

Development and validation of a portable visual acuity device for school-based detection of childhood visual impairment

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Abstract

Background:

Uncorrected refractive error remains one of the leading causes of preventable visual impairment among school-aged children, particularly in resource-limited settings where access to standardized vision screening remains challenging. Conventional visual acuity assessment using the Snellen chart requires trained personnel, controlled illumination, and adequate testing space, limiting its feasibility in large-scale school screening programs. This study aimed to develop and validate a portable device for remote visual acuity assessment among school children.

Methods:

A school-based cross-sectional validation study was conducted among 1,118 children aged 6–16 years in Mysuru and Chamarajanagar districts of Karnataka, India. Visual acuity measured using the developed portable device was compared with the standard Snellen chart, which served as the reference standard. Diagnostic performance was evaluated using sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), overall accuracy, and receiver operating characteristic (ROC) curve analysis. Agreement and reliability were assessed using intraclass correlation coefficients (ICC), Cronbach's alpha, and Bland–Altman analysis.

Results:

The portable device demonstrated high diagnostic performance, with sensitivity of 87.2% (95% CI: 81.8–91.4), specificity of 97.2% (95% CI: 96.0–98.2), PPV of 86.8% (95% CI: 81.3–91.2), NPV of 97.3% (95% CI: 96.1–98.3), and overall accuracy of 95.4% (95% CI: 94.0–96.6). The area under the ROC curve was 0.922 (95% CI: 0.894–0.950; $p < 0.001$), indicating excellent discriminative ability. Agreement-based reliability showed a single-measure ICC of 0.79 and average-measure ICC of 0.93. Bland–Altman analysis demonstrated minimal systematic bias (mean bias: -0.00081 logMAR), with narrow limits of agreement, confirming strong agreement between the portable device and the reference standard.

Conclusions:

The portable visual acuity device demonstrated excellent diagnostic accuracy, strong reliability, and high agreement with the Snellen chart. The device represents a practical and scalable solution for school-based vision screening and may improve early detection of visual impairment in resource-limited settings.

BACKGROUND

Uncorrected refractive error (URE) remains one of the leading causes of preventable visual impairment among children and adolescents worldwide. Despite being easily detectable and correctable, URE continues to impose a substantial burden on educational performance, cognitive development, psychosocial well-being, and long-term productivity. Recent global estimates indicate that refractive error remains the most common cause of visual impairment among pediatric populations, particularly in low- and middle-income countries where access to early vision screening and corrective services remains limited [1–3].

Visual acuity (VA) assessment is the cornerstone of pediatric vision screening and remains the most practical functional indicator for early detection of visual impairment and suspected refractive error. Conventional chart-based screening methods, particularly the Snellen chart and Tumbling E continue to be widely used in clinical practice and school screening programs due to their simplicity, low cost, and broad acceptance. However, these conventional methods have important limitations. Accuracy in the examination requires standardized illumination, fixed testing distance, sufficient physical space, and trained personnel, conditions that are often difficult to maintain in real-world school settings, especially in rural and resource-constrained environments [4, 5].

Operational barriers further reduce the effectiveness of school-based vision screening programs. Large student volumes, limited infrastructure, inconsistent environmental conditions, and variability in examiner skills frequently affect screening quality. Additionally, younger children may experience reduced attention span, anxiety, poor cooperation, and difficulty maintaining concentration during testing, which can influence visual acuity measurements and contribute to false-positive referrals or missed diagnoses [5, 6]. These limitations highlight the need for more standardized, reliable, and child-friendly screening approaches.

Recent advances in digital health technologies have led to the development of portable and remote visual acuity assessment tools aimed at improving accessibility and standardization. Smartphone-based applications and portable digital screening systems have demonstrated promising diagnostic performance and improved operational flexibility. However, many existing tools remain limited by cost, dependence on smartphones or internet connectivity, environmental variability, and insufficient validation in large-scale school-based settings [7, 8]. Furthermore, few devices have been specifically designed for scalable use in resource-limited school screening programs.

To address these challenges, a portable device-based visual acuity assessment system was developed to provide a standardized, practical, and field-friendly alternative to conventional screening methods. The device was designed to enable portable visual acuity testing under controlled viewing conditions while maintaining compatibility with standard clinical visual acuity assessment principles. This study aimed to develop and validate the device diagnostic accuracy, reliability, and agreement of the portable visual acuity device compared with the standard Snellen chart among school children aged 6–16 years in South India.

METHODS

Study design, setting, and participants

A school-based cross-sectional diagnostic validation study was conducted among school-going children aged 6–16 years from selected schools in Mysuru and Chamarajanagar districts of Karnataka, South India. Children aged 6–16 years whose parents or guardians provided written informed consent and who provided assent were included in the study. Children with ocular pathology, neurological disorders, disabilities affecting visual assessment, or inability to cooperate with testing procedures were excluded.

The sample size was estimated based on expected sensitivity and specificity of approximately 90% from previous digital visual acuity validation studies, [9] assuming a 95% confidence interval and 20% relative precision. The final calculated sample size was 1,118 participants. A multistage sampling strategy was employed. Schools served as sampling units, and Probability Proportionate to Size (PPS) sampling was used to allocate participants according to student population. Eligible students were selected using simple random sampling.

Development and refinement of the portable visual acuity device

The portable visual acuity device was developed using a validated structured multistage framework comprising conceptualization, prototype development, expert review, preliminary field testing, pilot testing, and final refinement. The development process was guided by key principles of clinical equivalence, optical accuracy, accommodation control, operational standardization, portability, and suitability for non-cycloplegic visual acuity screening under field conditions.

The device was designed to replicate standard Snellen chart–based visual acuity testing while overcoming limitations associated with conventional chart-based assessment, including testing distance variability, examiner dependency, inconsistent environmental conditions, and space constraints. The device architecture consisted of two 2.4-inch TFT displays integrated within a head-mounted unit for monocular visual acuity assessment. Each display was independently controlled by Arduino UNO microcontrollers. A separate Arduino Nano controlled a 0.96-inch OLED display that automatically displayed the final visual acuity result. The device was powered using three rechargeable 18650 lithium-ion batteries with voltage regulation through an LM2596 DC–DC step-down converter. The structural housing was fabricated using acrylic material to ensure stability, durability, and safety during repeated field use.

Following prototype development, the device underwent evaluation by a multidisciplinary expert panel comprising ophthalmologists, community medicine specialists, and technical experts. Expert feedback focused on clinical relevance, optotype clarity, display quality, optical alignment, ergonomics, workflow efficiency, and pediatric suitability. Based on expert recommendations, modifications were made to improve display positioning, device stability, head alignment, structural ergonomics, and visual comfort.

The modified device was subsequently tested among a small sample of children within the target age group to assess practical feasibility, comfort, comprehension of instructions, visual alignment, and testing workflow. Particular attention was given to head positioning, fixation stability, and comfort across different age groups. Since the device operated at a short viewing distance of 10 cm, accommodation control was a major design consideration. To minimize accommodative variability, the final device incorporated a fixed enclosed viewing distance, controlled luminance, high-contrast optotype presentation, and standardized monocular testing conditions. The enclosed design also reduced peripheral distractions and improved fixation stability. [10]

Pilot testing was then conducted under field conditions to evaluate device functionality, operational feasibility, workflow efficiency, and examiner standardization. The pilot phase was used solely for refinement of device design and testing protocol and was excluded from final analysis. Final modifications were incorporated before initiation of the main validation study.

Optical principles, optotype calibration, and device functioning

The device was designed based on standard visual acuity assessment principles, wherein each optotype subtends a visual angle of 5 minutes of arc and each critical detail subtends 1 minute of arc at the intended testing distance. To maintain equivalence with conventional Snellen chart testing, optotype dimensions were digitally calibrated for a fixed viewing distance of 10 cm. [11]

Optotype dimensions were calculated using standard trigonometric relationships [12]:

- Letter height (H) = $2 \times D \times \tan(5'/2)$
- Letter width (W) = $4/5 \times H$
- Stroke thickness (S) = $H/5$

where D represents the viewing distance.

This ensured psychophysical equivalence between optotypes displayed on the device and standard Snellen optotypes viewed at 6 meters.

The device functioned by presenting calibrated Snellen optotypes sequentially in decreasing size to one eye at a time while the fellow eye remained occluded. Participants identified the displayed optotypes verbally. Based on participant responses, the examiner progressively changed optotype sizes until the smallest identifiable visual acuity threshold was reached. The final visual acuity value was automatically displayed on the OLED screen in Snellen equivalent and later converted to logMAR values for statistical analysis [13].

Data collection and visual acuity assessment procedure

Data collection was conducted using a structured questionnaire proforma and standardized visual acuity assessment protocol. The questionnaire proforma collected information on socio-demographic characteristics and visual assessment findings based on the standard proforma used for visual acuity assessment [14, 15]. It also included parameters for evaluating the validity and reliability of the assessment tool.

Each participant underwent visual acuity assessment using both the standard Snellen chart and the portable visual acuity device under comparable environmental conditions. Visual acuity testing was performed monocularly for both right and left eyes. The Snellen chart served as the reference standard. For device-based assessment, participants wore the head-mounted device and optotypes were presented sequentially in decreasing sizes. Responses were recorded systematically, and visual acuity outcomes were generated automatically. Device-based measurements were repeated across three testing sessions under standardized conditions to assess repeatability and test–retest reliability. All assessments were conducted by trained investigators following standardized operating procedures to minimize inter-observer variability.

Cut-off criteria and outcome measures

Cut-off criteria and outcome measures

Visual acuity measurements obtained using both the Snellen chart and the portable visual acuity device were converted into logMAR values for analysis [12]. Visual acuity impairment was defined as visual acuity > 0.3 logMAR (worse than 6/12) in either eye. Visual acuity ≤ 0.3 logMAR was classified as normal [14, 16].

The primary outcome was diagnostic performance of the portable visual acuity device compared with the Snellen chart. Diagnostic performance indicators included sensitivity, specificity, positive predictive value, negative predictive value, overall accuracy, and area under the receiver operating characteristic curve. Secondary outcomes included agreement between the device and reference standard, test–retest reliability across repeated sessions, and Bland–Altman agreement analysis. [17]

Statistical analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 29.0 (Licensed to JSSAHER). Descriptive statistics were used to summarize participant characteristics and study variables. Diagnostic performance was evaluated by calculating sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy, along with their corresponding 95% confidence intervals. Receiver operating characteristic curve analysis was performed to evaluate discriminative ability, and area under the curve was calculated. Agreement between the portable visual acuity device and the Snellen chart was assessed using Intraclass Correlation Coefficients (ICC) based on a two-way mixed-effects model with absolute agreement. Both single-measure and average-measure ICC values were reported. Internal consistency was assessed using Cronbach's alpha. Bland–Altman analysis was

performed to assess agreement between measurement methods and repeated sessions by calculating mean bias and limits of agreement. A p-value < 0.05 was considered statistically significant.

Ethical approval

Ethical approval for this study was obtained from the Institutional Ethics Committee of JSS Medical College, JSS Academy of Higher Education & Research, Mysuru (IEC No.: JSS/MC/PG/PhD2/2024–25). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision) and its subsequent amendments, as well as applicable national and institutional guidelines for research involving human participants. Written informed consent was obtained from the parents or legal guardians of all participants prior to enrollment. Written assent was obtained from all participating children before data collection. Participation was voluntary, and participants were informed of their right to withdraw from the study at any stage without any consequences. The confidentiality and privacy of all participants were maintained throughout the study by anonymizing the collected data and restricting access to authorized research personnel only.

RESULTS

Participant characteristics

A total of 1,118 school-going children aged 6–16 years were included in the study. The largest proportion of participants belonged to the 14–16-year age group (42.8%), followed by 10–13 years (33.5%) and 6–9 years (23.7%). Of the total participants, 597 (53.4%) were male and 521 (46.6%) were female. Most participants were from rural settings (61.6%), while 38.4% were from urban areas. With respect to educational level, 39.9% were enrolled in secondary education, 33.4% in upper primary education, and 26.7% in lower primary education (Table 1).

Table 1. Socio-demographic characteristics of the participants (N = 1118)

Diagnostic performance of the portable visual acuity device

The portable visual acuity device demonstrated high diagnostic performance compared with the standard Snellen chart for detection of visual acuity impairment in both eyes. For right-eye assessment, the device correctly identified 120 true positive cases and 949 true negative cases. Sensitivity was 82.2% (95% CI: 75.3–88.0), specificity was 97.6% (95% CI: 96.5–98.5), and overall diagnostic accuracy was 95.6% (95% CI: 94.2–96.7). ROC analysis showed excellent discriminative ability with an AUC of 0.899 (95% CI: 0.862–0.936; $p < 0.001$). For left-eye assessment, the device correctly identified 130 true positive cases and 934 true negative cases. Sensitivity was 81.8% (95% CI: 75.0–87.3), specificity was 97.4% (95% CI: 96.3–98.3), and overall diagnostic accuracy was 94.9% (95% CI: 93.4–96.1). The AUC was 0.896 (95% CI: 0.860–0.932; $p < 0.001$).

Overall diagnostic performance demonstrated strong classification capability, with sensitivity of 87.2% (95% CI: 81.8–91.4), specificity of 97.2% (95% CI: 96.0–98.2), positive predictive value of 86.8%, negative

predictive value of 97.3%, and overall accuracy of 95.4% (95% CI: 94.0–96.6). Receiver operating characteristic analysis demonstrated excellent discriminative performance, with an AUC of 0.922 (95% CI: 0.894–0.950; $p < 0.001$), indicating excellent ability of the device to differentiate normal and impaired visual acuity (Table 2, Figure 1).

Table 2. Diagnostic performance of the portable visual acuity device compared with Snellen chart

Figure 1. Receiver operating characteristic (ROC) curves comparing the portable visual acuity device with the Snellen chart for the right eye (A), left eye (B), and both eyes (C).

Agreement and reliability analysis

Agreement between the portable visual acuity device and the Snellen chart was assessed using Intraclass Correlation Coefficients (ICC). The device demonstrated good to excellent agreement for both monocular and overall visual acuity assessment. For right-eye agreement, the single-measure ICC was 0.86 (95% CI: 0.85–0.88), while the average-measure ICC was 0.93 (95% CI: 0.92–0.93). For left-eye agreement, the single-measure ICC was 0.86 (95% CI: 0.85–0.88), and the average-measure ICC was 0.92 (95% CI: 0.91–0.93). Overall agreement analysis demonstrated a single-measure ICC of 0.79 (95% CI: 0.77–0.80) and an average-measure ICC of 0.93 (95% CI: 0.93–0.94). Cronbach’s alpha values ranged from 0.92 to 0.93, indicating high internal consistency.

Test–retest reliability across three testing sessions demonstrated good to excellent repeatability. Overall single-measure ICC was 0.718 (95% CI: 0.698–0.738), while average-measure ICC was 0.939 (95% CI: 0.933–0.944), indicating excellent stability of repeated measurements (Table 3).

Table 3. Agreement and reliability analysis of the portable visual acuity device

Bland–Altman agreement analysis

Bland–Altman analysis was performed to assess agreement between measurements obtained using the portable visual acuity device and the Snellen chart, as well as repeatability across testing sessions. For right-eye assessment, the comparison between the device and Snellen chart demonstrated minimal systematic bias (mean bias: +0.009 logMAR), with limits of agreement ranging from –0.172 to +0.198 logMAR. Session-wise comparisons showed similarly small mean differences and acceptable limits of agreement, indicating good repeatability. For left-eye assessment, agreement between the portable device and Snellen chart showed negligible systematic bias (mean bias: –0.011 logMAR), with limits of agreement ranging from –0.231 to +0.209 logMAR. Session-wise comparisons demonstrated narrow limits of agreement, supporting strong temporal consistency. For overall visual acuity assessment, Bland–Altman analysis demonstrated excellent agreement between the portable device and Snellen chart, with negligible systematic bias (mean bias: –0.00081 logMAR). The limits of agreement ranged from –0.167 to +0.166 logMAR, indicating minimal measurement variability and strong clinical interchangeability. Repeatability analysis across sessions also showed narrow limits of agreement and minimal variability across repeated measurements (Table 4; Figures 2–4).

Table 4. Bland–Altman agreement analysis for portable visual acuity device

Figure 2: Bland–Altman Agreement Analysis Between the Portable Visual Acuity Device and the Snellen Chart and Across Test–Retest Sessions for the Right Eye(N=1118)

Figure 3: Bland–Altman Agreement Analysis Between the Portable Visual Acuity Device and the Snellen Chart and Across Test–Retest Sessions for the Left Eye(N=1118)

Figure 4: Bland–Altman Agreement Analysis Between the Portable Visual Acuity Device and the Snellen Chart and Across Test–Retest Sessions for the Overall Eye(N=1118)

Test administration characteristics

The mean duration required to complete portable device-based visual acuity assessment was 12.68 ± 3.54 minutes. The mean interval between device-based assessment and standard Snellen chart testing was 8.98 ± 3.81 minutes. For repeatability assessment, the average interval between testing sessions was 13.21 ± 2.38 minutes. All assessments were conducted under standardized testing conditions to ensure consistency across measurements.

DISCUSSION

This study evaluated the diagnostic accuracy, agreement, and reliability of a newly developed portable visual acuity device for screening visual acuity impairment among school-aged children. The findings demonstrated that the device achieved high diagnostic performance, with an overall sensitivity of 87.2%, specificity of 97.2%, positive predictive value of 86.8%, negative predictive value of 97.3%, and overall accuracy of 95.4%. Receiver operating characteristic analysis further demonstrated excellent discriminative ability, with an area under the curve of 0.922. Agreement analysis showed good to excellent reliability with high ICC values, while Bland–Altman analysis demonstrated minimal systematic bias and narrow limits of agreement. Collectively, these findings indicate that the portable device provides reliable and clinically comparable visual acuity measurements relative to the standard Snellen chart.

The diagnostic performance observed in the present study is consistent with findings from recent literature evaluating digital and portable visual acuity assessment tools. Suo et al. conducted a systematic review and meta-analysis of mobile application-based visual acuity tests and reported pooled sensitivity and specificity values comparable to conventional chart-based assessment, concluding that digital visual acuity tools have strong potential for screening and teleophthalmology applications [8]. The high specificity observed in our study is particularly important in screening programs, as it reduces false-positive referrals and improves screening efficiency in resource-constrained settings.

The overall diagnostic accuracy of 95.4% and AUC of 0.922 observed in this study indicate excellent discriminative performance of the developed device. These findings compare favorably with recent digital visual acuity platforms used for remote and community-based assessment. Thirunavukarasu et

al. validated the DigiVis web-based visual acuity platform and reported strong agreement with standard clinical testing, supporting the reliability of digital vision assessment in remote settings [18]. Similar findings have been reported in recent teleophthalmology studies, which demonstrate that appropriately calibrated digital visual acuity systems can provide clinically acceptable accuracy for screening and remote monitoring [7,19].

Agreement analysis in the present study demonstrated excellent comparability between the portable device and Snellen chart, with negligible mean bias (-0.00081 logMAR) and narrow limits of agreement. Bland–Altman analysis showed minimal systematic measurement error for right eye, left eye, and overall visual acuity assessment. These findings suggest that the device measurements are clinically interchangeable with conventional chart-based assessment for screening purposes. The strong agreement observed in this study is consistent with recent studies validating digital visual acuity tools, where minimal mean differences and narrow limits of agreement have been reported across different platforms [18,19].

Reliability analysis further demonstrated good to excellent consistency of measurements. Agreement-based ICC values were high across right eye, left eye, and overall analysis. Test–retest reliability across three repeated sessions also showed excellent repeatability, with an average-measure ICC of 0.939. High repeatability is essential for screening tools because consistent performance across repeated assessments minimizes false referrals and missed cases. Previous validation studies of digital visual acuity tools have similarly reported strong repeatability and reproducibility, supporting the use of digital platforms in routine screening and remote ophthalmic care [7,8].

The findings of this study have important public health implications, particularly in resource-constrained settings where school-based vision screening programs often face challenges related to limited infrastructure, environmental variability, and shortage of trained personnel. Portable visual acuity devices capable of providing rapid, standardized, and accurate screening may improve accessibility and facilitate early detection of visual impairment, thereby supporting timely referral and intervention.

CLINICAL IMPLICATION

The validated portable visual acuity device offers a practical, reliable, and cost-effective tool for early detection of refractive errors among school children. Its portability and ease of use make it suitable for community-based screening, school health programs, and resource-limited settings where access to ophthalmic services is limited. Early identification and timely referral of children with visual impairment can improve academic performance, reduce the burden of undiagnosed refractive errors, and support integration of vision screening into routine primary healthcare and school health initiatives.

STRENGTHS AND LIMITATIONS

A major strength of this study lies in the development of a novel portable head-mounted visual acuity device specifically designed for school-based screening. The device incorporated mathematically

calibrated Snellen optotypes, standardized testing distance, accommodation control, and controlled luminance, ensuring improved measurement consistency. The study further included a large representative sample of 1,118 children from urban and rural settings, demonstrating strong external validity. High diagnostic accuracy, excellent repeatability, and strong user acceptance further support the potential scalability of the device for large-scale public health screening programs.

This study has several limitations. The use of a fixed descending optotype sequence may introduce learning effects during repeated sessions. Visual acuity assessment was performed under non-cycloplegic conditions, which may not fully reflect true refractive status in younger children. The fixed short viewing distance may impose accommodative demand, potentially affecting measurement consistency. Additionally, the Snellen chart was used as the reference standard instead of ETDRS logMAR charts, and the use of alphabetic optotypes may limit applicability among younger children or those with low literacy.

CONCLUSION

The portable visual acuity device demonstrated excellent diagnostic accuracy, strong agreement, and high repeatability for screening visual acuity impairment among school-aged children. The device showed high sensitivity, specificity, and overall discriminative performance when compared with the standard Snellen chart, indicating its reliability as a screening tool for visual acuity assessment. The device offers significant advantages in portability, operational standardization, and applicability in resource-limited settings.

Abbreviations

AUC

Area Under the Curve

CI

Confidence Interval

ICC

Intraclass Correlation Coefficient

LoA

Limits of Agreement

logMAR

Logarithm of Minimum Angle of Resolution

NPV

Negative Predictive Value

OLED

Organic Light Emitting Diode

PPV

Positive Predictive Value

PPS
Probability Proportionate to Size
ROC
Receiver Operating Characteristic
SD
Standard Deviation
TFT
Thin Film Transistor
VA
Visual Acuity

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the Institutional Ethics Committee of JSS Medical College, JSS Academy of Higher Education & Research, Mysuru (IEC No.: JSS/MC/PG/PhD2/2024–25). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision) and its subsequent amendments, as well as applicable national and institutional guidelines for research involving human participants. Written informed consent was obtained from the parents or legal guardians of all participants prior to enrollment. Written assent was obtained from all participating children before data collection. Participation was voluntary, and participants were informed of their right to withdraw from the study at any stage without any consequences. The confidentiality and privacy of all participants were maintained throughout the study by anonymizing the collected data and restricting access to authorized research personnel only.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

- **Krishnamurthy KV** and **Sunil Kumar D** conceptualized the study, developed the portable visual acuity device, coordinated data collection, performed statistical analysis, and drafted the manuscript.
- **Soumya HV** provided ophthalmological expertise, validation support, and critical review of the manuscript.
- **Vanishri Arun** contributed to technical design, engineering development, and device optimization.
- **Rakshitha J** contributed to data collection, developed the portable visual acuity device, statistical interpretation, and drafted the manuscript. All authors read and approved the final manuscript.
- All authors read and approved the final manuscript.

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Tables

Table 1
Socio-demographic characteristics of the
participants (N = 1118)

Variable	Category	n (%)
Age group	6–9 years	265 (23.7)
	10–13 years	374 (33.5)
	14–16 years	479 (42.8)
Gender	Male	597 (53.4)
	Female	521 (46.6)
Education	Lower primary	298 (26.7)
	Upper primary	374 (33.4)
	Secondary	446 (39.9)
Residence	Urban	429 (38.4)
	Rural	689 (61.6)

Table 2
Diagnostic performance of the portable visual acuity device compared with Snellen chart

Measure	Right Eye	Left Eye	Overall
Sensitivity (%)	82.2	81.8	87.2
Specificity (%)	97.6	97.4	97.2
PPV (%)	83.9	83.9	86.8
NPV (%)	97.3	97.0	97.3
Accuracy (%)	95.6	94.9	95.4
AUC	0.899	0.896	0.922
• $p < 0.05$ was considered statistically significant.			
• Positive predictive value (PPV) and negative predictive value (NPV) do not require p-values, as they are dependent on disease prevalence.			
• 95% confidence intervals were computed using exact binomial methods			

Table 3
Agreement and reliability analysis of the portable visual acuity device

Parameter	Single ICC	Average ICC	Cronbach's Alpha	P value
Right eye agreement	0.86	0.93	0.93	< 0.001
Left eye agreement	0.86	0.92	0.92	< 0.001
Overall agreement	0.79	0.93	0.93	< 0.001
Right eye test–retest	0.831	0.937	0.937	< 0.001
Left eye test–retest	0.803	0.924	0.926	< 0.001
Overall test–retest	0.718	0.939	0.939	< 0.001
• Intraclass correlation coefficients (ICC) were calculated using a two-way mixed-effects model with absolute agreement.				
• Single-measure ICC reflects reliability of a single assessment; average-measure ICC reflects reliability across repeated measurements.				
• Overall visual acuity was defined as impairment in either eye.				
• $p < 0.05$ was considered statistically significant.				

Table 4
Bland–Altman agreement analysis for portable visual acuity device

Eye	Comparison	Mean Bias	Upper LoA	Lower LoA	SD
Right Eye	Snellen vs Device	+ 0.00939	+ 0.19771	−0.17200	0.09608
	Session 1 vs Session 2	−0.00590	+ 0.19900	−0.21100	0.10472
	Session 2 vs Session 3	+ 0.00590	+ 0.17100	−0.15900	0.08432
	Session 1 vs Session 3	0.00000	+ 0.16300	−0.16300	0.08319
Left Eye	Snellen vs Device	−0.01100	+ 0.20901	−0.23102	0.11225
	Session 1 vs Session 2	+ 0.00635	+ 0.24400	−0.23100	0.12104
	Session 2 vs Session 3	+ 0.01480	+ 0.18000	−0.15100	0.08449
	Session 1 vs Session 3	+ 0.02120	+ 0.20110	−0.15870	0.09177
Overall	Snellen vs Device	−0.00081	+ 0.16604	−0.16765	0.08513
	Session 1 vs Session 2	+ 0.00018	+ 0.16683	−0.16647	0.08502
	Session 2 vs Session 3	+ 0.01038	+ 0.13812	−0.11737	0.06517
	Session 1 vs Session 3	+ 0.01055	+ 0.14274	−0.12163	0.06744
• Bland–Altman analysis was performed to assess agreement between the portable visual acuity device and the Snellen chart, as well as test–retest reliability across sessions.					
• Mean bias represents the average difference in logMAR visual acuity values between the two measurements being compared.					
• Upper and lower limits of agreement (LoA) were calculated as mean bias $\pm$ 1.96 $\times$ standard deviation (SD) of the differences.					
• Positive mean bias indicates marginally higher visual acuity values recorded by the portable device, whereas negative values indicate lower readings compared to the reference measurement.					

Figures

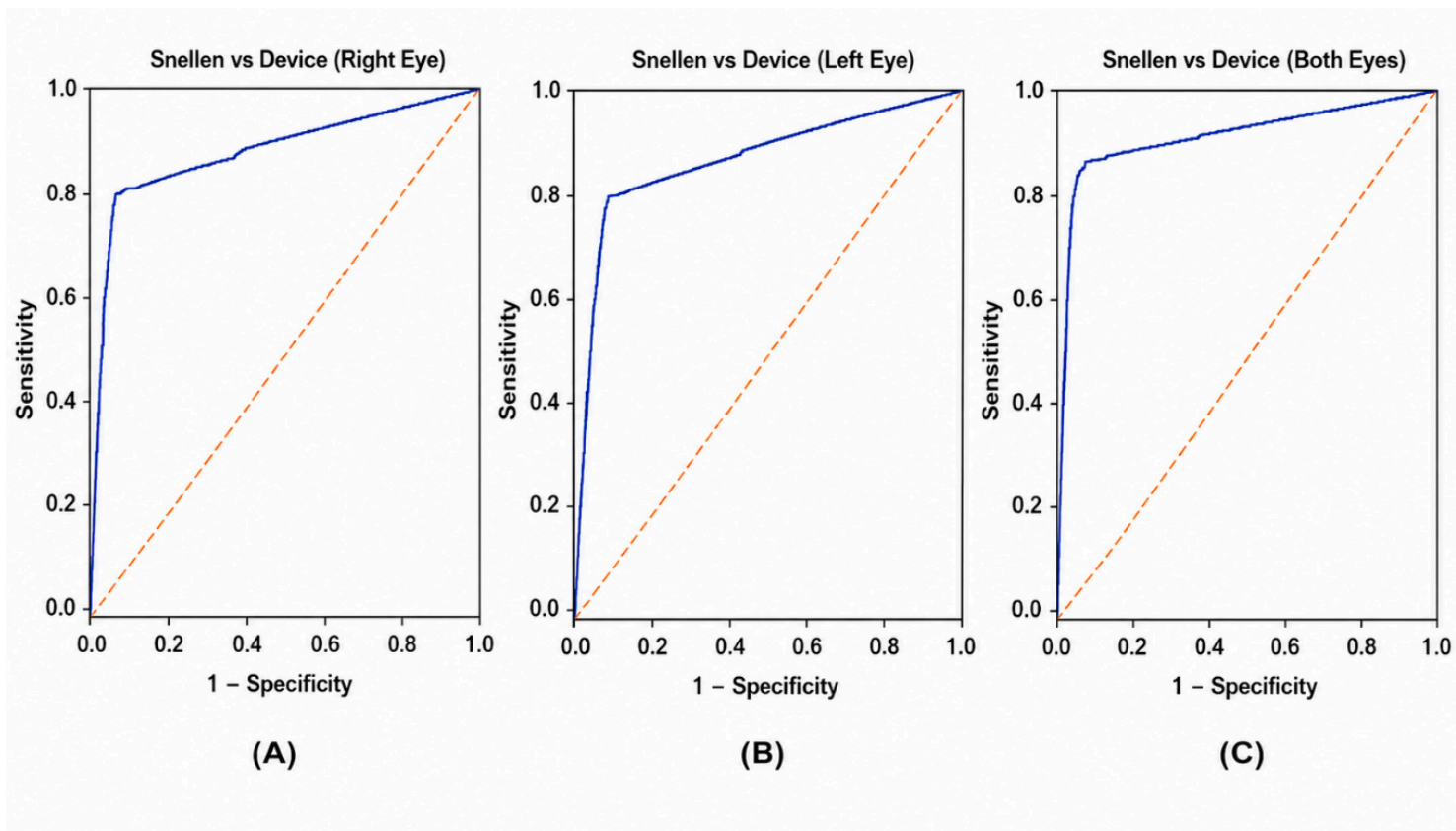


Figure 1

Receiver operating characteristic (ROC) curves comparing the portable visual acuity device with the Snellen chart for the right eye (A), left eye (B), and both eyes (C).(N=1118)

Legend: The ROC curves demonstrate the diagnostic performance of the portable visual acuity device for detecting refractive errors using the Snellen chart as the reference standard. The diagonal line represents the line of no discrimination.

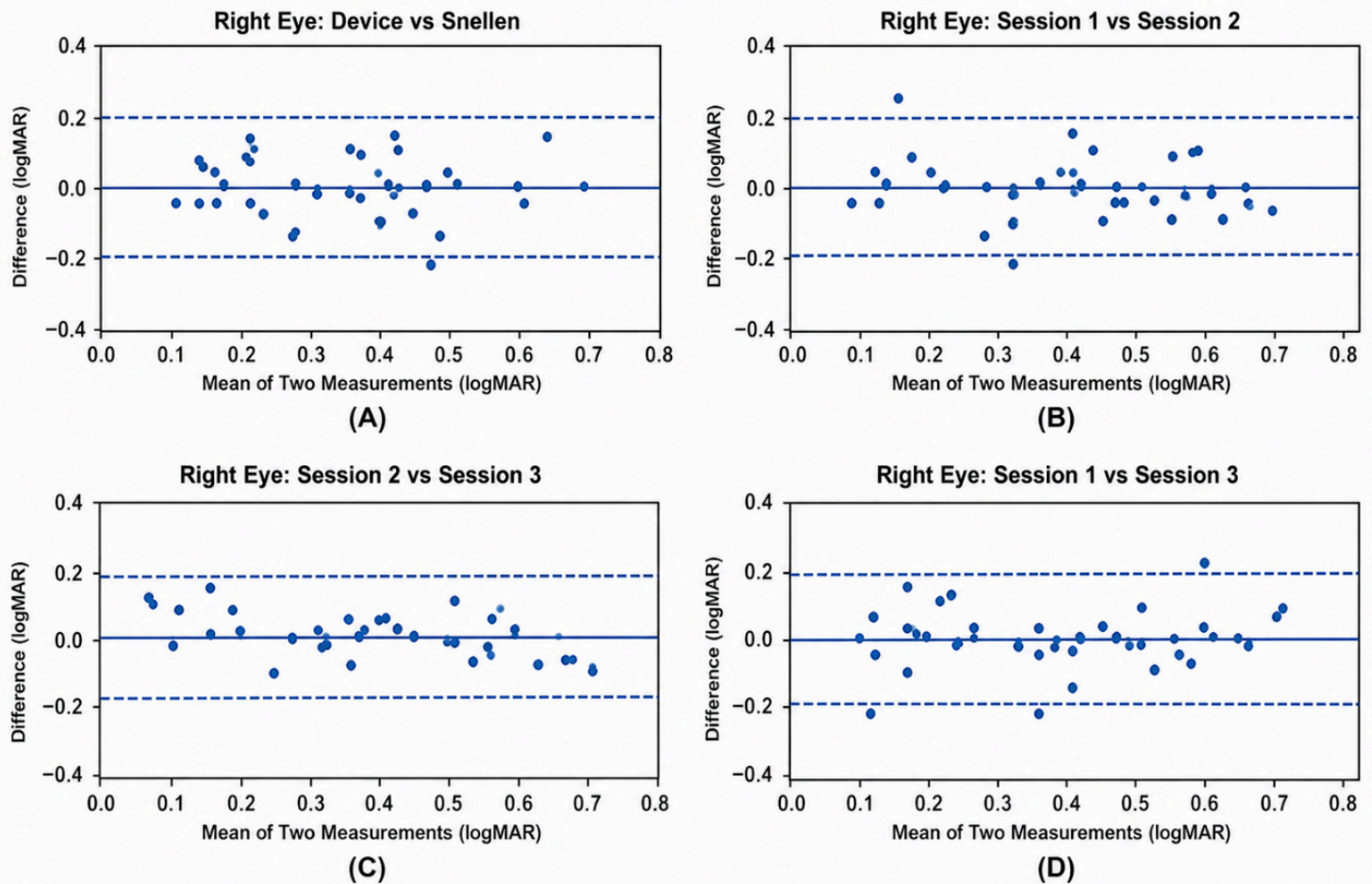


Figure 2

Bland–Altman Agreement Analysis Between the Portable Visual Acuity Device and the Snellen Chart and Across Test–Retest Sessions for the Right Eye(N=1118)

Legend: Bland–Altman plots showing agreement between the portable visual acuity device and the Snellen chart, and the test–retest reliability of the portable device for the right eye. **(A)** Device vs Snellen, **(B)** Session 1 vs Session 2, **(C)**Session 2 vs Session 3, and **(D)** Session 1 vs Session 3. The solid line represents the mean difference (bias), and the dashed lines represent the 95% limits of agreement.

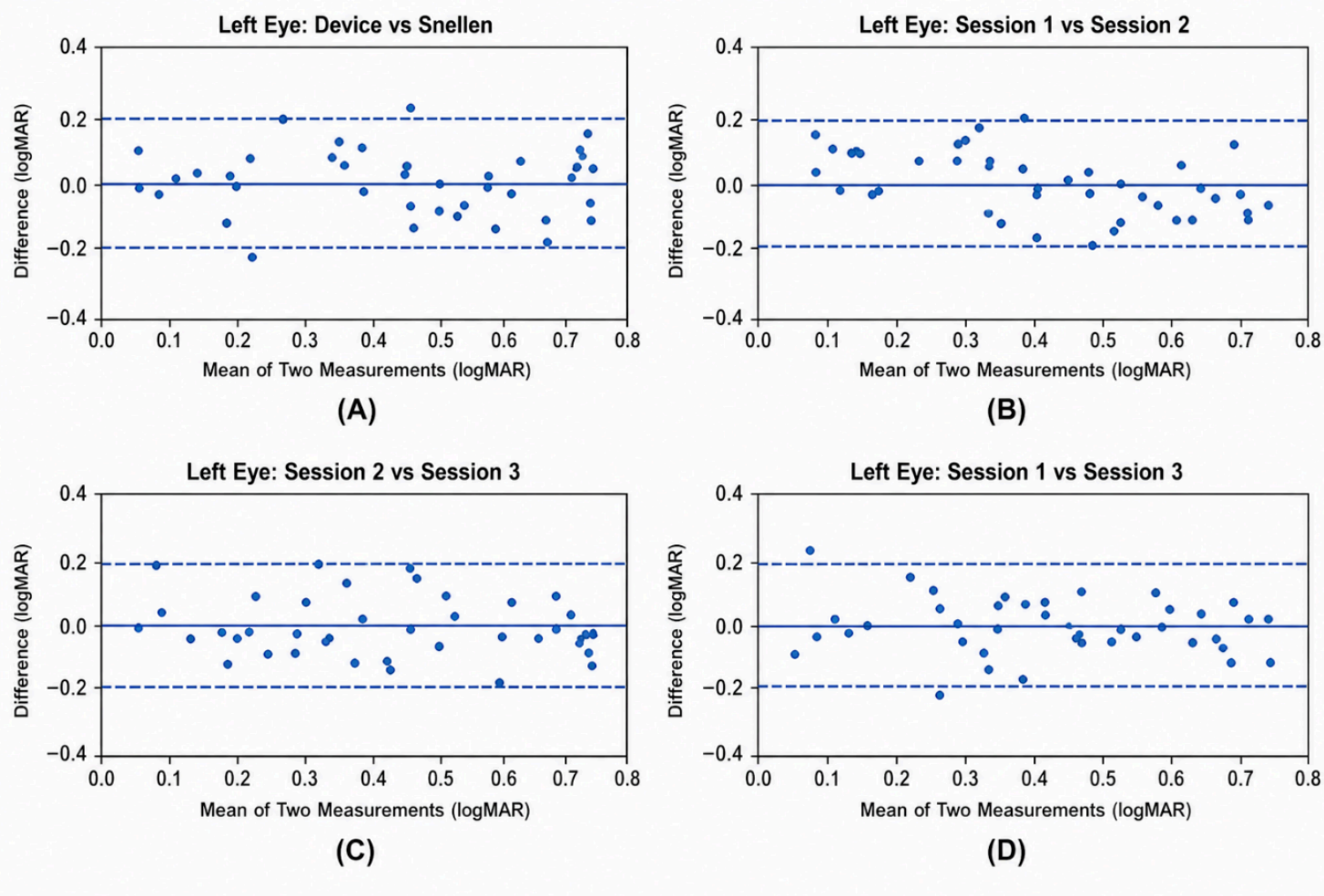


Figure 3

Bland–Altman Agreement Analysis Between the Portable Visual Acuity Device and the Snellen Chart and Across Test–Retest Sessions for the Left Eye(N=1118)

Legend:Bland–Altman plots showing agreement between the portable visual acuity device and the Snellen chart, and the test–retest reliability of the portable device for the left eye. **(A)** Device vs Snellen, **(B)**Session 1 vs Session 2, **(C)** Session 2 vs Session 3, and **(D)**Session 1 vs Session 3. The solid line represents the mean difference (bias), and the dashed lines represent the 95% limits of agreement.

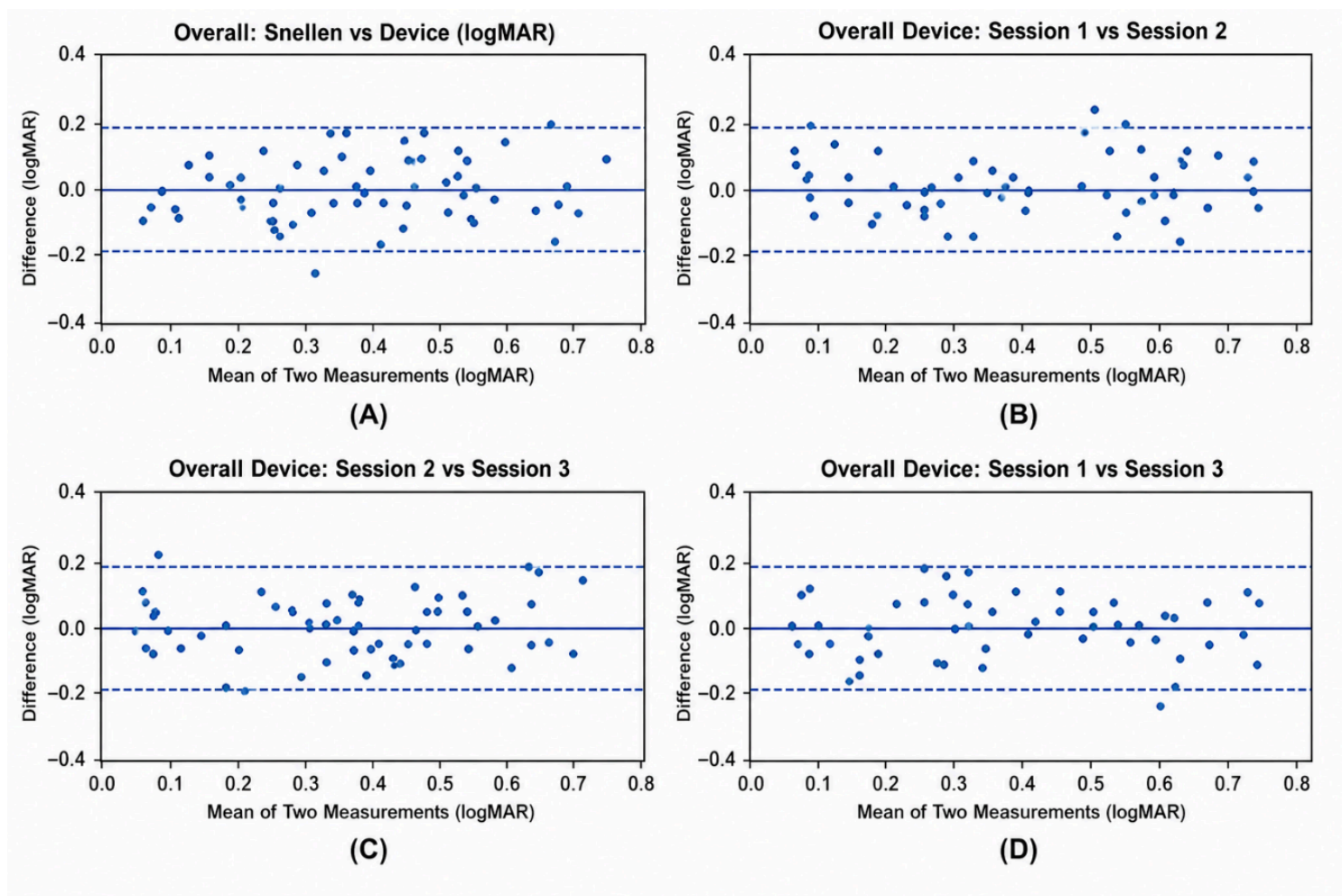


Figure 4

Bland–Altman Agreement Analysis Between the Portable Visual Acuity Device and the Snellen Chart and Across Test–Retest Sessions for the Overall Eye(N=1118)

Legend:Bland–Altman plots showing agreement between the portable visual acuity device and the Snellen chart, and the test–retest reliability of the portable device using combined measurements from both eyes. **(A)** Device vs Snellen, **(B)** Session 1 vs Session 2, **(C)**Session 2 vs Session 3, and **(D)** Session 1 vs Session 3. The solid line represents the mean difference (bias), and the dashed lines represent the 95% limits of agreement.

Supplementary Files

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- [AdditionalFile1.docx](#)