Agreement between a mobile applet-based visual acuity self-test program and the conventional method for distance and near visual acuity test

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Article

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Abstract

PURPOSE: To investigate the agreement between a mobile applet-based visual acuity (VA) self-test program and the conventional VA tests.

METHODS: This consecutive case series study included 121 children and adults (242 eyes). Patients were classified into three groups according to age (children, adolescents, and adults). They underwent uncorrected distance visual acuity (UDVA) testing, distance visual acuity with frame spectacle (DVA with FS) testing at 2.5-m distance, uncorrected near visual acuity (UNVA) testing, and near visual acuity with frame spectacle (NVA with FS) testing at a 0.4-m distance using a mobile applet-based VA self-test program and conventional VA tests in two eyes.

RESULTS: Correlations among UDVA, DVA with FS, UNVA, and NVA with FS between the two methods were significant in all subjects (all $P<0.001$). The intraclass correlation coefficient were 0.960, 0.845, 0.960, and 0.669, respectively (all $P<0.001$). The proportions of bias outside the 95% confidence interval limit of agreements were 6.20%, 4.82%, 7.08%, and 6.10%, respectively. There were significant differences in NVA with FS between the two methods ($P<0.05$) in the adolescent group, but no differences in measured parameters were found among children and adult groups.

CONCLUSIONS: There is good agreement between the mobile applet-based VA self-test program and the conventional VA tests. The VA self-test has good practical value especially in the current pandemic, allowing self-screening of visual acuity, myopia control, and remote management of visual impairment in oculopathy.

Summary

What was known before

- The visual acuity (VA) screening as the most basic part of ophthalmic examinations requires professional settings.
- During the COVID-19 pandemic, the use of electronic devices for home-based health management become significant.
- Only few VA self-test programs were clinically validated to perform both distance and near VA tests.

What this study adds

- The mobile applet-based VA self-test program was easy to load and operate without professional guidance, in favor of rapid promotion and application.
- The mobile applet-based VA self-test had good agreement with conventional methods for distance and near VA, with practical value and important social significance for self-screening of VA, myopia control and remote health management.
Introduction

Visual impairment is an important public health issue worldwide, with a heavy socioeconomic burden. More than 400 million people globally have mild to severe visual impairment. An uncorrected refractive error is the most common cause of visual impairment [1]. Children exposed to ophthalmic diseases, including refractive error, strabismus, or amblyopia, at the critical stage of visual development may have low vision that can profoundly affect their quality of life [2, 3]. Most visual impairments are preventable and controllable through early detection and treatment [1].

Visual acuity (VA) screening is the most basic part of ophthalmic examination. Currently, the screening is performed by professional technicians using established devices [4]. However, patients in remote areas have limited access to healthcare services, and this is further reduced with the current coronavirus disease 2019 (COVID-19) outbreak [5]. Time at school is reduced, and parents’ work is negatively affected when children need multiple visits to ophthalmology clinics for myopia control [2]. At the peak season of vision screening for children, usually winter and summer vacations, conventional VA testing is time-consuming and requires a professional optometrist.

Electronic devices have been increasingly used for home-based health management [6, 7], but few have been clinically validated for both distance and near VA tests [8]. Thus, this study aimed to introduce a VA self-test program based on a mobile WeChat applet (also called mini-program). We also verified the accuracy of its application in children and adults by comparing it with the conventional VA tests, to assist in autonomous vision screening, prevention and control of myopia, and remote disease management during the COVID-19 pandemic.

Methods

Study design and subjects

This consecutive case series study included 242 eyes of 121 patients aged 3–40 years who visited the Eye and ENT Hospital of Fudan University between December 2021 and February 2022. The inclusion criterion was no use of soft contact lenses for at least 2 weeks or rigid gas permeable contact lenses for at least 4 weeks. The exclusion criteria were as follows: history of orthokeratology lens or low-concentration atropine use; history of keratopathy, cataract, glaucoma, retinal detachment, neuro-ophthalmic disease or other eye diseases; history of ophthalmic surgery or trauma; history of systemic diseases; and severe psychological or psychiatric diseases. Table 1 shows the demographic patient characteristics. The subjects were classified according to age into the children group (age 3–10 years, 86 eyes of 43 people), adolescent group (age 11–20 years, 50 eyes of 25 people), and adult group (age 21–40 years, 106 eyes of 53 people). Figure 1 shows the distribution of SE (spherical equivalent) and corrected distance visual acuity (CDVA) according to age.
## Table 1
### Patient demographics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ALL</th>
<th>Children</th>
<th>Adolescent</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD Range</td>
<td>Range</td>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>Age (years)</td>
<td>17.74 ± 9.57</td>
<td>(3, 40)</td>
<td>14.96 ± 3.13</td>
<td>27.42 ± 4.23</td>
</tr>
<tr>
<td></td>
<td>7.44 ± 1.70</td>
<td>(3,10)</td>
<td>(11,20)</td>
<td>(21,40)</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>56/65</td>
<td>22/21</td>
<td>14/11</td>
<td>20/33</td>
</tr>
<tr>
<td>Axial length (mm)</td>
<td>25.04 ± 1.65</td>
<td>(20.24, 29.58)</td>
<td>25.36 ± 1.69</td>
<td>25.73 ± 1.20</td>
</tr>
<tr>
<td></td>
<td>23.53 ± 1.34</td>
<td>(20.24, 25.92)</td>
<td>(22.24, 28.92)</td>
<td>(23.06, 29.58)</td>
</tr>
<tr>
<td>Refraction sphere (D)</td>
<td>-3.09 ± 3.20</td>
<td>(-11.75, 8.00)</td>
<td>-3.33 ± 2.74</td>
<td>-4.98 ± 2.21</td>
</tr>
<tr>
<td></td>
<td>(-0.85 ± 0.91)</td>
<td>(-6.25, 0)</td>
<td>(-1.15 ± 0.83)</td>
<td>(-0.84 ± 0.73)</td>
</tr>
<tr>
<td>Refraction cylinder (D)</td>
<td>-0.42 ± 2.34</td>
<td>(-5.00, -8.00)</td>
<td>-3.90 ± 2.98</td>
<td>-5.40 ± 2.24</td>
</tr>
<tr>
<td>Spherical equivalent, SE (D)</td>
<td>-3.52 ± 3.26</td>
<td>(-11.88, 8.00)</td>
<td>(-11.13, 1.63)</td>
<td>(-11.88, -0.88)</td>
</tr>
<tr>
<td>K-flat (D)</td>
<td>42.51 ± 1.31</td>
<td>(39.10, 45.90)</td>
<td>41.90 ± 1.43</td>
<td>42.59 ± 1.31</td>
</tr>
<tr>
<td>K-steep (D)</td>
<td>43.81 ± 1.68</td>
<td>(39.70, 50.58)</td>
<td>43.46 ± 1.73</td>
<td>43.73 ± 1.57</td>
</tr>
</tbody>
</table>

This study was approved by the Ethics Committee of the Eye and ENT Hospital of Fudan University (20211208, Date: 12/08/2021) and was conducted in accordance with the Declaration of Helsinki. All procedures were performed after obtaining written informed consent from patients.

## Examinations

Two VA examinations were performed: the VA self-test and the conventional method. The Pentacam (Oculus Optikgerate Wetzlar, Germany) was used to measure the mean corneal curvature (Km), and the Humphrey IOLMaster 500 (Carl Zeiss Meditec, Germany) was used to measure axial length (AL) in adults. The Humphrey IOLMaster 700 (Carl Zeiss Meditec, Germany) was used to measure Km and AL in juvenile. Tropicamide phenylephrine eye drops (Mydrin-P ophthalmic solution; Santen, Osaka, Japan) were administered three times at 10-minute intervals for cycloplegia after VA tests in juvenile subjects. Full cycloplegia was assumed if light reflex was absent. A phoropter (RT-5100; Nidek Technologies, Japan) was used for optometry.
VA testing

The optotypes (tumbling E) were designed according to the Standard for logarithmic visual acuity charts (GB/T 11533 – 2011, China). The centers of the distance/near VA testing light box and mobile phone were all fixed at the same height in the same examination room. The ambient brightness was defined as an indoor bright environment without reflection, glare, or direct sunlight. Fixed seats were set up 2.5 m or 40 cm away from the two devices. The right eye was tested first with the contralateral eye covered. Uncorrected distance visual acuity (UDVA) and uncorrected near visual acuity (UNVA) were measured using conventional VA testing light boxes and VA self-test, respectively.

If the subjects wore frame spectacles, further tests were required using both methods for distance VA with frame spectacles (DVA with FS) and near VA with frame spectacles (NVA with FS). Subjects were given a 1-minute break to reduce eye strain during the different test intervals. Conventional VA tests were performed by an experienced optometrist. One staff member without a medical background learned the measurement procedures and assisted the participants in the self-test. The VA self-test was conducted according to the built-in testing procedures, with the subjects verbally answering the direction of optotypes and the staff clicking the corresponding answers on the mobile phone. The optometrist and staff were blinded to each other’s test results, and the subjects were blinded until all VA tests were completed.

Conventional VA tests

The display device for conventional VA tests was an ACP-60 Liquid Crystal Eye Chart (Supore instruments Co Ltd., Shanghai, China) with a display area of 529 (W) × 298.5 (H) mm, resolution of 1920 × 1080 pixels, pixel density of 92 pixels per inch (ppi), brightness of 250 cd/m², and contrast ratio of 1000:1. Conventional NVA tests were performed using the tumbling E chart (VSK-VC-J 0.3m, Wehen Vision, China). The corresponding VA value was recorded as the test result when the number of correctly recognized optotypes exceeded half of the total in the row.

Mobile VA self-test

The VA self-test can be performed using a mobile device that can install an Android or iOS application. The Huoyan Visual Acuity Testing Program (Huoyan Medical Technology Co.,Ltd., Shanghai, China) was operated on the WeChat applet/mini program platform, and the testing device was an Android smartphone (VIVO X20Plus), with a display area of 146 × 73 mm, resolution of 2160 × 1080 pixels, pixel density of 376 ppi, brightness of 425 cd/m², and contrast ratio of 60000:1. After entering the platform, the screen was automatically adjusted to the highest brightness, and the subjects calibrated the size of the optotype to 1 cm by adjusting the length of the scale bar following the instructions. The subjects then selected the testing mode: DVA (Fig. 2A) or NVA (Fig. 2B) with or without frame spectacles.

During the DVA test, one assistant inputted the results. Then, a tumbling “E” optotype was displayed, and the staff clicked the directions according to the answers (Fig. 2B). The program automatically provided
the optotypes until the end point. The initial size of the optotype was 0.6 Decimal by default (can be adjusted manually), and if the right or wrong answers added up to 3, the program would automatically enter the next round and give a smaller/bigger level of optotypes until 3 wrong/right answers were obtained. The results of UDVA, DVA with FS, UNVA, and NVA with FS were automatically generated and displayed (Fig. 2C).

**Statistical analysis**

The VA results were converted to LogMAR: LogMAR VA = log (1/Decimal VA), 5-Mark record VA = 5 − log (1/Decimal VA). Continuous variables were presented as the mean ± standard deviation (SD) and range. Pearson's correlation analysis was used to evaluate the correlations between the two methods. Repeatability (intra-device agreement) was evaluated using intraclass correlation coefficients (ICCs) (A, 1) (absolute agreement, two-way random effect model). According to the principles of McGraw and Wong [9], very good agreement was defined as an ICC value of > 0.7, good agreement as ICC values of 0.4–0.7, and poor agreement as an ICC value < 0.4.

Bland-Altman plots were used to present the agreement between the two methods, and the 95% confidence level (CI) of the limits of agreements (LoAs) were calculated for the upper and lower LoAs. The Kolmogorov-Smirnov test was used to evaluate data normality. The generalized linear model, as a multivariate parameter test method, was used to analyze the differences and correlations between groups and to exclude binocular-inclusion effects. Wilcoxon test was used for non-normally distributed data. All statistical analysis were performed by a researcher not involved in VA testing, using the Statistical Package for the Social Sciences (version 25.0, SPSS, Inc., Chicago, IL, USA). Two-tailed tests were applied on all data, and \( P < 0.05 \) was considered statistically significant.

**Results**

**Visual acuity measurements**

All examinations were completed successfully, with all types of data loss of less than 5%. The UDVA, UNVA, DVA with FS, and NVA with FS were measured in 242 eyes of all subjects, 240 eyes of 120 subjects, 166 eyes of 83 subjects, and 164 eyes of 82 subjects, respectively, using the two methods. The results are shown in Table 2. The Pearson correlation coefficients for the two methods were 0.960, 0.846, 0.960, and 0.671 (all \( P \) values < 0.001) for the UDVA, DVA with FS, UNVA, and NVA with FS tests, respectively. The differences (LogMAR) between the two methods (Fig. 3) were 76.45%, 81.25%, 89.76%, and 89.63% within ± 0.1 LogMAR for UDVA, UNVA, DVA with FS and NVA with FS, respectively.
### Table 2
Conventional-test and Self-test Visual Acuity (VA, LogMAR)

<table>
<thead>
<tr>
<th>VA (LogMAR)</th>
<th>N (eyes)</th>
<th>Conventional-test</th>
<th>Self-test</th>
<th>Pearson correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± sd</td>
<td>mean ± sd</td>
<td>r</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>UDVA</td>
<td>242</td>
<td>0.56 ± 0.40</td>
<td>0.52 ± 0.39</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.18, 1.00)</td>
<td>(-0.30, 1.00)</td>
<td></td>
</tr>
<tr>
<td>DVA with FS</td>
<td>166</td>
<td>0.04 ± 0.14</td>
<td>0.03 ± 0.14</td>
<td>0.846</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.30, 0.70)</td>
<td>(-0.30, 0.52)</td>
<td></td>
</tr>
<tr>
<td>UNVA</td>
<td>242</td>
<td>0.33 ± 0.36</td>
<td>0.31 ± 0.37</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.08, 1.10)</td>
<td>(-0.30, 1.00)</td>
<td></td>
</tr>
<tr>
<td>NVA with FS</td>
<td>164</td>
<td>0.02 ± 0.09</td>
<td>-0.01 ± 0.10</td>
<td>0.671</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.18, 0.30)</td>
<td>(-0.30, 0.30)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: UDVA, Uncorrected distance visual acuity; DVA, Distance visual acuity; UNVA, Uncorrected near visual acuity; NVA, Near visual acuity; FS, Frame Spectacles.

### Agreement tests

The ICCs between the conventional VA tests and VA self-tests of UDVA, DVA with FS, UNVA, and NVA with FS were 0.960, 0.845, 0.960, and 0.669, respectively (all *P* < 0.001, Table 3). Figure 4 shows the Bland-Altman plots of the two methods. For UDVA, DVA with FS, UNVA, and NVA with FS, the proportion of points outside the LoAs was 6.20% (15/242), 4.82% (8/166), 7.08% (17/240), and 6.10% (10/164), respectively, with a mean proportion of 6.05%. The corresponding values were 5.81%, 8.82%, 3.57%, and 6.25%, respectively, in the children group; 6.00%, 0%, 8.00%, and 8.82%, respectively, in the adolescent group; and 6.60%, 4.08%, 9.43%, and 5.10%, respectively, in the adult group.
Table 3
Inter-device agreement as determined by ICC (A, 1)

<table>
<thead>
<tr>
<th>ICC(A,1)</th>
<th>Conventional-test and Self-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC value</td>
<td>95% CI</td>
</tr>
<tr>
<td>UDVA</td>
<td>0.960</td>
<td>(0.949, 0.969)</td>
</tr>
<tr>
<td>DVA with FS</td>
<td>0.845</td>
<td>(0.796, 0.884)</td>
</tr>
<tr>
<td>UNVA</td>
<td>0.960</td>
<td>(0.948, 0.969)</td>
</tr>
<tr>
<td>NVA with FS</td>
<td>0.669</td>
<td>(0.575, 0.746)</td>
</tr>
</tbody>
</table>

Abbreviations: ICC (A, 1); intraclass correlation coefficients (inter-rater reliability, two-way random effect model). UDVA, Uncorrected distance visual acuity; DVA, Distance visual acuity; UNVA, Uncorrected near visual acuity; NVA, Near visual acuity; FS, Frame Spectacles.

Differences among the three age groups

As shown in Table 4, there were no statistically significant differences between the two methods for all three age groups (all $P > 0.05$). This is with the exception for the NVA with FS that was significantly different between the two methods ($P < 0.05$) in the adolescent group, with an average difference of $-0.045 \pm 0.020$ LogMAR.
Table 4
Conventional-test and Self-test Visual Acuity (VA, LogMAR) of 3 different groups according to age.

<table>
<thead>
<tr>
<th>VA (LogMAR)</th>
<th>Groups</th>
<th>N (eyes)</th>
<th>Conventional-test</th>
<th>Self-test</th>
<th>P</th>
<th>Δ (Self-test - Conventional-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDVA</td>
<td>Children</td>
<td>86</td>
<td>0.20 ± 0.28</td>
<td>0.19 ± 0.27</td>
<td>0.746</td>
<td>-0.014 ± 0.042</td>
</tr>
<tr>
<td></td>
<td>Adolescent</td>
<td>50</td>
<td>0.52 ± 0.37</td>
<td>0.48 ± 0.37</td>
<td>0.449</td>
<td>-0.042 ± 0.056</td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>106</td>
<td>0.87 ± 0.21</td>
<td>0.82 ± 0.23</td>
<td>0.126</td>
<td>-0.057 ± 0.037</td>
</tr>
<tr>
<td>DVA with FS</td>
<td>Children</td>
<td>34</td>
<td>0.08 ± 0.15</td>
<td>0.05 ± 0.15</td>
<td>0.421</td>
<td>-0.021 ± 0.026</td>
</tr>
<tr>
<td></td>
<td>Adolescent</td>
<td>34</td>
<td>0.04 ± 0.15</td>
<td>0.05 ± 0.15</td>
<td>0.832</td>
<td>0.006 ± 0.028</td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>98</td>
<td>0.02 ± 0.13</td>
<td>0.01 ± 0.14</td>
<td>0.491</td>
<td>-0.012 ± 0.018</td>
</tr>
<tr>
<td>UNVA</td>
<td>Children</td>
<td>84</td>
<td>0.07 ± 0.17</td>
<td>0.05 ± 0.16</td>
<td>0.613</td>
<td>-0.022 ± 0.044</td>
</tr>
<tr>
<td></td>
<td>Adolescent</td>
<td>50</td>
<td>0.27 ± 0.37</td>
<td>0.24 ± 0.38</td>
<td>0.579</td>
<td>-0.032 ± 0.058</td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>106</td>
<td>0.57 ± 0.32</td>
<td>0.55 ± 0.32</td>
<td>0.522</td>
<td>-0.025 ± 0.039</td>
</tr>
<tr>
<td>NVA with FS</td>
<td>Children</td>
<td>32</td>
<td>0.03 ± 0.08</td>
<td>0.01 ± 0.10</td>
<td>0.366</td>
<td>-0.017 ± 0.019</td>
</tr>
<tr>
<td></td>
<td>Adolescent</td>
<td>34</td>
<td><strong>0.03 ± 0.11</strong></td>
<td><strong>-0.02 ± 0.11</strong></td>
<td><strong>0.023</strong></td>
<td>-0.045 ± 0.020</td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>98</td>
<td>0.01 ± 0.09</td>
<td>-0.01 ± 0.10</td>
<td>0.213</td>
<td>-0.015 ± 0.012</td>
</tr>
</tbody>
</table>

Children group: aging 3–10 years; Adolescent group: aging 11–20 years; Adult group: aging 21–40 years.

Abbreviations: UDVA, Uncorrected distance visual acuity; DVA, Distance visual acuity; UNVA, Uncorrected near visual acuity; NVA, Near visual acuity; FS, Frame Spectacles.

**P** Conventional-test vs. Self-test.

Values with statistical significance are shown in bold.

**Discussion**

Visual acuity tests are one of the most fundamental components of ophthalmic clinical practice for disease diagnosis and observation of therapeutic effects. The visual acuity test is conducive for early
oculopathy detection and timely treatment, reducing social and medical burdens. The recent increase in
use of smartphone platforms has facilitated the popularization of vision screening and refractive error
identifying in children [10, 11]. The VA self-test can be theoretically carried out anywhere and is faster,
safer, and more efficient than conventional tests conducted in hospitals, thus making it especially helpful
during the COVID-19 pandemic. However, there are currently few verified VA self-testing programs and
even fewer programs that can be used for both distance and near VA testing.

This study found good correlation and agreement among four VA tests between the mobile applet-based
VA self-test and the conventional method, with LoAs ranging from −0.26 to 0.18 (Fig. 4). A study testing
UDVA with an iPhone SE at 1.2 m and the Snellen chart or ETDRS chart showed differences of 0.04
LogMAR (LoAs: -0.06, 0.13 LogMAR) and 0.02 LogMAR (LoAs: -0.06, 0.096) [12], while the differences
were 0.100 to -0.010 LogMAR (LoAs: -0.400, 0.273 LogMAR) in another study comparing a different
program run on iPhone 7 (or 7 plus) and the ETDRS chart [4]. A different study using an Android tablet
reported the mean difference was less than 0.1 LogMAR (LoAs: ± 0.3 LogMAR) [13]. Our findings were
consistent with those of previous studies, suggesting the feasibility and practical value of mobile devices
for performing different kinds of VA tests.

This study provides evidence of good agreement between the VA self-test and the conventional method in
different age groups for participants aged 3–40 years. In contrast, a study [13] showed a significant
difference between smartphone programs and conventional methods for UNVA tests in adults. Another
study [12] also showed a significant difference in adult CDVA testing between the testing App and the
Snellen charts, with a mean difference of 0.04 ± 0.05 LogMAR. However, no significant difference was
found in the four VA tests in the adult group in the current study, with a maximum mean difference of
-0.057 ± 0.037 LogMAR. Visual acuity results of the two methods were relatively close in the adult group,
indicating a similarly good performance of the mobile VA testing platform. A study in adolescents [4]
reported mean differences of -0.010 LogMAR (LoAs: -0.052, 0.032 LogMAR) and 0.092 LogMAR (LoAs:
-0.133, -0.051 LogMAR) for UDVA and UNVA, respectively, between automatic testing programs and
conventional methods. Meanwhile, the current study found no significant differences in UDVA or UNVA
between the methods in the adolescent group. A previous study on children's UDVA testing [14–16]
reported a difference of -0.018 to 0.04 LogMAR, which was in close agreement with our findings.
Collectively, the results of the previous and current studies indicate that the mobile applet-based VA self-
test has high potential for application in the population aged 3–40 years.

In the adolescent group, the NVA with FS was significantly higher in the conventional VA test than in the
VA self-test. Previous studies have suggested deviations in NVA testing utilizing smart devices [17, 18],
and this could be attributed to the differences in device parameters, including brightness, contrast ratio, or
resolution [4]. Satgunam et al. [13] suggested that a viewing angle of approximately 1.4’ for one pixel at a
distance of 40 cm was larger than the minimum resolution angle of the human eye (1’) and may lead to
image distortion, thereby underestimating VA in the younger population with relatively good vision.
Similarly, Phung et al. [19] suggested that the difference in NVA between various VA testing methods was
greater in subjects with good VA.
Another explanation may be the visual crowding phenomenon [20] because of the different ways of optotype presentation: the smartphone-based testing program presented fewer or only one optotype at a time [17]. In the current study, the pixel density of the conventional VA testing light box was lower than that of the smartphone (92 vs. 376 ppi), and thus, the display of optotypes’ edges may be more delicate in the smartphone. In addition, the highest brightness of the smartphone screen was greater than that of the VA light box (425 cd/m² vs. 250 cd/m²), and it was easier to distinguish optotypes. Some studies have shown a slight underestimation of NVA with FS [4, 13, 19] or no significant difference [21]. In addition, the discrepancy in the initial size of the optotypes and settings of the testing endpoints may also be a contributing factor to the difference in results. Further investigations on the initial size of optotypes are warranted to clarify their impact on the testing outcomes. However, the overall mean difference was relatively small (0.045 LogMAR), indicating that the VA self-test is a feasible, efficient, and reliable VA testing tool [21].

Multiple devices were used in previous studies, such as a mobile phone [22]; computer or tablet[15]; and a computer screen to display and a mobile phone to input [14, 23]. With respect to the testing distance, a flexible tape and marker pen were required to determine the distance in this study. Birch et al. [15] provided a 3-meter-long string to determine the test distance. Thirunavukarasu et al. [23] introduced a novel automated distance calibration system using the camera of a second device to determine the measurement distance, which could automatically adjust the size of the optotypes within a certain range (1.5–2.5 m) according to the actual distance. This study used only a mobile phone as the display and input device. For home-based testing, a one-time mark is adequate for long-term measurements. The future development of automatic distance measurements is of high practical value for applications of the VA self-test under different circumstances.

The VA self-test utilizes the WeChat mini-program (also called applet) platform; therefore, patients only need to search for the program in WeChat to load and use it immediately, without additional installment. WeChat is an instant messaging service worldwide, with more than 1 billion users, and the number of daily active users of WeChat mini-programs reached 450 million in 2021 [24]. The COVID-19 pandemic has overwhelmed the healthcare systems [25], and ophthalmic health issues associated with home confinement or online learning have increased [26, 27]. The mobile VA self-test is easy to operate, with no need for professional guidance, in favor of its rapid promotion and application.

This study had some limitations. First, this study did not include different devices for the VA self-test, but differences in the brightness, contrast ratio, and resolution of screens may have an impact on the test results, especially the NVA test [13]. Future research comparing different devices for the VA self-test may help to further distinguish the different testing outcomes. Second, subjects were required to maintain a correct measuring distance; therefore, a home-based or fixed setting was recommended to ensure the best accuracy.

In conclusion, there is good agreement between the mobile applet-based VA self-test and the conventional VA tests. The VA self-test has good practical value and important social significance in the COVID-19 era.
owing to its usefulness for self-screening of visual acuity, myopia control, and remote management for visual impairment in oculopathy.

**Declarations**

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**Ethics Approval and Consent to Participate:** This study followed the tenets of the Declaration of Helsinki and was approved by the ethics committee of the Eye and ENT Hospital of Fudan University (20211208, Date: 12/08/2021). Informed consent was obtained from all participants.

**Consent for Publish:** Written informed consent was obtained from the patients for the publication of this paper. Patient names and the eyes/facial region of study participants is not applicable.

**Availability of Data and Material (ADM):**

The datasets generated and/or analyzed during the current study are not publicly available due to funding requirement but are available from the corresponding author on reasonable request.

**Authors' contributions:** Study concept and design (YX, YY, JZ, XZ); data collection (YX, YY, FL, JZ); data analysis and interpretation (YY, YX); drafting of the manuscript (YX, YY, JZ); critical revision of the manuscript (YX, YY, JZ); supervision (XZ, JZ). All authors read and approved the final manuscript.

**References**


Figures
Figure 1

Subjects characteristics of age and refraction.

[A] Distribution between age and spherical equivalent.

[B] Distribution between age and corrected distance visual acuity.
Figure 2

Huoyan Visual Acuity Testing Program.

[A] The distance visual acuity test mode.

[B] The near visual acuity test mode. A tumbling E optotype is displayed at the center with digits illustrated the size of the optotype above and answer buttons below.

[C] Result interface, including uncorrected visual acuity (red digits) and visual acuity with frame spectacles (green digits).
Figure 3

Correlations between self-testing program and conventional method in distance or near visual acuity test with or without frame spectacles.

[A] Uncorrected Distance Visual Acuity.


[C] Distance Visual Acuity with Frame Spectacles.

[D] Near Visual Acuity with Frame Spectacles.
Figure 4

Bland-Altman plots for visual acuity self-testing program and conventional methods

[A] Uncorrected Distance Visual Acuity

[B] Uncorrected Near Visual Acuity

[C] Distance Visual Acuity with Frame Spectacles

[D] Near Visual Acuity with Frame Spectacles.