

# A near-vision chart for children aged 3–5 years old: new designs and clinical applications

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## Abstract

• **AIM:** To introduce a new near-vision chart for children aged 3–5 years old and its clinical applications.

• **METHODS:** The new near-vision chart which combined the Bailey–Lovie layout with a newly devised set of symmetry symbols was designed based on Weber–Fechner law. It consists of 15 rows of symmetry symbols, corresponding to a visual acuity range from 1.3 to 0.1 logMAR. The optotypes were red against a white background and were specially shaped four basic geometric symbols: circle, square, triangle, and cross, which matched the preschool children's cognitive level. A regular geometric progression of the optotype sizes and distribution was employed to arrange in 15 lines. The progression rate of the optotype size between two lines was 1.2589 and two smaller groups of optotypes ranging from 0.7 to –0.1 logMAR were included for repetitive testing. A near visual acuity was recorded in logMAR or decimal, and the testing distance was 25 cm.

• **RESULTS:** This new near-vision chart with pediatric acuity test optotypes which consists of 4 different symbols (triangle, square, cross, and circle) met the national and international eye chart design guidelines. When performing the near visual acuity assessment in preschoolers (3–5y old). It overcame an inability to recognize the letters of the alphabet and difficulties in designating the direction of black abstract symbols such as the tumbling 'E' or Landolt 'C', which the subjects were prone to lose interest in. Near vision may be recorded in different notations: decimal acuity and logMAR. These two notations can be easily converted

each other in the new near-vision chart. The measurements of this new chart not only showed a significant correlation and a good consistency with the Chinese national standard logarithmic near-vision chart ( $r=0.932$ ,  $P<0.01$ ), but also indicated good test–retest reliability (89% of retest scores were within 0.1 logMAR units of the initial test score) and a high response rate.

• **CONCLUSION:** The results of this study support the validity and reliability of near visual acuity measurements using the new near-vision chart in children aged 3–5y over a wide range of visual acuities, and the new eye chart was especially suitable for the detection of amblyopia risk factors and low vision examination in children (3–5y of age). It can be applied in routine clinical practice.

• **KEYWORDS:** preschool children; Weber-Fechner law; Chinese national standard logarithmic near-vision chart

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## INTRODUCTION

Evidence-based studies indicate vision screening is an efficient and cost-effective method to identify children with visual impairment or eye conditions that are likely to lead to visual impairment [1]. As a part of vision screening, young children are often possible much earlier to test at near than at distance of 3 m. This may be the only way of measuring monocular values, especially for testing young children; moreover, the child is more accustomed in using vision at near than at greater distances. The number of tests at near has grown over the years because the needs in screening and assessment of children vary at different ages and different functional levels, hence introduction of the test at near familiarizes the child with the test situation. In fact, near vision is functionally more important than distance vision in the life of a young child. There are a number of methods used to screen a child's near vision. The method selected is largely dependent on the age of the child and the clinical experience of the examiner. By age 3, pediatric vision screening with acuity measurements is the most widely used method because most children are able to cooperate for subjective visual acuity testing using an eye

chart [2]. For these situations, it is important that an appropriate near-vision chart be selected to improve accuracy and precision of pediatric vision screening for the earlier discovery of pediatric vision disorders and visual acuity must be accurately documented. Historically, although a variety of near acuity testing targets have been developed, the most commonly used are the Snellen letter, tumbling E, logMAR and Jaeger chart which require both a high level of visual perception and the ability to determine directionality, and may not be suitable for children aged 3-5 years old [3]. Recent investigations of children's cognitive development demonstrate that infants often learn to distinguish the outline of a geometrical figure before they begin to discriminate the orientation during visual perception development because asynchrony between visual and cognitive development in early childhood is always present [4]. Generally speaking, infants first learn to tell up from down, then they learn to recognize left from right; finally, they learn to distinguish the front and back, and furthermore it is easier for infants to indicate the directions of up, down, front, back than they do about left and right [5]. Thus it is hard to determine accurately the best possible visual acuity that a child (3-5y of age) can achieve and makes the assessment of change in visual acuity difficult because of unequal steps between lines, uncomparable crowding, inadequate number of large optotypes on a traditional chart, by using a near-vision chart currently used in clinical settings. For these reasons, it is desirable that a new near-vision chart be designed for use in clinical studies and low vision evaluations where accurate and repeatable visual acuity measurements are required. In this study, a new near-vision chart and notations based on Weber-Fechner law are designed for use in preschool children (3-5y of age) to cover the limits of the current near charts, and its primary clinical applications are evaluated.

**SUBJECTS AND METHODS**

The study protocol was approved by the Ethics Committee of the faculty before study commencement. The study followed the tenets of the Declaration of Helsinki. Informed consent was obtained from each subject's parent or guardian.

**Criteria for Visual Acuity Charts** The new near-vision chart which combines the Bailey-Lovie layout with red symmetrical symbols is intended for use with preschool children and illiterate subjects. It consists of four shapes which children of 3-5y first learn to discriminate and require minimal instruction (a circle, a square, a triangle and a cross), in a format that meets the criteria for standardized optotype tables. The order in which the symbols are presented on each line is randomized in compliance with ISO 8596 : 2009 [6]. The stroke width of each optotype is one point perspective and is equal to 1/5 of side-length of a square that is circumscribed around an optotype figure. Near acuity scores may be expressed as decimal, or logMAR. The testing distance is 25 cm. The new near-vision chart

**Table 1 Table of Emendations educued by changing the distance for the new near-vision chart**

Position	Test distance (cm)	Emendation
Foreward	10	-0.4
	12	-0.3
	15	-0.2
	20	-0.1
Original location	25	0
Backward	30	+0.1
	40	+0.2
	50	+0.3
	100	+0.6

conforms to the design principles used in the national standard logarithmic near vision chart, in terms of visual angle, visual record, intersymbol spacing and interline spacing.

**Methods of Visual Acuity Testing** For best results, a near visual acuity measurement device which is based on the principle of ultrasonic distance measurement allows accurate settings of testing distance and artificial light is needed during the near vision testing process. Near vision was measured under two luminance levels: 1) luminance levels of not less than 300 lx is required while direct illumination is used; 2) the recommended chart background luminance should be not less than 200 cd/m<sup>2</sup> while retro-illumination is used. It is desirable that test chart be installed so that the effects of glare and reflections are minimized and the subject be allowed adequate time to light adapt to the test environment prior to the initiation of testing. The measurement of visual acuity in children (3-5 years old) is usually from right to left eye, with each eye tested independently. Visual acuity in each eye is tested as the opposite eye is covered with an eyepatch or eye pad. Take care not to press on the eye itself. When an optometrist holds a pointer near the optotype you want the child to identify and immediately remove the pointer, the child subject is asked to read out loud the outlines of all indicated optotypes, starting with large rows and continuing to smaller rows until the optotypes cannot be reliably recognized anymore. In the new near-vision chart all optotypes on each line have to be identified. A desirable standard test distance is 25 cm, where the logMAR score is read directly. Testing at other distances is accepted, where the true logMAR value is obtained by adding the emendation value which corresponds to a specified test distance in Table 1 from the labeled logMAR value.

**Optometry** If near visual acuity is expressed as a decimal, a line of optotypes is generally considered to have been read correctly when more than half of the optotypes presented have been read correctly on the new chart. The recorded acuity score shall identify the size of the smallest optotype

that can be recognized. For statistical analysis, near acuity scores from the new near-vision chart can be converted into logMAR notation. The logMAR notation allows the near visual acuity level to be expressed in terms of interpolated values. The following formula, which is assigned a value of 0.02 log unit to each optotype identified, was used to transform scores to logMAR values:  $L=1.3-0.02T_c$ , where the capital letter 'L' and 'T<sub>c</sub>' are the convenient form of the logMAR and the total number of optotypes measured correctly, respectively. The conversion between logMAR and decimal notation of the new near-vision chart is shown in Table 2. In performing near vision testing it is of great importance to note at what distance the chart is to be held from the subject. The new near-vision chart was used to screen uncorrected near visual acuity at 25 cm. If an uncorrected near visual acuity in either eye is less than 0.6 at age 3, 0.8 at age 4, 1.0 at age 5 or if there are two or more lines of difference in the uncorrected near acuity between the two eyes, then that might indicate a loss of vision.

**Clinical Trials** A total of 150 subjects which are able to cooperate for visual acuity testing using both the new near-vision chart and the national standard logarithmic near-vision chart were randomly selected from among 240 preschool children (3-5y of age; mean  $4.1 \pm 0.8y$ ), recruited in ophthalmology outpatient service. Visual acuity was measured under the following conditions: 1) illumination for interior lighting, 500 lx; 2) testing distance, 25 cm.

**Statistical Analysis** Data are expressed as mean  $\pm$ SD. Statistical analysis was performed using the SPSS for one-way analysis of variance. Bland-Altman analysis for paired data was performed<sup>[7]</sup>.

**RESULTS**

**Features of the New Chart** As shown in Figure 1, the new near-vision chart used follows Bailey-Lovie design principles<sup>[8]</sup>. It has 15 rows and incorporates five symbols on every row. The near-acuity values range from 0.05 to -1.2 (logMAR grade notion 1.3 to -0.1) at 25 centimeters. Each row is simply a scaled-down version of the row above. The spacing between adjacent borders on each row is equal to the width of a symbol. The progression rate of optotype size between two lines is 1.2589 and distance between lines is equal to the height of the optotypes in the next line down. Two smaller groups for repetitive testing are used to minimize memorization. Different shapes for testing near vision are arranged in a random order. Adjacent optotypes are different in the new near-vision chart. The near acuity score can be recorded as logMAR notation or decimal notation.

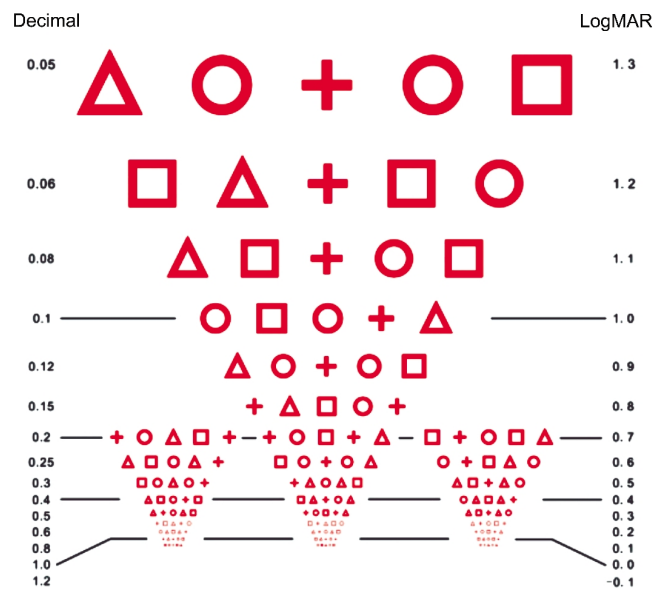
**Statistical Analysis for Assessing Agreement** The mean of near visual acuity which was measured using Chinese standard logarithmic near-vision chart in the right eyes of 150 subjects was  $(0.254 \pm 0.154)$  logMAR, The mean of near visual acuity which was measured using the new near-vision

**Table 2 Conversion table for logMAR notation and decimal notation**

logMAR notation	Decimal notation				
	<sup>1</sup> 5 / 0.000	<sup>1</sup> 4 / 0.020	<sup>1</sup> 3 / 0.040	<sup>1</sup> 2 / 0.060	<sup>1</sup> 1 / 0.080
1.3	0.050	0.048	0.046	0.044	0.042
1.2	0.063	0.060	0.058	0.055	0.052
1.1	0.079	0.076	0.072	0.069	0.066
1.0	0.100	0.095	0.091	0.087	0.083
0.9	0.126	0.120	0.115	0.110	0.105
0.8	0.158	0.151	0.145	0.138	0.132
0.7	0.200	0.191	0.182	0.174	0.166
0.6	0.251	0.240	0.229	0.219	0.209
0.5	0.316	0.302	0.288	0.275	0.263
0.4	0.398	0.380	0.363	0.347	0.331
0.3	0.501	0.479	0.457	0.437	0.419
0.2	0.631	0.603	0.575	0.550	0.525
0.1	0.794	0.759	0.724	0.692	0.661
0.0	1.000	0.955	0.912	0.871	0.832
-0.1	1.259	1.202	1.148	1.096	1.047

<sup>1</sup>Correct number / Add logMAR of Decimal notation.

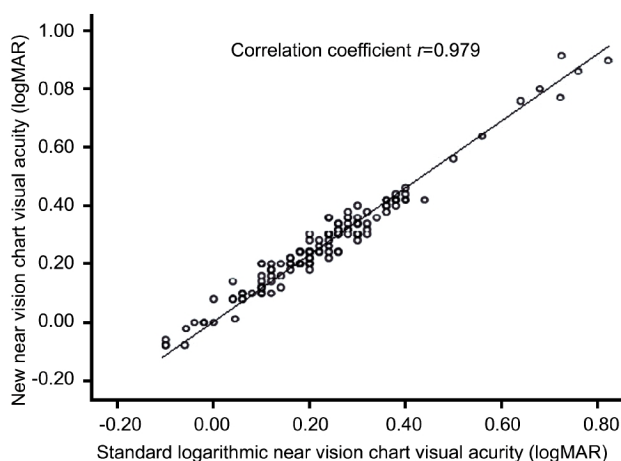
**Standard near vision chart for household children**  
(Test distance 25 cm)



**Figure 1 Near-vision chart for children aged 3–5 years old.**

chart for children aged 3-5 years old in the right eyes of 150 subjects was  $(0.215 \pm 0.143)$  logMAR. For 150 subjects, the difference in the two near acuity measurements was 0.039 logMAR, linear regression equation in population between measurements obtained with standard logarithmic near-vision chart and the new chart was  $y = -0.015 + 0.908x$ , correlation between acuity results obtained with the two charts was high ( $r = 0.979$ ,  $P < 0.01$ ). As is shown in Figure 2, there were no statistically significant differences in near acuity scores obtained between the two charts in clinical trials ( $P > 0.05$ ). The 95% confidence interval for the difference in mean acuity level between the new chart and national standard logarithmic near vision chart was  $(-0.0251 \text{ logMAR}, 0.103 \text{ logMAR})$ .

**Statistical Analysis for Test –retest Reliability** The correlation between the initial and the retest near acuity scores was 0.967, with 97% of retest scores within 0.1 logMAR units of the initial test score. For a change between two acuity scores, the 95% confidence interval was the



**Figure 2** Correlation between the National Standard Logarithmic near vision chart and the new chart for children aged 3–5 years old. Visual acuity data obtained with the new near-vision chart for children aged 3–5 years old visual acuity chart are plotted against equivalent data for the National Standard Logarithmic near vision chart.

difference  $\pm 0.074$  logMAR units (Figure 3).

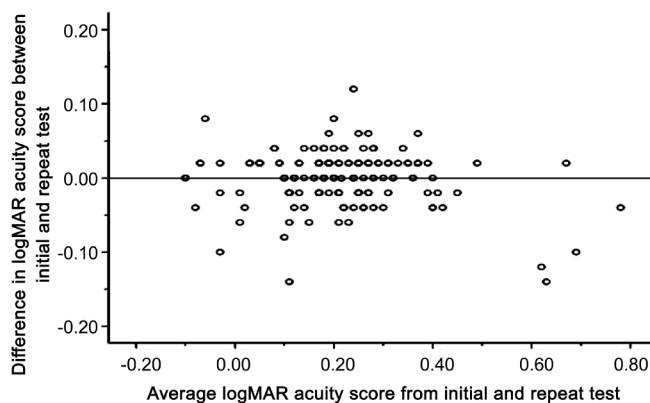
**Comparison of Means of Near Binocular Visual Acuity**

As shown in Table 3, the 150 subjects were divided into three subgroups according to their month age 36-47, 48-59, and 60-71mo. In the three different age groups, the mean of near binocular visual acuity which was measured using national standard logarithmic near-vision chart was  $(0.31 \pm 0.10)$  logMAR,  $(0.24 \pm 0.11)$  logMAR,  $(0.19 \pm 0.18)$  logMAR, respectively; the mean of near binocular visual acuity which was measured using the new near-vision chart for children aged 3-5 years old was  $(0.26 \pm 0.09)$  logMAR,  $(0.20 \pm 0.10)$  logMAR,  $(0.15 \pm 0.17)$  logMAR, respectively. For 150 subjects, the largest difference in the two corresponding means of near binocular visual acuity is 0.05 logMAR in the 36-47mo age group.

**Statistical Analysis for Response Rate** As shown in Table 4, the 240 subjects were divided into three subgroups according to their month age 36-47, 48-59, and 60-71mo. The response rates of the two near-vision charts were improved from 94%, 71% to 96%, 86%, and then to 100%, 95%, respectively. The largest response rate difference was in the 36-47mo age group, where the response rates are 94%, 71%, respectively. We determined the response rate detailed in Figure 4.

**DISCUSSION**

**Theoretical Basis** The new near-vision chart which combines the Bailey-Lovie layout with the red symbol set is designed based on Weber-Fechner law. It may be applied in various clinical settings because the new chart is designed in compliance with GB11533-2011 Chinese national standard for logarithmic visual acuity charts. Besides, it has several potential advantages over the other commonly used near visual acuity chart.



**Figure 3** Bland–Altman plot of test–retest difference versus average test–retest acuity. Data plotted as the test–retest difference versus the mean test–retest acuity suggested that test–retest reliability did not vary with the level of visual acuity. A negative difference indicates that the repeat acuity test score was worse than the initial score<sup>[9]</sup>.

**Table 3** Comparison of the means of near binocular visual acuity of children concerning those of different age groups cooperating in both tests

Age group (mo)	Number	Means of binocular visual acuity (logMAR)	
		I	II
36-47	50	0.31±0.10	0.26±0.09
48-59	50	0.24±0.11	0.20±0.10
60-71	50	0.19±0.18	0.15±0.17

I: National standard logarithmic near-vision chart; II: New near-vision chart for children aged 3-5y old.

Firstly, red optotypes which are displayed on a white background are shaped symmetric symbols that children between the ages of 3 and 5 years first learn to discriminate and require minimal instruction<sup>[10]</sup>. Their advantages include: 1) blur equally at threshold to reduce chances of guessing; 2) well-standardised; 3) left-right symmetry to eliminate left-right confusion; 4) similar in discriminability; 5) evidence-based; 6) culturally neutral<sup>[11]</sup>.

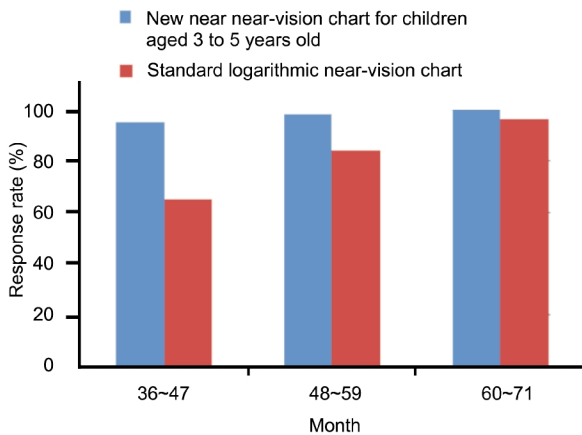
Secondly, by definition, visual acuity refers to the measure of the eyes' ability to distinguish object details and shape at a given distance in the fovea centralis. Because fovea centralis contains only cones that are sensitive to the red light (L cones, 65%), the green light (M cones, 33%), and the blue light (S cones, 2%) without rods, it contributes to providing the best possible vision screening for amblyopic children of 3-5 years old by stimulating cone cells in the foveal region of the children retina using the new eye chart, which consists of set of red optotypes whose hue values range between 630 nm and 650 nm <sup>[12]</sup>. Furthermore, when red optotypes are being arranged in the form of charts, a previous study shows that crowded symbols should be preferred because of higher sensitivity for amblyopia<sup>[13]</sup>.

Thirdly, considering these factors that affect age-matched normal values of visual acuity including cognitive and motor development, an age-stratified diagnostic criteria which is carried out to determine near vision of subject in the new

**Table 4 Comparison of the response rate of children concerning that of different age groups cooperating in both tests**

Age group (mo)	I			II		
	Number of subjects	Number of complete response	Response rate (%)	Number of subjects	Number of complete response	Response rate (%)
36-47	80	57	71	80	75	94
48-59	80	69	86	80	77	96
60-71	80	78	95	80	80	100

I: Standard logarithmic near-vision chart; II: New near-vision chart for children aged 3-5y old.



**Figure 4 Comparison of response rates between the new near-vision chart for children aged 3–5 years old and standard logarithmic near-vision chart in the different age groups.**

near-vision chart will lead to a decrease in the expenses of vision screening and an improvement in the quality of screening<sup>[14]</sup>.

Fourthly, the new chart is designed for near vision testing at 25 cm. Basic principles of physics in optical imaging of the human eye suggest that the minimum distance of distinct vision for a normal person is 25 cm. At this distance, an object can be seen most distinctly without strain. Also, the smallest size the person can read with good speed gives their near acuity at 25 cm<sup>[15]</sup>. In addition, A standard near point distance of 25 cm is typically assumed in the design of optical instruments<sup>[16]</sup>. The average amplitude of accommodation in children between 3 and 5y of age is very high<sup>[17]</sup>. Compared with other common testing distance of near-vision chart, the testing distance of 25 cm may be more suitable for 3-5y preschooler because it is the closest place to near point of human eye during this period.

Finally, this new near-vision chart features multiple groups of optotypes for repetitive testing. This is helpful because multiple groups will lessen the possibility of unwanted memorization while testing. Nonmemorization leads to more accurate near vision records and higher repeatability<sup>[18]</sup>.

**Standardization** The new eye chart may also be referred to as a standardized near vision chart because the visual characteristics of the new chart conforms with Bailey-Lovie design principles for national standard logarithmic near vision chart in terms of optotype, visual angle, increasing rate of optotype size, and notation, which are in compliance

with the requirements defined in GB11533-2011<sup>[19]</sup>. Analysis of the agreements made available shows that there are no statistically significant differences between acuity results obtained with the two charts.

**Analysis of Statistical Results** In the case of children aged 3-5y, the statistical results of this study support the validity and reliability of the new near-vision chart which is used as a primary near acuity measuring tool in children (3-5y) over a wide range of visual acuities. The response rate of the new near-vision chart was higher than that of the standard logarithmic near-vision chart in each age group. Although the response rate of either near-vision chart for any age group increased with age, the mean paired difference in response rate between the two near vision charts would be gradually reduced with age in children (3-5y). The largest difference in response rate was in the 36-47mo age group, where the response rates were 95% and 65%, respectively. This conclusion may be explained by various factors. Younger children are more interested in optotype symbols on the new chart than in capital letter E on the standard logarithmic near vision chart because they preferred to black<sup>[20]</sup>. When reaching visual acuity threshold, children who get the same prompt provided by the inspector are willing to continue to identify the optotypes on the new near-vision chart while they run out of patience with visual acuity testing when the national standard logarithmic near vision chart is adopted. Although there is a significant correlation between near acuity scores of the new eye chart and the national standard logarithmic near vision chart, the new eye chart may overestimate the near acuity score determined by the national logarithmic near vision chart in children (3-5y). This difference may be attributed to the fact that it is easier for the child to identify and name geometric shapes of optotypes on the new eye chart instead of the direction which an optotype faces on the national logarithmic near vision chart. Based on the previous studies, optotypes on the new near-vision chart include more recognition and interpretation clues than that on the national standard logarithmic near vision chart. The capital letter E is seen as a dim C and the direction of capital E can be guessed by estimating which side of the capital letter is lighter when the capital letter E is blurred to the point of being barely perceptible. The optotype symbols on the new near-vision

chart, when blurred, are recognized by the number of corners pointing either out or into the dim ring, a visual task quite different from the recognition of the capital letter E [21]. The relationship between age and near visual acuity is measured numerically and the results show that the means of near binocular visual acuity obtained from using the new eye chart and national standard logarithmic near vision chart increase with age, whereas the mean paired near acuity difference between the two near vision charts will be gradually reduced. This may be in part because there is an expected improvement in recognition acuity with the increasing age.

In summary, this new near-vision chart which is scientifically designed using the Bailey-Lovie format meets the national and international eye chart design guidelines for standardization. It adapts to the limited capacity of young children and illiterates in the selection of clinical optotypes. Moreover, age-stratified diagnostic criteria are proposed for referral. Furthermore, near and distance tests based on the same optotypes reveal differences in visual acuity between distance and near vision and are, thus, an improvement compared with the present situation in many countries where near vision is measured with text tests only [22]. In addition, discrepancies between visual acuity measured using reading material and visual acuity measured using symbol charts may have diagnostic value [23]. For statistical analysis, acuity scores from the new near-vision chart can be converted into logMAR notation. The logMAR notations are equivalent in both distance and near tests and allow direct comparison between the distance and near acuity levels [24]. For these reasons, it may represent an ideal alternative to the standard logarithmic near vision chart for the prediction of amblyopia and screening of low vision in children aged 3–5y, especially under the age of 4y.

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