• Clinical Research •

A computerized resolution visual acuity test in preschool and school age children

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Abstract

● **AIM:** To develop a novel approach called the Autoacuity Tester, and to evaluate its validity, especially the sensitivity and specificity for detecting amblyopia.

● **METHODS:** Children aged from 3 to 12y (n=552) were enrolled in the study. The validity of the Autoacuity Tester was evaluated by comparing it to the Tumbling E Early Treatment Diabetic Retinopathy Study (ETDRS) acuity chart for school age children, and Lea Symbols and Teller acuity card (TAC) for preschool children. The repeatability was assessed by coefficient of repeatability (COR). The sensitivity and specificity for detecting amblyopia were calculated.

● **RESULTS:** The mean difference (95% limits of agreement) between the Autoacuity Tester and the ETDRS tests were -0.03 (-0.24, 0.19) logMAR for the school age group. In preschool children, the mean difference was 0.04 (-0.14, 0.21) logMAR between the Autoacuity Tester and the TAC and 0.00 (-0.17, 0.18) logMAR between the Autoacuity Tester and the Lea Symbols. For the school age group, the COR was 0.20 logMAR for the Autoacuity Tester and 0.18 logMAR for the ETDRS. For the preschool group, the COR was 0.13 logMAR for the Autoacuity Tester and 0.21 logMAR for TAC. The Autoacuity Tester (88%) is more sensitive than TAC (72%) in detecting amblyopia (P=0.04), while had similar specificity (92% *vs* 90%, P=0.20).

● **CONCLUSION:** The Autoacuity Tester provides a reliable alternative for assessing visual acuity, and offers advantage of higher testability and repeatability for preschool children.

● **KEYWORDS:** visual acuity test; computerized; children; sensitivity; amblyopia

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INTRODUCTION

Visual acuity is an essential measure of visual function. Visual acuity is valuable to the assessment of individuals suspected of having optical, ocular, retinal or neural pathway disorders. Visual acuity aids in the early detection of eye diseases including amblyopia and cataract, so that timely intervention is possible[1-2]. However, measuring visual acuity in young children remains a challenge. The subjective approaches to assessing visual acuity are recognition acuity and resolution acuity tests[3-5]. Recognition acuity assessment is typically performed using a visual acuity chart containing optotypes in various shapes, orientations, and sizes, such as the Tumbling E, Lea Symbols (*e.g.*, house, heart, circle and square) and letters (H, O, T and V). While recognition acuity assessment has been widely used for decades, it is not an easy test for young children. Many studies have shown that success and reliability in completing letter or symbol chart tests positively correlates with the subject's age[6-7]. Young children often struggle to complete acuity charts composed of letters, numbers, and symbol optotypes. Some visual acuity tests such as the "Landolt C" or "Tumbling E" require that children discern symbol orientation, yet children, younger than age five, often struggle to recognize letter reversals[8]. Visual acuity charts, that require symbol recognition, may be difficult for young children. Making connections between known concrete objects and abstract representations is a complex process that is not fully developed under the age of six[9].

Resolution acuity assessment is based on preferential looking (PL) techniques in which infants prefer to look at a patterned stimulus[10-11], such as with forced-choice preferential looking (FPL), operant preferential looking (OPL) and Teller acuity cards (TAC). Resolution acuity assessment is less cognitively challenging compared to recognition acuity tests. However, these tests take much longer and the apparatus is more cumbersome than the recognition acuity method. They are, therefore, used mainly in infants who are incapable of recognizing symbols or letters. Although TAC underestimates amblyopia, it serves as an alternative procedure for individuals who cannot complete recognition tests[12].

In this study, we developed a computerized visual acuity testing program (called the Autoacuity Tester) for testing visual acuity in young children. This study aims to evaluate the testability, validity and repeatability of the Autoacuity Tester.

SUBJECTS AND METHODS

Ethical Approval Informed consent for study participation was obtained from a parent or guardian. The research conformed to the tenets of the Declaration of Helsinki and followed a protocol approved by the Institutional Research Board of Zhongshan Ophthalmic Center.

Participants Five hundred and fifty-two children from 3 to 12 years of age participated in the study. To evaluate the Autoacuity Tester, the study enrolled children of a range of ages and with and without known vision problems. School age children (aged 6 to 12y, n=70) and children diagnosed with amblyopia (aged 3 to 10y, n=49) were recruited from the optometry center in Zhongshan Ophthalmic Center in Guangzhou, Guangdong Province, China. Preschool aged children (aged 3 to 6y, n=241) were recruited from 24 kindergartens in Guangzhou, Guangdong Province, China. Ten children from each class were selected using a random number generator. In addition, we recruited 192 (3 to 5 years old) children from kindergartens for repetitive testing using the Autoacuity Tester in Shenzhen, Guangdong Province, China.

Procedures All children underwent ophthalmic examination including cover test, autorefractometer, slit lamp and fundoscopy. All examinations were conducted in Zhongshan Ophthalmic Center by licensed eye care practitioners (optometrists and ophthalmologists).

Autoacuity Tester, Lea Symbols, TAC and ETDRS tests were performed by different examiners who worked in separate rooms, so that they were masked to the results of other examiners. Tests were performed in random sequence to control for fatigue and learning effects. All the monocular tests were done using occluders. Before testing with the Autoacuity Tester, each child was instructed on how to use the pointer to identify the testing object in the screen. Children were pretested binocularly at 1 m to assess the child's ability to identify the testing object. After completing the pretest, the child completed monocular visual acuity using all of the tests. In both school and preschool children, the best-corrected visual acuity (BCVA) in both eyes was measured. To assess the repeatability of visual acuity tests, retests were carried out in all children approximately 30min after the initial test.

The Autoacuity Tester By age one year, children can find the position of a patterned object[13]. The Autoacuity Tester takes advantage of the early development of this ability, to create a procedure to measure visual acuity. It requires the subject to identify the position of a patterned object on a screen by clicking on the patterned region.

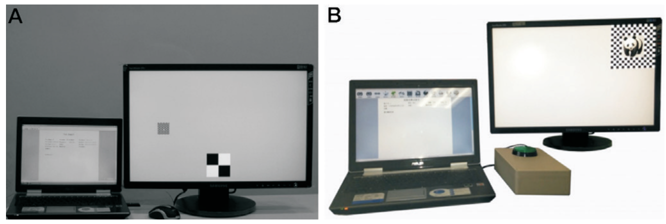

Figure 1 The Autoacuity Tester The routine is run on a laptop attached to a liquid crystal display. A checkerboard as testing object is presented at the display. In mode 1 (A), the mouse-controlled cursor appears on the left side. In mode 2 (B), the panda appears on the checkerboard. After child finishes the test, a test report is presented on the screen of the laptop computer, including subject information and statistics related to reaction to each testing level, measured visual acuity and test time.

The Autoacuity Tester uses a computer to generate checkerboards of various spatial frequencies. These checkerboards are presented against a background and serve as visual testing objects (Figure 1). Once the test starts, a checkerboard appears in a random position in the screen at each presentation. It has two modes. Mode 1 was designed for school children: they need to move the cursor over the checkerboard using the mouse, and click on it when the position of the checkerboard is identified. Mode 2 was designed for preschool children: they need to push the button when the moving panda jumps into the checkerboard. The response is recorded into computer and analyzed automatically.

The testing procedures using a staircase algorithm are summarized as following: 1) A large checkerboard (comparable to 20/200 in Snellen or 1.0 logMAR) consisting of four squares appears, indicating the start of test. 2) The checkerboard of the same spatial frequency appears three times in random positions. A level is considered "pass" if 3/3 or 2/3 checkerboards are identified, and "fail" if two or more checkerboards in a level are missed. 3) If performance is at a pass level in a given test, testing continues to a level with a smaller visual angle ($VA_{n+1}=1/2VA_n$). 4) If the performance is a "fail", testing continues to a level with bigger visual angle [$VA_{n+1}=(VA_n+VA_{n-1})/2.5$]. Testing continues, repeating either step 3 or step 4. 6) Testing stops when the next level represents a visual angle smaller than one of the previous failed steps (*i.e.*, $VA_{n+1}<VA$ "smallest failed").

Testing results, including visual acuity and testing time, are displayed in the screen and stored in the database for statistical analysis. The acuity is calculated as the highest spatial frequency the subject identifies.

The pattern is randomly displayed on the screen in one of 5 positions (center, upper left, lower left, upper right, and lower right). The size of the checkerboard remains unchanged during the test. In our study, it was set to around 1 cycle per degree (comparable to 20/1200 in Snellen or 1.8 logMAR) at 4.2 m distance. Also, a wireless mouse is used for testing. The cursor's spatial frequency is low, which is 3 cycles per degree (comparable to 20/400 in Snellen or 1.3 logMAR), to ensure its visibility. In our study, the routine was run on a laptop (AsusZ99D) attached to a 24-inch liquid crystal display (Samsung245T, luminance: 400 cd/m^2, contrast: 100%, resolution 1920×1200 pixels). Room illumination was 85 cd/m^2. The testing distance was 4.2 m with an available vision range of 20/200 (1.0 logMAR) to 20/10 (-0.3 logMAR).

Other Visual Acuity Tests School children were tested with Tumbling E ETDRS, while preschool children were tested with Lea Symbols and TAC. The Tumbling E ETDRS chart was placed in an illuminated cabinet (background luminance 350 cd/m^2; letter luminance 20 cd/m^2) at a test distance of 4 m with an available vision range of 20/200 (1.0 logMAR) to 20/10 (-0.3 logMAR). A letter-by-letter procedure was used in scoring. The TAC was performed at 55 cm, with the cards presented from lower to higher spatial frequencies. The Lea Symbols was tested at 3 m. Visual acuity was recorded as the last line on which at least 3 of the 5 symbols are identified correctly. Room illumination for these visual acuity tests was 85 cd/m^2.

Sensitivity/Specificity Analysis In order to calculate the specificity for the three tests, we enrolled children diagnosed with amblyopia to increase proportion with amblyopia. We randomly selected 51 children from the 241 preschool children together with the 49 children who were diagnosed with amblyopia and enrolled from Zhongshan Ophthalmic Center to form a group.

We used sensitivity/specificity and receiver operating characteristic (ROC) to evaluate the ability of the visual acuity tests to detect vision problems. ROC curve plots sensitivity/specificity pairs corresponding to a particular decision threshold.

The cut points for failing a visual screening test were based on vision screening recommendations provided by the vision screening committee of AAPOS (http://www.aapos.org/terms/conditions/131): aged 36-47mo, visual acuity of 20/50 (0.4 logMAR); aged 48-59mo, visual acuity of 20/40 (0.3 logMAR); aged 5y or above, visual acuity of 20/32 (0.2 logMAR); or more than 2 lines in interocular difference in visual acuity. Criteria for diagnosing amblyopia[14]: 1) unilateral amblyopia: interocular difference of BCVA more than 2 lines; 2) bilateral amblyopia: aged under 4y, BCVA under 20/50 (0.4 logMAR) in either eye; aged above 4y, BCVA under 20/40 (0.5 logMAR) in either eye.

Table 1 Characteristics of study participants

Characteristics	School age children (*n*=70)	Preschool children (*n*=241)
Age (y)		
Mean±SD	8.9±1.5	5.8±0.4
Range	7-12	4-6
Male, *n* (%)	43 (61.4)	130 (53.9)
Amblyopia, *n* (%)	10 (14.3)	5 (2.1)

A licensed ophthalmologist in Zhongshan Ophthalmic Center examined children who failed the visual screening to diagnose any vision problems.

Data Analysis All visual acuity scores were converted into logMAR for statistical analysis. The analyses of agreement and repeatability we used the acuity data from right eyes in the first test. Bland-Altman plots, and limits of agreement [LOA; *i.e.*, 95% confidence interval (CI) for the difference between the two methods] were used to determine the validity of the Autoacuity Tester as compared with the other visual acuity tests. To determine the test-retest repeatability of each test, the paired *t*-test, the coefficients of repeatability (COR; which represents 1.96 times the standard deviation for the difference) and the Bland-Altman plots were used to compare the results between test and retest. A one-way analysis of variance (ANOVA) was used to compare the testing times among visual acuity tests. We performed these analyses for school age and preschool age children separately, because they were tested using different visual acuity tests. All statistical analyses were performed in SAS 8.0 and Medcalc 12.7.

RESULTS

Characteristics of the Study Subjects As shown in Table 1, among 311 participants, 241 were preschool children with mean age of 5.8±0.4y (range: 4 to 6y), and 70 children were school age with mean age of 8.9±1.5y (range 7 to 12y). More than half (55.6%) of children were male, and 5% had amblyopia. All children finished visual acuity tests successfully.

School Children

Agreement between Autoacuity Tester and ETDRS The mean visual acuities were 0.36±0.18 logMAR for the Autoacuity Tester and 0.33±0.20 logMAR for the ETDRS test. The mean difference was 0.03 logMAR with 95% LOA (-0.24, 0.19) logMAR. Bland-Altman plot suggests that the difference did not vary with the level of visual acuity, indicating consistency between two tests (Figure 2).

Test-retest repeatability All 70 school children were retested with the Autoacuity Tester and ETDRS. The mean visual acuity in initial test and retest along with the mean difference was concluded in Table 2. The COR was 0.20 logMAR for Autoacuity Tester (Figure 3A) and 0.18 logMAR for the ETDRS test (Figure 3B).

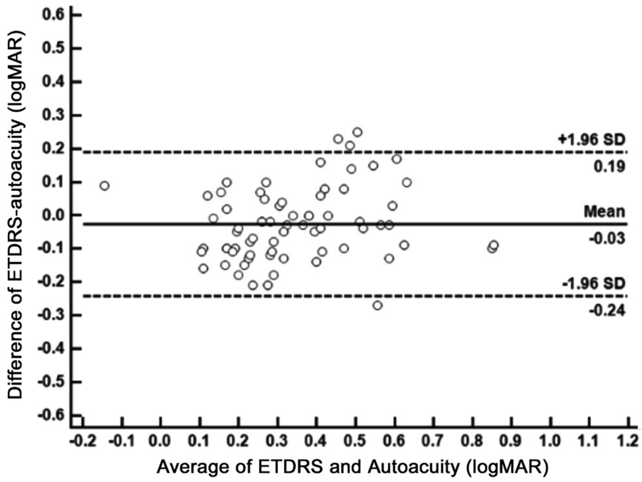

Figure 2 Agreement between ETDRS and Autoacuity Tester in school age children Bland-Altman plot, difference (ETDRS-Autoacuity Tester) against mean, comparing ETDRS with Autoacuity Tester for right eyes (*n*=70) for school age children. 95% LOA for visual acuity between the two tests was within 0.22 logMAR, and the difference did not vary with the level of visual acuity.

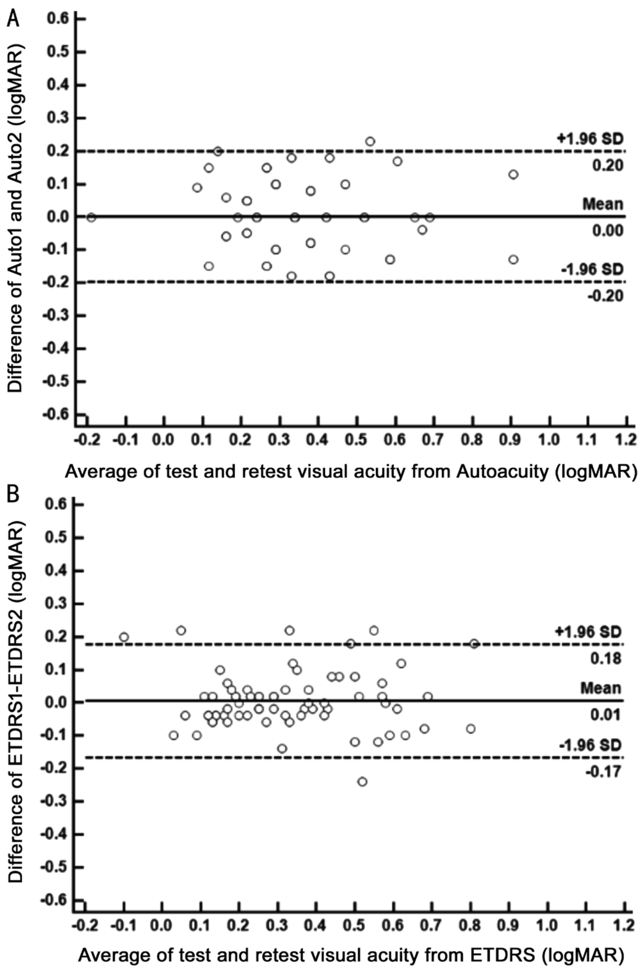

Figure 3 Test-retest repeatability in school age children Bland-Altman plot, difference (test-retest) against mean, comparing test and retest for both tests for right eyes of school age children (*n*=70). The 95% LOA for visual acuity from Autoacuity Tester was (-0.20, 0.20) logMAR (A), and was (-0.17, 0.18) logMAR using ETDRS (B).

Table 2 Test-retest repeatability mean±SD

Visual acuity	School age children (*n*=70)		Preschool children (*n*=241)	
	Autoacuity Tester	ETDRS	Autoacuity Tester	TAC
Test-1	0.36±0.18	0.33±0.20	0.10±0.09	0.06±0.11
Test-2	0.36±0.19	0.33±0.20	0.09±0.08	0.06±0.12
Difference	0.002±0.10	0.005±0.09	0.02±0.07	0.002±0.10

Table 3 Characteristics of preschool children enrolled from kindergartens in Shenzhen mean±SD

Visual acuity	Age (y)		
	3 (*n*=21)	4 (*n*=91)	5 (*n*=80)
Test-1	0.35±0.16	0.28±0.14	0.26±0.08
Test-2	0.32±0.13	0.28±0.12	0.24±0.09
Difference	0.03±0.19	0.002±0.12	0.02±0.10

Preschool Children

Agreement between Autoacuity Tester, Teller acuity card and Lea Symbols The mean visual acuities were 0.1±0.085 for the Autoacuity Tester, 0.06±0.11 for the TAC and 0.10±0.11 for the Lea Symbols. The mean difference and 95% LOA between the Autoacuity Tester and TAC were 0.04 (-0.14, 0.21) logMAR, (Figure 4A). The mean difference and 95% LOA were 0.00 (-0.18, 0.17) logMAR between Autoacuity Tester and the Lea Symbols (Figure 4B), and -0.03 (-0.24, 0.18) between TAC and Lea Symbols (Figure 4C).

Test-retest repeatability All the preschool children were retested using Autoacuity Tester and TAC (Table 2). The COR were 0.13 logMAR for the Autoacuity Tester (Figure 5A) and 0.21 logMAR for the TAC (Figure 5B).

To further evaluated the impact of age, we performed repeatability test in 192 preschool children (aged 3 to 5y), enrolled in kindergartens in Shenzhen, using the Autoacuity Tester. The characteristics of the preschool children were listed in Table 3. The COR were 0.39 logMAR in 3-year-old children (Figure 6A), 0.24 logMAR in 4-year-old children (Figure 6B) and 0.19 logMAR in 5-year-old children (Figure 6C). These data suggesting the repeatability improved with age. For 3-year-old, the Autoacuity Tester was less repeatability with the COR of 0.39 logMAR (more than two lines). Therefore, we proposed that the Autoacuity Tester is suitable for children over 3 years old.

Testing Time The Autoacuity Tester software recorded testing time automatically. For school age children, the mean testing time was 90±57s for initial test and 83±39s for retest (*P*=0.29, paired *t*-test). For preschool children, the mean testing time was 178±33s for initial test, and 164±28s for the retest (*P*<0.001, paired *t*-test). We also recorded the testing time for TAC and Lea Symbols using a stopwatch. For TAC, the mean testing time was 158±37s for initial test, and 131±23s for the retest. The mean testing time for Lea Symbols was 144±63s.

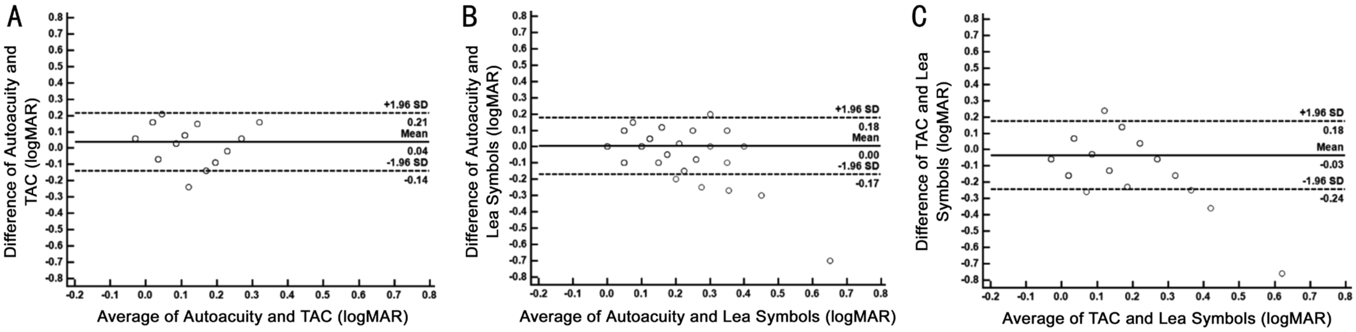

Figure 4 Agreement between TAC, Lea Symbols and Autoacuity Tester in preschool children Bland-Altman plot, difference (TAC-Autoacuity Tester) against mean, comparing TAC with Autoacuity Tester for right eyes (n=241) for preschool children. The 95% LOA for visual acuity between the two tests differed within 0.18 logMAR (A). Comparing Lea Symbols with Autoacuity Tester, 95% LOA for visual acuity between the two tests differed within 0.18 logMAR (B). Comparing TAC with Lea Symbols, 95% LOA for visual acuity between the two tests differed within 0.21 logMAR (C).

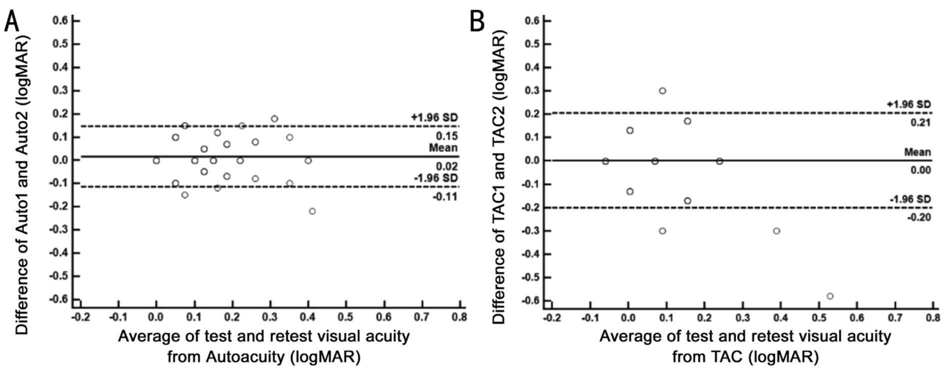

Figure 5 Test-retest repeatability in preschool children Bland-Altman plot, difference (test-retest) against mean, comparing test and retest for right eyes of preschool children (n=241 for Autoacuity Tester, n=241 for TAC). The 95% LOA of visual acuity from Autoacuity Tester was (-0.11, 0.15) logMAR (A), and was (-0.20, 0.21) logMAR using TAC (B).

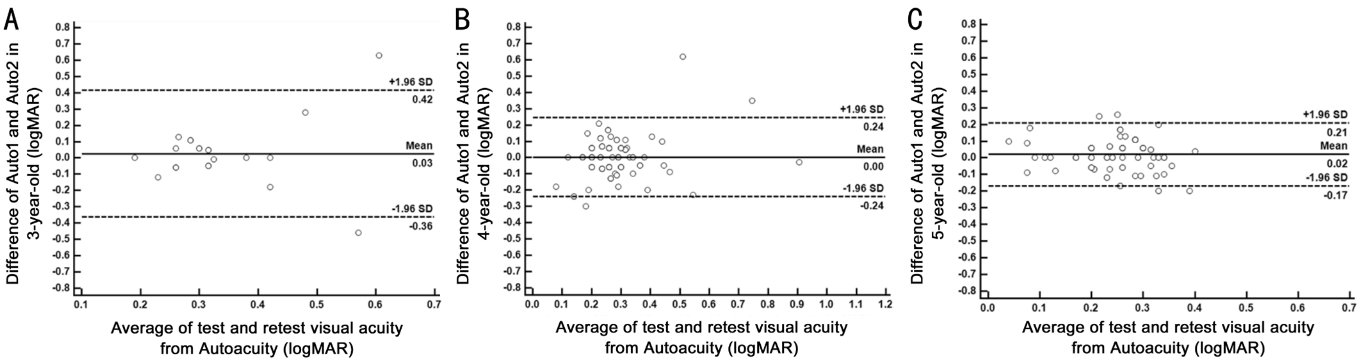

Figure 6 The impact of age on the Autoacuity Tester Bland-Altman plot, difference (test-retest) against mean, comparing test and retest for right eyes of 3-year-old, 4-year-old and 5-year-old children using the Autoacuity Tester. The 95% LOA of visual acuity was (-0.36, 0.42) logMAR in 3-year-old children (A), (-0.24, 0.24) logMAR in 4-year-old children (B) and (-0.17,0.21) logMAR in 5-year-old children (C).

Lea Symbols had the shortest testing time of the initial test, the second was TAC, the third was the Autoacuity Tester (P<0.001, ANOVA).

Sensitivity and Specificity for Detecting Amblyopia Using the screening failure criteria, the Autoacuity Tester had sensitivity of 88%, and specificity of 92% for detecting amblyopia (Table 4), which are higher than TAC in sensitivity (72%, P=0.04). Lea Symbols had 92% sensitivity and 90% specificity. The ROC curve (Figure 7) provided an overview of the trade-off between sensitivity and specificity as the cut point

Table 4 Sensitivity of Autoacuity Tester, TAC and Lea Symbols

Visual acuity test (n=100)	Sensitivity	Specificity
Autoacuity Tester (95%CI)	0.88 (0.75, 0.95)	0.92 (0.80, 0.97)
TAC (95%CI)	0.72 (0.57, 0.83)	0.90 (0.77, 0.96)
Lea Symbols (95%CI)	0.92 (0.80, 0.97)	0.90 (0.77, 0.96)

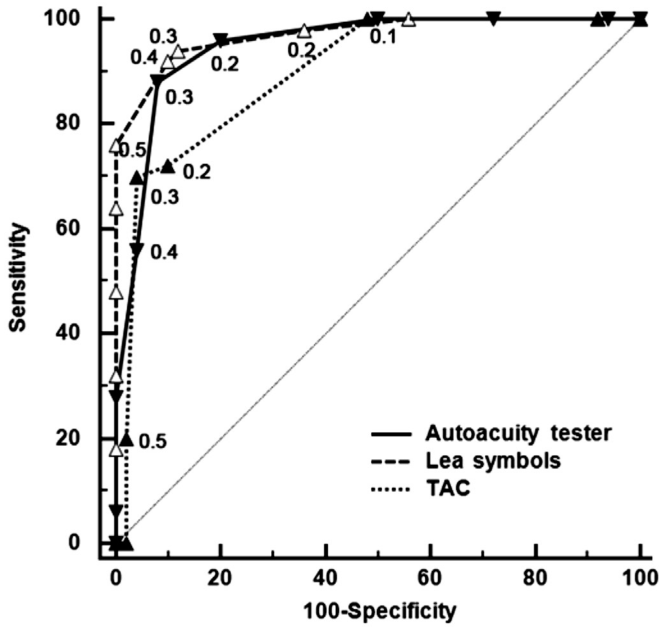

Figure 7 The ROC curves for Autoacuity Tester, Lea Symbols and TAC The ROC curves provided an overview of the trade-off between sensitivity and specificity. The ROC curves for Autoacuity Tester and Lea Symbols were very similar.

value was shifted. We compared the area under the ROC curve (AUC), the AUC of Autoacuity Tester (0.95) is statistically significant (*P*=0.04) larger than the AUC of TAC (0.90). Moreover, the AUC of Autoacuity Tester and Lea Symbols were not significantly different (*P*=0.20).

DISCUSSION

This study describes a new computerized visual acuity testing program, Autoacuity Tester, for vision screening in children. Several investigators[15-16] have attempted to develop computerized visual acuity testing. Computers provide objectivity, automatic recording of results, and are easy to administer. Existing studies were all for recognition acuity assessments, which may be cognitively challenging for preschool children. In contrast to recognition acuity methods, resolution acuity assessments do not require children to recognize symbols or letters. They require them to identify the position of a patterned object, which is developmentally an easier task. Our results demonstrate that the Autoacuity Tester provides a valid and sensitive alternative for assessing visual acuity in children.

The visual acuity charts are currently recommended different for school children and preschool children. Snellen or Tumbling E were recommended for school-aged (aged older than 6y), while Lea symbols or single surrounded HOTV were recommended for preschool aged children (aged 3 to 6y)[1]. The reason for this is that preschool children have difficulty differentiating symbol directions and limited comprehension[17]. Therefore, we designed the cutoff point as age 6y and divided the Autoacuity Tester into two mode. Mode 1 was more accurate because subjects need to move the mouse directly to indicate the position of the object, which is not easy to just guess the position of the target but is relatively difficult for young children to operate. Therefore, mode 2 was designed for preschool children, which only requires the subject to click the button when the object is in the correct position.

We chose the Tumbling E ETDRS chart to verify the validity of our new test in school children. The differences in visual acuity between Autoacuity Tester and the ETDRS test for school age children were similar to test-retest differences from the ETDRS itself, suggesting the validity of the Autoacuity Tester. The agreement limits between the Autoacuity Tester and the ETDRS tests in school age children showed that differences in visual acuities from the Autoacuity Tester and the ETDRS were within 2 lines on the ETDRS chart. The COR of Autoacuity Tester for school children was 0.20 logMAR, comparable to that of ETDRS (0.18 logMAR), indicating two tests have similar test-retest repeatability. Previous research reported similar COR for ETDRS tests[18-20], ranging from 0.13 to 0.20 logMAR. The COR of Autoacuity Tester was comparable to those using computerized methods. Using an automated Landolt C test, Ruamviboonsuk *et al*[18] reported that 95% of retests differed within ±0.20 logMAR in 107 participants (age: 31.6±12.3y). In a study of 112 children (10.2±2.82y), Aslam *et al*[20] reported COR of 0.267 logMAR for a new computer tablet-based method for automated testing of visual acuity.

We used TAC and Lea Symbols to verify the validity for Autoacuity Tester in preschool children. Previous studies found grating visual acuity and recognition visual acuity were not being processed in the same neural channels, which might explain why grating visual acuities were better than recognition visual acuities[21]. It is well-established that TAC might underestimates amblyopia[22]. In this study, we assessed another kind of grating acuity by using checkerboards as visual stimulus and make grating visual acuity comparable to recognition visual acuity. Therefore, we used both TAC and Lea Symbols as control.

Child cooperation remains a problem in vision screening. Previous studies demonstrated that the testability of abstract letter or symbol charts, including Lea Symbols, HOTV and Tumbling E charts, ranged from 54% to 98.7% for children aged from 2y to 6y[23-26]. In our study, all subjects completed all the three visual acuity tests successfully. Although it was the first time for children to take the Autoacuity Tester, they did not need to learn repeatedly. The Autoacuity Tester avoids abstract symbol recognition and orientation perception, which are not fully developed in children until 6 years old, and is therefore less demanding in younger children.

For preschool children, 95% of visual acuity differences between Autoacuity Tester and the TAC were within 0.18 logMAR. 95% of visual acuity differences between Autoacuity Tester and the Lea Symbols were within 0.18 logMAR. While the 95% of visual acuity differences between Lea Symbols and the TAC were within 0.21 logMAR, indicating the Autoacuity Tester has a better concordance with the two different tests. COR for Autoacuity Tester was 0.13 logMAR in preschool children, indicating better repeatability compared to the repeatability of TAC (0.21 logMAR).

Testing time is an important factor to consider for vision screening in children, as children cannot maintain their attention to test for a long period of time. Avoiding cumbersome and time-consuming testing procedures will improve the testability and validity of visual acuity test in young children. In a study comparing the Acuity Cards, the Dot Visual Acuity test, the Broken Wheel test and the American Optical pictures in young children, McDonald and Chaudry[27] reported that 3-year-old finished test in 3 to 4min, while 2-year-old finished tests in 4 to 7min. In our study, most subjects finished the Autoacuity Tester, Lea Symbols and TAC within 3min. Although there was a statistical difference among testing times, all three tests took less than three minutes. Therefore, we thought there was no clinically significant among the testing time of these three acuity tests. Lea symbols was suggested as the best practice for vision screening of children aged 3 to 6 years old[7]. The testing time of the Autoacuity Tester is similar to Lea symbols, indicating that its testing time is within an acceptable range.

Sensitivity and specificity are key criteria in determining the validity of a visual acuity test. The sensitivity of the Autoacuity Tester (88%) is comparable to that of other visual acuity tests. According to the Vision in Preschooler Study[28-29], at 90% specificity, the sensitivities of the top four tests for detecting amblyopia ranged from 90% to 77%. Comparison of the performance on the two tests at the specificity level closest to 90% required that the failure criterion be adjusted to be one line smaller for the Autoacuity Tester than for the TAC. Likewise, comparison of the performance between the Autoacuity Tester and Lea Symbols at 90% specificity level required that the failure criterion be adjusted to be one line smaller for the Lea Symbols than for the Autoacuity Tester. However, there was no statistically significant differences between the performances of the two tests. The Autoacuity Tester performed significantly better than the TAC (P<0.05) for detecting amblyopia. We used checkerboards of different spatial frequencies as a visual stimulus, which may be the possible reason for the higher sensitivity of Autoacuity Tester. This pattern was also used in Wright card, which showed a higher sensitivity than TAC[30].

A comparison of testing protocol between Autoacuity Tester and TAC showed that the Autoacuity Tester enjoys several advantages including: 1) better standardization of the testing procedure; 2) contrast, testing distance and temporal windows are all controllable; 3) less subjective bias as the Autoacuity Tester records test results automatically; 4) Autoauity Tester yielded a higher sensitivity.

In conclusion, results of this study show that the Autoacuity Tester provides a valid and highly sensitive alternative for assessing visual acuity in preschool and school age children. This new computerized approach showed by different spatial frequency checkerboard as testing object is less cognitively challenging, adding benefits of standardized, automated testing and recording procedure. The Autoacuity Tester might be a good vision-screening tool among preschool and school children.

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Authors' contributions: Wu MX, Tsau Y, Qin YY, Liu ZZ, Zhu LY designed the experiments. Qin YY, Liu ZZ, Zhu LY, Bao X, Luo FR performed the experiments. Qin YY, Liu ZZ, Zhu LY analyzed the data. Qin YY, Liu ZZ wrote the manuscript. Wu MX, Tsau Y, Liu YZ supervised the project. Wu MX reviewed the paper.

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