UNIVERSA MEDICINA

pISSN: 1907-3062 / eISSN: 2407-2230

Univ Med 2024;43:280-286

DOI: https://doi.org/10.18051/UnivMed.2024.v43.280-286

ORIGINAL ARTICLE

Stereoacuity test as a screening tool for amblyopia and binocular vision in children 6-12 years of age

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Date of first submission, August 12, 2024
Date of final revised submission, October 14, 2024
Date of acceptance, October 17, 2024

Cite this article as: Surasmiati NMA, Wetarini K, Wijayati MP, Suryathi MA. Stereoacuity test as a screening tool for amblyopia and binocular vision in children 6-12 years of age. Univ Med 2024;43:272-279

ABSTRACT

BACKGROUND
Stereoacuity is essential for depth perception and daily activities, complementing visual acuity. Assessing stereoacuity in children is vital for detecting binocular vision disorders and amblyopia. This study aimed to compare the *Toegepast Natuurwetenschappelijk Onderzoek* (TNO) test and the Titmus Fly test in school-based vision screening for children aged 6-12 years.

METHODS
A cross-sectional study was conducted in social service settings with 122 elementary school children aged 6-12 years. Examinations included visual acuity, refraction, Ishihara color vision, and stereoacuity using both the TNO and Titmus Fly tests. Statistical comparisons were made using the Wilcoxon Signed-Ranks Test, and stereoacuity differences based on demographic factors and visual acuity were assessed using the Mann-Whitney U Test. The level of agreement between the two tests was determined using Bland-Altman analyses.

RESULTS
Visual acuity significantly influenced stereoacuity results in the Titmus Fly test (p=0.001), with children having abnormal visual acuity performing worse. Approximately 68% of children reported that the Titmus Fly test was easier to perform. The mean difference between TNO and Titmus Fly measurements was 79.52 ± 63.75 (95% CI = 68.14–90.90; p=0.001), demonstrating a consistent bias between the two tests.

CONCLUSION
The Titmus Fly test is easier for children (6–12 years) to perform, but it tends to overestimate stereoacuity values compared to the TNO test, making the two methods non-interchangeable and not reliable. Stereoacuity assessment remains essential in school-based vision screening for evaluating binocular vision and amblyopia, especially in children with refractive errors.

Keywords: Stereoacuity, TNO test, Titmus Fly test, school-based vision screening, children

INTRODUCTION

Stereoacuity is the highest form of binocular vision with spatial and depth perception.[1,2] Binocular vision is the ability of both eyes to maintain focus on a single point or object simultaneously, thereby creating a single visual image. Binocular vision aids in the perception of depth, distance, and spatial relationships as well as three-dimensional images. Stereoacuity depends on good vision in both eyes, accurate and stable alignment of the visual axis, and intact binocular cortical mechanisms. Stereoacuity tests are mandatory in screening, assessing, and monitoring treatment outcomes of amblyopia and its causes, including strabismus and refractive errors.[2,3]

There are two primary forms of stereoacuity testing: the random dot test and the contour test.[1] The contour test is limited by the presence of monocular or non-stereoscopic binocular cues, which enable some children with no stereoacuity to pass the first 2-4 levels. Conversely, the random dot test eliminates these cues, requiring depth perception to be achieved solely through global binocular evaluation of corresponding and disparate points. The Titmus test provides a contour-based stereoacuity assessment, whereas the *Toegepast Natuurwetenschappelijk Onderzoek* (TNO) test is an example of a random dot test.[1]

A school-based study in India used the Titmus Fly test to assess stereoacuity in children aged 7-14 years and reported that the stereoacuity is significantly influenced by refractive errors and its ease of use. However, the Titmus test has been criticized for monocular cues that could lead to inaccurate results in children without actual stereopsis.[4] Another study in Greenland used the Lang stereotest II,[5] while a recent Italian study utilized a digital mobile application for stereoacuity screening, showing promise in terms of reliability and portability.[6]

School-based vision screening programs primarily focus on detecting refractive errors, as part of broader efforts to eradicate childhood blindness.[7,8] Previous studies have predominantly utilized the Titmus Fly test to assess stereoacuity in school-aged children. In contrast, our study provides a direct comparison between the TNO and Titmus Fly tests, aiming to identify a more practical and reliable method for assessing stereoacuity in elementary school children. The present study was undertaken to assess a challenging method of screening for amblyopia and binocular vision in children 6-12 years of age.

METHODS

Research design

This cross-sectional study was conducted in March 2024, involving all students from Bebalang Elementary school 1, Bangli.

Research subjects

A total of 123 elementary school children were tested and examined in the vision screening. The sampling technique used was total sampling, with inclusion criteria being all active and registered students at Bebalang Elementary school 1. Exclusion criteria were students who were not willing to participate. Parents or guardians of each of the students provided signed informed consent and an agreement letter prior to the evaluation.

Data collection

The instruments used for data collection included a Snellen chart, trial lens set and frame, Ishihara color blindness test plates, portable slit lamp (also used for direct fundoscopy), TNO test booklet with red-green glasses, and Titmus Fly test booklet with polarized glasses.

Visual acuity was assessed using a Snellen chart positioned at a distance of 6 meters. Emmetropia was defined as a visual acuity of ≥6/9 in both eyes. For students with visual acuity less than 6/9, subjective refraction was performed using a trial-and-error method. Refraction outcomes were classified as myopia (corrected with negative spherical lenses), hypermetropia (corrected with positive spherical lenses), astigmatism (corrected with negative cylindrical lenses), and compound myopic astigmatism (corrected with a combination of negative spherical and cylindrical lenses).

All children underwent an anterior segment examination using a portable slit lamp to identify any external ocular abnormalities, and direct fundoscopy to assess the clarity of the fundal reflex. Color vision was evaluated using Ishihara plates. Each child underwent a cover test and stereoacuity assessment using the TNO test (Laméris Ootech BV, Nieuwegein, Netherlands, 12th edition) and the Titmus Fly test (Vision Assessment Corporation, *Elk Grove Village, IL,* USA). Stereoacuity results were expressed in seconds of arc (1° = 60 minutes of arc, 1 minute = 60 seconds of arc), with lower values indicating better stereoacuity. Normal stereoacuity was defined as less than 60 seconds of arc on the TNO test and 63 seconds of arc on the Titmus test.

The TNO test was primarily designed for screening pre-school children for binocular vision defects. Stereoacuity was measured using the TNO test, which employs red-green glasses to assess global stereopsis. The test consists of seven plates: the first four assess gross stereopsis, while the remaining three provide quantitative stereopsis levels. The TNO book is positioned 40 centimeters (cm) perpendicular to the subject's visual axis. The stimulus is a random dot anaglyph circle with a missing segment, described to children as a cake missing a slice. The direction of the missing part (up, down, left, or right) serves as the answer key. Sensitivity is measured in seconds of arc, with stereopsis values ranging from 240 to 15 seconds of arc.

The Titmus Fly Test was administered at a distance of 40 cm. The Titmus stereotest includes a variety of contour targets, with the most common being a series of rings for older patients, animals for children, and a large stereoscopic image of a house fly primarily used for screening. The circle test measures stereoacuity ranging from 800 to 40 seconds of arc, while the animal test measures 400, 200, and 100 seconds of arc. The fly test assesses different levels of stereoacuity, with disparities ranging from approximately 700 to 400 seconds of arc, and a threshold of 3000 seconds of arc. The test requires polarized lenses to dissociate the patient's vision. After putting on the polarized glasses, children were instructed to point to the fly's wings. If successful, they were then asked to identify one elevated circle out of four in each set. For those unable to identify a target, the test was repeated to ensure accurate stereoacuity measurement. Children who wore spectacles had the polarized glasses placed over their regular glasses.

Statistical analysis

The Mann-Whitney U Test was used to assess the differences in stereoacuity results across demographic characteristics (age, gender) and visual acuity. Descriptive statistics, including mean and standard deviation, were calculated for each test, and Wilcoxon Signed-Ranks Test was employed to evaluate the difference in the distribution of stereoacuity results between the TNO and Titmus tests.

The Bland-Altman plot, along with the limits of agreement (LoA), is widely used as an index for assessing test-retest reliability or reproducibility between two measurements. The agreement between the TNO and Titmus test results was analyzed using the Bland-Altman method. The limits of agreement were defined as the 95% confidence intervals around the mean difference of the measurement pairs. A significant difference ($p<0.05$) indicates a lack of agreement between the two measurement methods, suggesting that the tests do not produce comparable results.

Ethical clearance

Ethical approval for this study was granted by the Research Ethics Committee of the Faculty of Medicine, Udayana University, under registration number 1935/UN14.2.2.VII.14/LT/2024.

RESULTS

A total of 123 elementary school children from 6 to 12 years participated in the vision screening, with 122 completing all assessments. The participants' age ranged from 6 to 12 years, with 53.3% of the participants being male. Approximately 96.72% of the children at Bebalang Elementary school 1 demonstrated normal visual acuity. One child (0.82%) presented with a visual acuity of 3/60 prior to correction, which improved to 20/50 with corrective lenses, leading to a diagnosis of amblyopia. Among the six children identified with refractive errors, five were diagnosed with compound myopic astigmatism, and one with myopia. Additionally, four children (3.28%) were found to have color vision deficiencies (Table 1).

Table 1. Demographic and ocular morbidity distribution of the study population and the results of the screening test (n=122)

Characteristics	**n**	**%**
Age (years)		
6-9	64	52.50
10-12	58	47.50
Gender		
Male	65	53.30
Female	57	46.70
Ocular morbidity		
Normal (VA >20/30)	116	95.10
Myopia	1	0.82
Myopic astigmatism	5	4.10
Amblyopia	1	0.82
Ishihara test		
Normal	118	96.72
Abnormal	4	3.28

VA: Visual Acuity

The comparison between the stereoacuity outcomes using the TNO and Titmus Fly tests across different demographic and clinical factors such as age, gender, and visual acuity is described in Table 2. Based on age group comparison (6-9 and 10-12 years), the results indicate no significant difference in stereoacuity for either the TNO or Titmus Fly tests (p=0.866 and p=0.578, respectively).

Based on gender differences, a significant disparity was found in the TNO test results, with males demonstrating worse stereoacuity than females (p=0.041). However, no such difference was observed with the Titmus Fly test, which indicates that gender does not significantly influence stereoacuity outcomes (p = 0.784). This finding suggests that the TNO test may be more sensitive to subtle differences between males and females, whereas the Titmus Fly test appears more consistent across genders.

Visual acuity was found to be a significant factor in stereoacuity results for the Titmus Fly test. This association between Titmus Fly results and visual acuity indicates that children with abnormal visual acuity had significantly worse stereoacuity compared to those with normal acuity (p=0.001). Interestingly, no significant difference was observed in the TNO test (p=0.422), suggesting that the Titmus Fly test may be more sensitive to variations in visual acuity.

The comparison of stereoacuity results between the TNO and Titmus tests are shown in Table 3. For the TNO test, the mean stereoacuity was 107.70 ± 109.28 seconds of arc, with 68.0% of participants achieving a stereoacuity of ≤60 seconds of arc. In comparison, the Titmus test had a lower mean stereoacuity of 52.64 ± 40.32 seconds, with 75.4% of participants achieving ≤63 seconds of arc. The Wilcoxon Signed Ranks Test revealed a significant difference between the two tests (p=0.001). Additionally, 68.03% of participants found the Titmus test easier to perform compared to the TNO test.

The stereoacuity results of the TNO and Titmus Fly tests were compared using the Bland-Altman method. According to the analysis, the mean difference between the TNO and Titmus Fly measurements was 79.52 ± 63.75 seconds of arc (95% CI = 68.14-90.90). The difference was statistically significant (p=0.000), suggesting a consistent bias in the measurements (Figure 1). Therefore, the TNO and Titmus Fly tests are not comparable and cannot be considered reliable for interchangeable use.

DISCUSSION

Our study found that the majority of the children (62–81%) achieved stereoacuity within the normal range (<60-63 seconds of arc) in both the TNO and Titmus Fly tests. The normal criteria used in this study are in line with standards reported in the studies by Cho et al.[9] and Potluri et al.[4] However, the Titmus Fly test consistently yielded lower stereoacuity values than the TNO test, which are in line with earlier studies.[4,9,10] This finding indicates that the Titmus Fly test may overestimate stereoacuity, as has been suggested by other researchers, while the TNO test remains a more accurate indicator of true binocular vision. Our results are consistent with the findings of Zhao and Wu[11], who also observed that the Titmus Fly test overestimated stereoacuity compared to random dot tests such as the TNO test. The results also confirm that random dot tests are more robust in detecting subtle binocular dysfunctions, as they eliminate monocular cues.

Table 2. Comparison of stereoacuity test results using TNO and Titmus fly tests by age, gender, and visual acuity

Characteristics	TNO	p value	Titmus	p value
Age (years)				
6-9	101.72 ± 100.37	0.866	52.36 ± 38.26	0.578
10-12	114.31 ± 118.87		52.95 ± 42.81	
Gender				
Male	122.77 ± 131.27	0.041*	56.89 ± 41.93	0.784
Female	90.53 ± 74.46		47.79 ± 38.19	
Visual acuity				
Normal	200.00 ± 220.18	0.422	49.33 ± 37.59	0.001*
Abnormal	102.93 ± 99.95		116.67 ± 40.83	

*Mann-Whitney U test, data presented as mean ± SD

Table 3. Comparison of stereopsis results between Titmus and TNO tests

Stereoacuity test	n		%	p value
TNO (sec of arc)		107.70 ± 109. 28		0.001*
≤60	83		68.00	
>60	39		32.00	
Titmus (sec of arc)		52.64 ± 40.32		
≤63	92		75.40	
>63	30		24.60	
Easier Examination Test				
TNO	39		31.97	
Titmus	83		68.03	

*Wilcoxon Signed Ranks Test, p value between TNO and Titmus test (mean ± SD)

Our study found no significant difference in stereoacuity between boys and girls on both the TNO and Titmus Fly tests, similar to other studies, which also reported no gender-based differences.[4] Regarding age, stereoacuity values seemed to improve slightly in older children, but these age-related differences were not statistically significant. This suggests that factors such as visual acuity and refractive errors may have a bigger impact. One key finding was that children with normal visual acuity had significantly better stereoacuity than those with abnormal vision, particularly on the Titmus Fly test. This supports earlier studies, which found that refractive errors, including amblyopia, are closely linked to subnormal stereoacuity.[11] Our study emphasizes the importance of including stereoacuity tests in school vision screenings, especially for children with refractive errors.

Our study data were collected during a school-based vision screening. Good visual acuity and stereopsis are crucial for performing daily activities such as driving and operating machinery, which require coordinated functioning of both eyes. While visual acuity, refractive error assessments, and color blindness tests are routine, stereoacuity testing is not typically included in screening programs for school-aged children. Vision screening for school children began in Europe in 1867, with similar programs initiated in America in 1894.[12] School-based eye health screening is a cost-effective approach for detecting refractive errors and preventing childhood blindness, but it generally does not assess stereoacuity.[13,14]

In this study, stereoacuity was assessed using TNO and Titmus Fly tests. Prior researches about stereoacuity screening had used Titmus,[4,15] TNO[6] and the latest, Stereoacuity Test App (SAT).[6] The Titmus test, based on three-dimensional polarized vectographs and involving targets polarized at a 90-degree angle, produces dichoptic images by creating depth illusions with polarized glasses. However, this method has drawbacks due to monocular cues from retinal disparity.[16] In contrast, the TNO stereo test uses a random dot pattern and requires red and green glasses to dissociate the patient's vision, eliminating monocular cues and facilitating retinal disparity. This test has the advantage of quantitative analysis without any change in examination distance. The TNO test is widely used, employing an anaglyph technique and the random dot principle to assess stereopsis without monocular cues.[1]

In our study, the Titmus Fly test was shown to be easier to perform than the TNO test. The accuracy and dependability of the TNO test are well recognized.[17,18] Nonetheless, the Titmus Fly test was found to be easier to perform for participants aged 6 to 12, particularly in community service settings. The Titmus Fly test, one of the earliest tests for identifying and measuring stereoacuity, was developed in the 1950s. However, the Titmus Fly test is known to overestimate stereoacuity.[19] One of the reasons of the lower accuracy of the Titmus test is the difficulty of conducting the test without leading questions that could cause patients to guess the answers.[16] This study found statistically significant mean differences between the two methods. The mean difference represents the average discrepancy or bias between the two methods. Several studies that compared TNO and Titmus also found higher TNO results, indicating worse stereoscopic performance.[11,20]

Digital stereoacuity tests have been developed and compared with both the Titmus and TNO[21] demonstrating good agreement. However, it is important to note that statistical significance does not necessarily imply practical or clinical significance. Practically, most respondents found it easier to perform the Titmus Fly test compared to the TNO test. It is essential to consider both this practical finding and the statistical significance to ascertain the practical implications of the results.

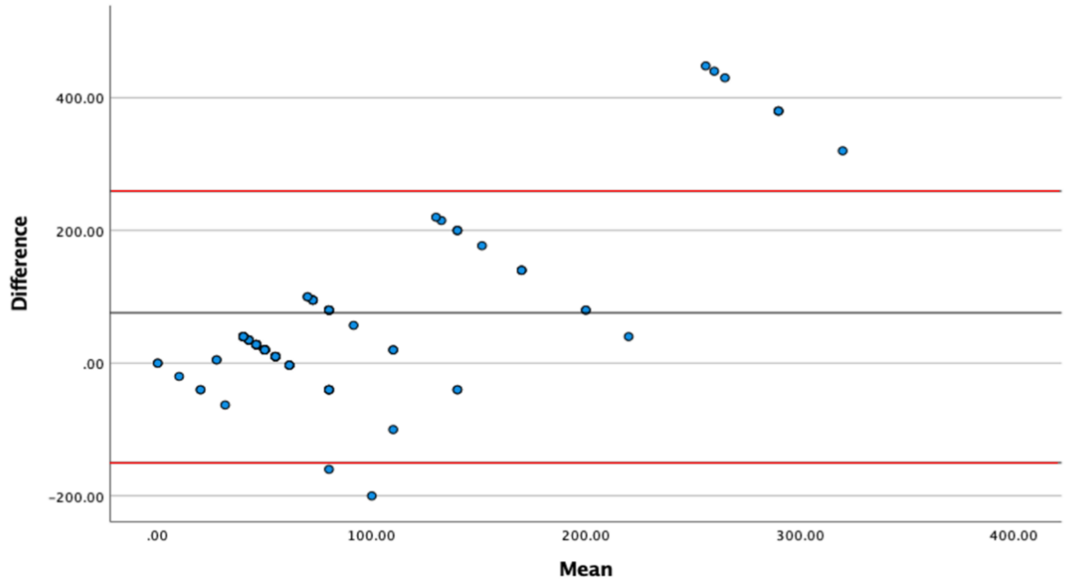

Figure 1. The Bland-Altman plot compares results from two stereoscopic measurements (TNO vs. Titmus). The plots depict the bias represented by the black line and the limits of agreement (LOAs) indicated by the red lines. The x-axis represents the mean score, while the y-axis represents the difference between measurements (mean difference ± 1.96 standard deviations).

This study's main limitation was the geographic restriction to a single suburban school. Future studies should consider expanding the sample size across different regions to confirm the generalizability of the findings. Additionally, including data on the duration for each test would provide valuable insights into the practical utility of each method, especially in community health settings where time is a constraint. Another area for improvement in future research could be the incorporation of newer digital stereoacuity tests, such as mobile applications, which have shown good agreement with traditional methods in previous studies.

CONCLUSION

This study demonstrated that the Titmus Fly and TNO tests are not interchangeable for assessing stereoacuity in children aged 6-12 years. However, the ease of administration of the Titmus Fly test offers practical benefits, particularly in large-scale or community-based vision screenings. This underscores the need for further research into developing more reliable yet user-friendly screening tools for stereoacuity in school-aged children. Stereoacuity evaluation is vital in school vision screenings for detecting binocular vision and amblyopia, especially in children with refractive errors.

Conflict of Interest

Competing interests: No relevant disclosure.

Acknowledgements

The authors thank the Head of Bangli Sub-district and principal of the Bebalang Elementary school 1, Bangli, for their cooperation and the ophthalmology residents of Prof Ngoerah General Hospital for their assistance in this study.

Funding

None.

Author Contributions

NMAS-1 contributed to study concept and design, data collection and assembly, statistical analysis, and manuscript writing. KW contributed to data analysis and interpretation, manuscript writing. MPW and NMAS-2 contributed to data collection, data analysis and interpretation. All authors reviewed the manuscript, approved the final manuscript, and take public responsibility for the content of the manuscript submitted to Universa Medicina.

Data Availability Statement

The datasets generated and/or analysed during the current study are available under request from the corresponding author.

Declaration of Use of AI in Scientific Writing

Nothing to declare.

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