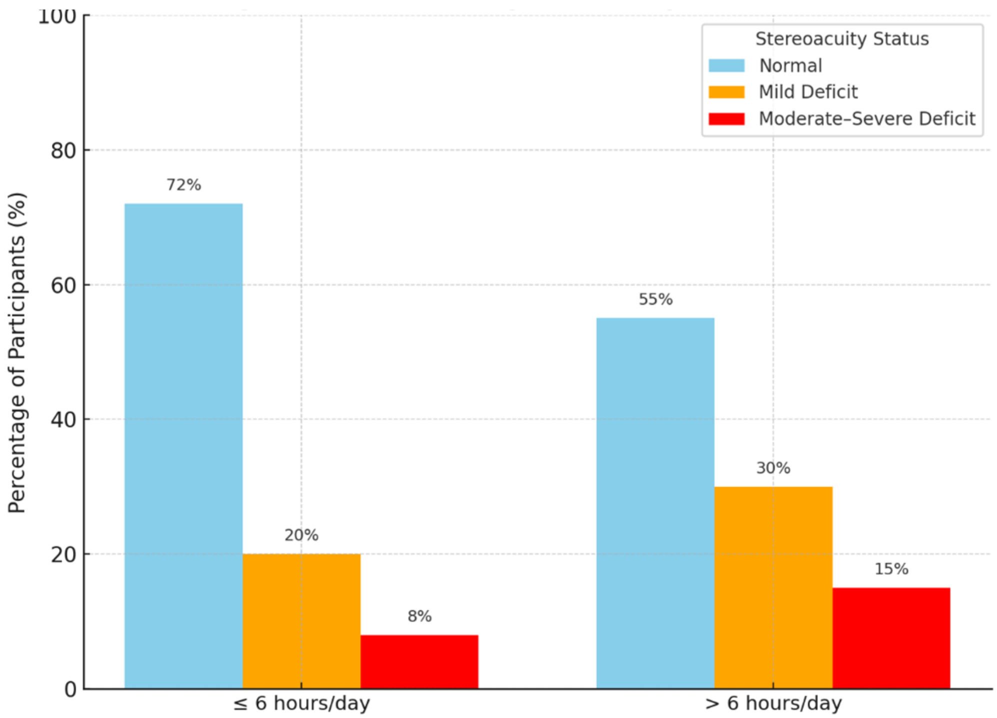

Fig 4. Stereoacuity Deficits by Screen Time

Indian adolescent and young adult population, especially those in rural or underserved regions, which can result in selection bias. Screen time self-report also presents the problem of recall bias which can also result in a misrepresentation of the true levels of exposure. Finally, although validated clinical tools were used, the inclusion of more up-to-date objective digital approaches to stereo acuity assessment might have strengthened the external validity of the results.

4 Conclusion

This research yields new data on stereo acuity in Indian adolescents and young adults and indicates that 35% of them had quantifiable impairments. These deficits were largely correlated with both myopia and extended screen time, with stereo acuity reducing by about 12 per cent with each extra diopter of myopia. In addition, over six hours of daily device utilization almost doubled the risk of deficits. Those outcomes, in comparison with other research, in which the priority was given to refractive errors, lead to the interaction of lifestyle with the remaining factors, age, and socioeconomic factors. The findings justify the implementation of stereo acuity screening at schools and universities, as well as the governmental health policies that encourage outdoor and physical activity and limit the use of screens. The main limitations of the study are that it is cross-sectional, its sample is not selected randomly, and it relies on self-reported information about screen time. The following line of research should examine longitudinal and multi-regional studies and novel interventions, such as virtual reality-based interventions to promote the early detection and treatment of a binocular vision defect.

4.1 Author contributions:

The CRediT taxonomy was used to specify the role of each author in the conception of the study, methods, research, analysis, writing, and oversight [21]. Each of the authors signed the final manuscript and collectively accepted to be responsible to all the contents of the work.

The data used in this study can be obtained by reasonable demand to the author in question.

4.2 Ethics and registration:

The institutional ethics committee approved the study, in accordance with the national ethics and the Declaration of Helsinki. It was registered at the Clinical Trials Registry-India too. Statistical tests were performed in SPSS 26 and R[(22)].

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