Normative Distribution of Visual Acuity in 3- to 6-Year-Old Chinese Preschoolers: The Shenzhen Kindergarten Eye Study

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PURPOSE. To document the distribution of uncorrected visual acuity (UCVA) in a defined population of Chinese preschoolers and to discuss its implications for vision referral.

METHODS. Preschoolers aged 3 to 6 years old were recruited from kindergartens in Shenzhen. Uncorrected visual acuity was estimated by using Early Treatment Diabetic Retinopathy Study Tumbling E charts, followed by cycloplegic refraction and ocular examination. The reference population was defined as children without clinically significant ocular abnormalities, with spherical equivalent refraction greater than -0.50 to less than $+2.00$ diopters (D), astigmatism less than 0.75 D, and anisometropia less than 2.00 D. The age-specific UCVA cutoffs were defined by the line where the single-sided 95th percentile of the reference population fell.

RESULTS. A total of 483 of the 1255 children enrolled were considered the reference population. The monocular UCVA cutoff fell on the line of 20/63 at age 3, 20/50 at age 4, and 20/40 at ages 5 and 6. Using no better than these lines as criteria generated referral rates of 9.4% to 27.8% in the general population at different ages, and detected 83.3% and more than 90.0% of those with myopia and amblyopia, respectively. Using uncorrected interocular difference of two or more lines referred 3.6% to 4.3% of the population but identified only approximately 20.0% of those with amblyopia.

CONCLUSIONS. Visual acuity is still developing in preschoolers even at age 6. Most children with myopia and amblyopia can be identified with age-specific, monocular UCVA cutoffs in vision screening using Tumbling E charts, with tolerable false-positive rates. Further studies are needed to define the age at which children without significant refractive errors reach 20/20 UCVA.

Keywords: visual acuity, vision screening, normative distribution

Determination of visual acuity (VA), especially uncorrected VA (UCVA), is generally the first clinical step in identifying abnormal vision.¹ Unfortunately, when screening children, VA criteria for referral of cases of suspected amblyopia and refractive error are not uniform internationally, particularly for children of preschool age.^{2–4} This is, in part, because of the different charts used in different countries, but also because the visual system and cognitive capacities are still developing in children of preschool age, requiring the development of age-specific, and chart-specific cutoffs for referral.

Amblyopia, one of the major causes of vision impairment in children, with a reported prevalence of 1% to 5% in population-based surveys,^{5–9} needs to be treated by the age of 5 to 7 for maximum effectiveness.^{10,11} Diagnosis of amblyopia depends to a significant extent on associations with amblyopia risk factors, which include strabismus and refractive errors, such as more severe myopia, hyperopia, astigmatism, and anisometropia.^{4,12} A valid referral VA criterion for preschool children

therefore ideally needs to detect both amblyopia itself, and amblyopia risk factors, including refractive errors.

Age-specific and chart-specific referral cutoffs can be established only on the basis of normative data, obtained by studying reference populations of children who do not have ocular abnormalities that would lower VA, and who do not have refractive errors that would be expected to reduce VA. Normative data of this kind have been reported in samples of children of African American, Hispanic, and European Caucasian ethnicity, and age-specific and chart-specific VA cutoffs have been proposed.^{13,14}

Detailed normative data on VA are not yet available for Chinese preschool children aged 3 to 6 years. In China, and in many other countries, Tumbling E charts are commonly used for VA screening. We have therefore carried out a cross-sectional study to estimate the normative distribution of UCVA in Chinese children 3 to 6 years old by using Tumbling E charts, exploring appropriate VA cutoffs for referral and their

implications for vision screening in Chinese children of preschool age.

METHODS

Study Population

The Shenzhen Kindergarten Eye Study was conducted in 2012, with the aims of investigating VA, refraction, and ocular biometry in children of preschool age, and identifying the risk factors for refractive errors and amblyopia.

The project conformed to the tenets of the Declaration of Helsinki and ethical approval was given by the institutional review board of Zhongshan Ophthalmic Center. Written informed consent was obtained from parents or guardians, after the study purposes and contents were explained in detail in a school seminar for them.

A total of 1255 children aged 3 to 6 years whose parents or guardians provided written consent were recruited of 1764 children from eight participating kindergartens in different administrative regions of Shenzhen, China, with a participation rate of 71.1%. The eight kindergartens were drawn from the first-class public kindergartens from either Shenzhen City or the adjoining Guangdong Province, with high standards of facilities and teaching staff.

Ocular/Physical Examinations

Field examinations were performed from June to July 2012 by a group of optometrists, ophthalmic nurses, and ophthalmologists. Examinations were conducted in each kindergarten during the weekdays while the classes were in session. Data were collected either manually (i.e., VA data) or automatically by the measuring devices (i.e., refraction data by the auto-refractor). A barcode system was used to record participant identity as a unique code, enabling marked reduction in errors in combining data obtained manually and automatically.

Uncorrected visual acuity was tested by a trained ophthalmic nurse, first in the right eye, and then in the left, at 4 m by using a retro-illuminated logMAR chart with Tumbling E optotypes (Precision Vision, La Salle, IL, USA). The standard operating protocol from the Refractive Error Study in Children was followed.¹⁵ In brief, the VA measurements began at a distance of 4 m with the top line (20/200). If the orientation of at least four of the five optotypes was correctly identified, the child was then tested by dropping down to line 4 (20/100). If one or less optotype was missed, the testing resumed at line 7 (20/50), continuing to line 10 (20/25) and finally line 11 (20/20). If at any level the child failed to recognize four of the five optotypes, the line immediately above the failed line was tested, until the child successfully completed a line. If the top line at 4 m was missed, the child was advanced to 1 m with progression down the chart as described above and the VA would be recorded after multiplying the denominator by 4. The lowest line read successfully was assigned as the VA for the eye undergoing testing. This protocol permits a short testing time, enabling children to concentrate better. A training session was held before the VA examinations in which the school teachers taught the children how to cooperate during the testing.

Strabismus was detected and quantified with cover-uncover tests and observation of the corneal reflex at both 0.5 and 4.0 m. After the child fixated on an object with both eyes open, the right eye was covered while the left eye was monitored to detect any correcting movement. A similar procedure was repeated for the left eye. Tropias were categorized as esotropia (outward movement of the fellow eye after the cover is

removed), exotropia (inward movement), or vertical tropia (downward or upward movement). Tropias were distinguished from phorias, which were identified from movement of the covered eye after the cover was removed. The degree of tropia was measured using Hirschberg's method for observation of the corneal light reflex.

Cycloplegia was then induced with 2 drops 1% cyclopentolate, administered 5 minutes apart, with a third drop administered 20 minutes later. Cycloplegia and pupil dilation were evaluated after an additional 15 minutes. Cycloplegia was considered complete if a pupillary light reflex was absent, with pupils dilated to 6 mm or larger. Refraction was performed with a desktop auto-refractor (KR8800; Topcon Corp., Tokyo, Japan). The data on spherical and cylindrical power and axis, and the barcode ID were automatically extracted from the device. Only the children with successful cycloplegia were included in the analysis. Subjective refraction was then assessed monocularly, using the autorefraction values as a starting reference. Lenses of different spherical and cylindrical diopters were inserted into the trial frame and the aided VA was measured at the same time. The principle of maximum plus to maximum VA was followed to determine the endpoint of subjective refraction. The best-corrected VA (BCVA) also was recorded based on the monocular subjective refraction, using the same protocol and VA chart.

The anterior segment, including eyelid, conjunctiva, cornea, iris, and pupil, and the posterior segment, including fundus, optic disc, and macula, were then evaluated by slit lamp examination and indirect ophthalmoscopy, performed by an ophthalmologist. A principal cause of visual impairment for eyes with UCVA less than or equal to 20/40 was assigned by that ophthalmologist.

Definitions

Spherical equivalent refraction was calculated as spherical diopters + 1/2 cylindrical diopters. Interocular difference (IOD) was defined as the absolute difference in VA between the two eyes. Myopia was defined as SER less than or equal to -0.50 D in either eye; hyperopia was defined as SER greater than or equal to +2.00 D in either eye. Astigmatism was defined as a cylindrical refractive error greater than or equal to 0.75 D, and anisometropia was defined as an SER difference greater than or equal to 2.00 D interocularly.

Different definitions of amblyopia were adopted in the current analysis. The American Academy of Ophthalmology (AAO) guidelines define unilateral amblyopia in preschool age children as an IOD of greater than or equal to two lines of BCVA, whereas bilateral amblyopia is defined as BCVA less than 20/50 in either eye at age 3 and BCVA less than 20/40 in either eye at ages 4 to 6.¹² The most recent Chinese Ophthalmology Society (COS) guidelines define amblyopia as decreased BCVA in one or both eyes, or an IOD greater than or equal to two lines, associated with tropia, anisometropia, uncorrected high refractive error, or form deprivation. The COS VA cutoffs were less than logMAR 0.3 BCVA (20/40) in children aged 3 to 5 years and less than logMAR 0.2 BCVA (20/32) in children aged 6 or older.¹⁶

Inclusion/Exclusion Criteria

Children aged 3 to 6 years with successful UCVA testing in both eyes were considered as the general study population. The children with complete cycloplegia and autorefraction in both eyes, and with refractive data not expected to limit VA, defined as spherical equivalent refraction (SER) less than +2.00 diopters (D) and greater than -0.50 D, less than 0.75 D cylinder at any axis, were included in the reference population.

TABLE 1. Demographic and Clinical Characteristics of the General and Reference Population

	The General Population	The Reference Population*
No. of children	1128	483
Age, y	5.0 ± 0.8	5.1 ± 0.9
Sex, female/male	513/615	233/250
SER, D†		
25th percentile (ages 3, 4, 5, 6)	1.00 (1.25, 1.00, 1.00, 0.88)	1.00 (1.25, 1.13, 1.00, 1.00)
Median (ages 3, 4, 5, 6)	1.38 (1.50, 1.50, 1.25, 1.25)	1.25 (1.38, 1.38, 1.25, 1.25)
75th percentile (ages 3, 4, 5, 6)	1.75 (1.75, 1.75, 1.75, 1.50)	1.50 (1.50, 1.63, 1.50, 1.38)

Data presented of the right eyes only, and with mean ± SD if not indicated otherwise.

* The reference population is defined as children without visually significant ocular abnormality or clinically significant refractive error, determined as SER between −0.50 and +2.00 D, cylindrical power < 0.75 D, interocular diopter difference < 2.00 D.

† Data presented with median and 25th and 75th percentiles.

Children with 2.00 D or more interocular SER difference were excluded, as were children with confirmed strabismus, nystagmus, visual axis occlusion, or other anterior segment or fundus abnormalities capable of causing visual impairment. Because of the stringent criteria used in defining the reference group, children not included in this group were not necessarily abnormal in terms of their refractive errors.

Statistical Analysis

Uncorrected visual acuity and BCVA measurements were recorded as categorical outcomes of logMAR VA or IOD. The distribution of UCVA in the reference population, also displayed as proportions of children achieving particular levels of VA or IOD, was calculated. Next, the age-specific proportions of children who would have been referred using different referral criteria were estimated in the reference group, as well as in all the children in this study cohort. Finally, the referred population was assessed for potential causes contributing to the decreased vision, such as refractive error and amblyopia. All analyses were performed by using Stata Statistical Software (Stata 12.0; Stata Corp., College Station, TX, USA) and a 0.05 significance level.

RESULTS

Study Population

The study consisted of a total of 1255 children, among which UCVA test was successfully performed in 1128 children (89.9%). A total of 483 (42.8%) children were considered as the reference population, based on the criteria outlined in the methods. Boys constituted 51.7% of the reference population, with age-specific percentages ranging from 56.9% in 3-year-olds to 47.9% in 6-year-olds ($P > 0.05$). The average age of the general population was 5.0 ± 0.8 years, with no statistically significant sex difference ($P = 0.554$), whereas the average age of the reference population was 5.1 ± 0.9 years, with girls on average 2 months older than boys ($P = 0.037$). The general demographic characteristics of the populations are shown in Table 1.

Vision and Ocular Examinations

Among the 1128 children with successful UCVA measurement, pupil dilation of at least 6 mm and no light reflex were achieved in 1073 (95.1%) in the right eye. No light reflex without full pupil dilation was achieved in 49 (4.3%), and the light reflex persisted in the remaining 4 (0.4%). In the left eyes, the respective numbers were 1076 (95.4%), 45 (4.0%), and 4 (0.4%). For the analysis with the reference population, the eyes

with no observable light reflex with pupil dilation of at least 6 mm were considered to be successfully cyclopleged and included in the study.

The distribution of SER by age is shown in Table 1. A general descending trend was observed, with the older the age, the less positive the SER. However, the difference in median refraction between the oldest and youngest age group was only 0.05 D. More positive SER values were observed in the general population than in the reference population, indicating that hyperopia was common in the general population of children.

The distributions of UCVA by age are presented in Figure 1. The change of percentages of each category of UCVA, indicated with the corresponding Snellen VA line, is shown. Uncorrected visual acuity improved with age; however, even by the age of 6, only 9.6% of the reference population reached 20/20 vision. Most measured monocular VAs fell in the categories of 20/40 and 20/32 at the age of 3, and shifted to 20/25 and 20/32 by the age of 6. The single-sided 50th percentile fell in the VA category of 20/40 at the age of 3, 20/32 at the ages of 4 and 5, and 20/25 at the age of 6. The single-sided 95th percentile fell in the VA category of 20/63 at the age of 3, 20/50 at the age of 4, and 20/40 at the ages of 5 and 6.

Uncorrected IOD showed much less variation than UCVA with age and sex (Table 2). In each age group, IOD of two or more lines (≥ 0.2 logMAR) ranged from 3.6% at the age of 3 to 4.3% at the age of 6. Most children showed an IOD of less than

FIGURE 1. Distribution of UCVA in the reference population, defined as children without clinically significant ocular abnormalities, and with SER > −0.50 to < +2.00 D, <0.75 D astigmatism, and <2.00 D anisometropia. The categories with *black-lined frames* are those that the 95th percentile cutoff line goes through.

TABLE 2. Distribution of VA IOD in the Reference Population

		VA IOD, Lines and logMAR Equivalent			
	<i>n</i>	0, 0.0	1, 0.1	2, 0.2	>2, >0.2
Age, y					
3	51	32 (62.8)	16 (31.4)	3 (5.9)	0 (0.0)
4	185	122 (66.0)	58 (31.4)	5 (2.7)	0 (0.0)
5	153	114 (74.5)	37 (24.2)	1 (0.7)	1 (0.7)
6	94	65 (69.2)	25 (26.6)	2 (2.1)	2 (2.1)
Sex					
Male	250	170 (68.0)	72 (28.8)	6 (2.4)	2 (0.8)
Female	233	163 (70.0)	64 (27.5)	5 (2.1)	1 (0.4)
Total	483	333 (68.9)	136 (28.2)	11 (2.3)	3 (0.6)

Data presented in the form of *n* (%); The reference population is defined as children without visually significant ocular abnormality or clinically significant refractive error, determined as SER between −0.50 and +2.00 D, cylindrical power < 0.75 D, and anisometropia < 2.00 D.

two lines at all ages, without significant sex differences ($P = 0.52$).

Referral Criteria

The absolute numbers and proportions of children being referred using different criteria in the reference population ($n = 483$) and the general population ($n = 1128$) are summarized in Table 3. Using the age-specific 95th percentile UCVA cutoffs from the reference population (defined as UCVA $\leq 20/63$ at

age 3, $\leq 20/50$ at age 4, and $\leq 20/40$ at ages 5 and 6) would generate referral rates of 9.4% for children at age 3, 26.2% at age 4, 27.8% at age 5, and 18.6% at age 6 in the general population. These criteria detected 0 of 0 cases of myopia and 2 of 30 cases of hyperopia at age 3, 5 of 6 cases of myopia and 32 of 118 cases of hyperopia at age 4, 5 of 5 cases of myopia and 19 of 67 cases of hyperopia at age 5, and 5 of 7 cases of myopia and 8 of 32 cases of hyperopia at age 6 (Table 4). Among all the referral cases, a total of 75 cases were regarded as without clinically significant refractive error, leading to a false-positive rate of 28.5%.

The effectiveness in terms of sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) in referral for amblyopia using the current VA cutoffs are shown in Table 5, based on the AAO and COS diagnostic criteria. The AAO criteria generally identified more amblyopia cases than the COS guidelines, most prominently diagnoses of bilateral amblyopia at age 4. A total of 92.5% (37/40) and 95.2% (20/21) of cases with amblyopia were detected using the AAO and COS definitions, respectively. False-positive rates were high, ranging from 75.4% to 96.6% at all ages with the AAO definition, and from 84.6% to 97.8% with the COS definition. Also inferred from Table 5 is the age-specific prevalence of unilateral and bilateral amblyopia. The former was relatively low and stable: 0.7% (1/139) at age 3, 1.3% (6/481) at age 4, 0.3% (1/320) at age 5, and 0.5% (1/187) at age 6. The latter, however, was relatively high and decreased with age, dropping from 5.6% (27/481) at age 4 to 0.6% (2/320) at age 5 and 0.5% (1/188) at age 6.

Criteria based on IOD, on the other hand, provide a more stable referral rate than VA. The proportions of children being

TABLE 3. Proportions of Children Referred With Different VA/IOD Criteria in the Reference and General Populations

VA/IOD Referral Criteria	The Reference Population*	The General Population
Total no. of children	483	1128
Age 3 no. of children	51	139
Monocular UCVA < 20/63†	1 (2.0)	6 (4.3)
Monocular UCVA < 20/50‡	5 (9.8)	13 (9.4)
UCVA < 20/50, both eyes	3 (5.9)	6 (4.3)
IOD > 1 line	3 (5.9)	5 (3.6)
UCVA < 20/50, 1 eye, and IOD > 1 line	1 (2.0)	3 (2.2)
Age 4 no. of children	185	481
Monocular UCVA < 20/50†	7 (3.8)	37 (7.7)
Monocular UCVA < 20/40‡	35 (18.9)	126 (26.2)
UCVA < 20/40, both eyes	18 (9.7)	73 (15.2)
IOD > 1 line	5 (2.7)	18 (3.7)
UCVA < 20/40, 1 eye, and IOD > 1 line	2 (1.1)	12 (2.5)
Age 5 no. of children	153	320
Monocular UCVA < 20/40†	3 (2.0)	30 (9.4)
Monocular UCVA < 20/32‡	20 (13.1)	89 (27.8)
UCVA < 20/32, both eyes	6 (3.9)	42 (13.1)
IOD > 1 line	2 (1.3)	13 (4.1)
UCVA < 20/32, 1 eye, and IOD > 1 line	2 (1.3)	12 (3.8)
Age 6 no. of children	94	188
Monocular UCVA < 20/40†	4 (4.3)	15 (8.0)
Monocular UCVA < 20/32‡	9 (9.6)	35 (18.6)
UCVA < 20/25, both eyes	3 (3.2)	15 (8.0)
IOD > 1 line	4 (4.3)	8 (4.3)
UCVA < 20/25, 1 eye, and IOD > 1 line	2 (2.1)	6 (3.2)

Data presented in the form of *n* (%) or *n*.

* The reference population is defined as children without visually significant ocular abnormality or clinically significant refractive error, determined as SER between −0.50 and +2.00 D, cylindrical power < 0.75 D, interocular diopter difference < 2.00 D.

† VA cutoff is determined as less than the line immediately above the VA category in which the 95th percentile of the reference population fell.

‡ VA cutoff is determined as less than the line of the VA category in which the 95th percentile of the reference population fell.

TABLE 4. Effectiveness in Referral for Refractive Errors Using the 95th Percentile UCVA Cutoff Criteria ($n = 1128$)

Ages	Referral, N^*	False-Positive Cases, n/N (%)†	Myopia, n/N (%)‡	Hyperopia, n/N (%)‡	Astigmatism, n/N (%)‡	Anisometropia, n/N (%)‡
3	13	6/13 (46.2)	0/0 (N/A)	2/30 (6.7)	5/51 (9.8)	0/0 (N/A)
4	126	40/126 (31.7)	5/6 (83.3)	32/118 (27.1)	73/204 (35.8)	1/1 (100.0)
5	89	20/89 (22.5)	5/5 (100.0)	19/67 (28.4)	56/115 (48.7)	0/0 (N/A)
6	35	9/35 (25.7)	5/7 (71.4)	8/32 (25.0)	22/67 (32.8)	0/0 (N/A)

N/A, not applicable, no cases were identified in either the general or the referral population.

* Data presented as N , number of referral cases using the monocular UCVA 95th percentile cutoff.

† Data presented as n/N (%); n as false-positive cases being referred, N as all referral cases. False-positive cases were defined as children without clinically significant refractive errors, including myopia, hyperopia, astigmatism, and anisometropia. One referral case at age 3 and one referral case at age 4 were without sufficient refractive status to determine their refractive status.

‡ Data presented as n/N (%); n as cases with defined refractive errors identified from the referral cases, N as cases with defined refractive errors identified from the general population, n/N is recognized as the referral sensitivity.

referred with IOD of two or more lines were 3.6% at age 3, 3.7% at age 4, 4.1% at age 5, and 4.3% at age 6 in the general population. Combining monocular UCVA with the IOD criteria further restricted the referred population, with little variation among different age groups. However, the effectiveness of detecting amblyopia based on the AAO criteria using the uncorrected IOD alone was 0.0% (0/2) at age 3, 21.2% (7/33) at age 4, 0.0% (0/3) at age 5, and 50.0% (1/2) at age 6, with an overall detection rate of 20.0%, presumably because most of the referral cases had an IOD of less than two lines of difference after correction for refractive errors. Moreover, the effectiveness of detecting unilateral amblyopia using such criteria was 0.0% (0/1) at age 3, 66.7% (4/6) at age 4, 0.0% (0/1) at age 5, and 100.0% (1/1) at age 6, with an overall detection rate of 55.6%.

DISCUSSION

The current findings provide strong evidence that UCVA in preschoolers aged 3 to 6 years improves with age. Even by the age of 6, most children in the reference group did not reach monocular 20/20 vision using the Early Treatment Diabetic Retinopathy (ETDRS) Tumbling E charts and our standard testing protocol. Using the 95th percentile as the basis for defining cutoffs, many children are referred as potential cases of bilateral amblyopia and diagnosed with it, particularly at age 4. But, given the general improvement of VA with age, VA in many of them may improve with natural development, without any need for treatment. Of the refractive errors, these cutoffs were effective only in detecting myopia, which in these age groups is very low in prevalence.

The cutoffs adopted to define the reference population are based generally on clinical understanding and some evidence about the relationship between UCVA and refraction.¹⁴ Slightly different criteria were used to define “clinically significant refractive error” across different studies.^{7,17,18} In this study, we chose to use “conservative” criteria to define the “reference” population. It can be argued that because very young children tend to have more hyperopia,¹⁹ these criteria will exclude a significant group of children with hyperopia greater than 2.00 D with otherwise normal vision. It can similarly be argued that the cutoff for astigmatism also may exclude children with effectively normal vision, as other reports have shown vision in children is not affected until cylindrical power is greater than or equal to 1.50 D.²⁰ However, the main issue in defining a reference population is to ensure that children with VA limited by their refractive status are not included, and hence loosening the current criteria for the reference population would increase the reference sample size, but would not be expected

to alter the distribution of VA, and might increase the risk of including children with refractively limited VA.

This study is, to the best of our knowledge, the first investigation of UCVA normative distribution using ETDRS Tumbling E charts in a group of homogeneous Chinese preschoolers. A study in Taiwan reported VA distribution in preschool children by using Landolt C and Tumbling E charts.²¹ Previously, several similar studies have been conducted in other ethnic groups and potential effects of ethnicity have been proposed. Age-specific distributions of 95th percentile VA thresholds from these studies are plotted in Figure 2.^{13,14,22,23} The HOTV norms study²² and the Multiethnic Pediatric Eye Disease Study (MEPEDS)¹³ both used HOTV single crowded letter charts and adopted a letter-by-letter recording system during VA measurements. The ETDRS norms study²³ conducted both letter-to-letter and line-to-line recording methods. The Landolt C and Tumbling E chart study in Taiwan²¹ used a line-to-line recording system, but only the BCVA was analyzed. The Sydney Pediatric Eye Disease Study compared the Amblyopia Treatment Study HOTV protocol, standardized ETDRS charts, and Teller Acuity Cards at the same time and recorded VA in a line-to-line fashion.¹⁴ The current study performed line-to-line recording using the ETDRS Tumbling E chart,⁸ which is arguably harder for younger children.^{22,24} Although the HOTV test is commonly used in Western countries for young children,^{13,14} the Tumbling E chart is more popular in China, and in many other countries. In our study, approximately 90% of children aged 3 to 6 years were able to perform an ETDRS Tumbling E chart VA assessment, when pretest instruction session by teachers is available. This also has been suggested in another study in children as young as 3 years of age.² In the current study sample, all the children were from first-class kindergartens where teaching facilities and qualities are of an advanced level, which may explain why VA testability using the ETDRS Tumbling E chart was high even in the 3-year-olds. Figure 2 suggests that VA improves similarly with age across several studies, despite the differences in charts used.

Establishing the appropriate monocular UCVA cutoffs for abnormal vision referral in preschoolers is not straightforward, based on the current findings. With the criteria VA set as less than or equal to the line in which the single-sided 95th percentile VA cutoff fell, 9.4% to 27.8% of the general population would be referred, depending on the age groups. A line-to-line testing strategy is usually adopted for VA screening in China, so that VA is assessed categorically instead of continuously. The greater the proportion of the population that falls on the same line as the 95th percentile VA, the higher the referral rates, along with the false-positive rates, will be. For example, in this study, among the 5-year-old children, 90.2% had a monocular UCVA greater than 20/40, whereas 7.8% were

TABLE 5. Effectiveness in Referral for Amblyopia Using the 95th Percentile UCVA Cutoff ($N = 1128$)

Ages	Referral, <i>n</i> / <i>N</i>	Amblyopia, AAO Definition					Amblyopia, COS Definition					
		Sensitivity										
		Unilateral Amblyopia,		Bilateral Amblyopia,		Specificity, <i>n</i> / <i>N</i> (%)	PPV, <i>n</i> / <i>N</i> (%)	NPV, <i>n</i> / <i>N</i> (%)	Sensitivity, <i>n</i> / <i>N</i> (%)	Specificity, <i>n</i> / <i>N</i> (%)	PPV, <i>n</i> / <i>N</i> (%)	NPV, <i>n</i> / <i>N</i> (%)
		<i>n</i> / <i>N</i> (%)	<i>n</i> / <i>N</i> (%)	<i>n</i> / <i>N</i> (%)	<i>n</i> / <i>N</i> (%)							
3	13/139	0/1 (0.0)	1/1 (100.0)	125/137 (91.2)	1/13 (7.7)	125/126 (99.2)	2/2 (100.0)	126/137 (92.0)	2/13 (15.4)	126/126 (100.0)		
4	126/481	4/6 (66.7)	27/27 (100.0)	353/448 (78.8)	31/126 (24.6)	353/355 (99.4)	12/13 (92.3)	354/468 (75.6)	12/126 (9.5)	354/355 (99.7)		
5	89/320	1/1 (100.0)	2/2 (100.0)	231/317 (72.9)	3/89 (3.4)	231/231 (100.0)	2/2 (100.0)	231/318 (72.6)	2/89 (2.3)	231/231 (100.0)		
6	35/188	1/1 (100.0)	1/1 (100.0)	153/186 (82.3)	2/35 (5.7)	153/153 (100.0)	4/4 (100.0)	153/184 (83.2)	4/35 (11.4)	153/153 (100.0)		

in the exact category of 20/40, which makes a total of 98% with UCVA greater than 20/50. When using UCVA of 20/40 or lower as a referral criterion, this criterion will lead to a high false-positive rate, as also suggested by Williamson et al.²⁵ and Chou et al.²⁶ This also can be illustrated by Figure 1, in which greater false-positive rates were associated with wider stacks in which the 95th percentile reference line fell.

With the current cutoff set by the lower 95th percentile limit of UCVA, the referral criteria identify most of the myopia cases ($SER \leq -0.50$ D), but fewer than one-third of hyperopia cases ($SER \geq 2.00$ D) or astigmatism (cylindrical power ≥ 0.75 D). The low sensitivity in detecting hyperopia and astigmatism is probably because many children in the general population with the defined levels of hyperopia or astigmatism have unaffected VA, as other studies have suggested.¹⁴ On the other hand, the overall sensitivity of detecting amblyopia by using the current criteria was approximately 90% with both the AAO and COS definition, whereas age-specific differences with each definition are obvious. These differences in sensitivity originate from the relations between the VA criteria in defining amblyopia and the current VA cutoff for referral. The criteria in AAO guidelines are BCVA lower than 20/50 at age 3, lower than 20/40 at age 4 and older, or an IOD of two or more lines,¹² whereas the COS uses BCVA lower than 20/40 as the criterion in children aged 3 to 5, and BCVA lower than 20/32 as the criterion in children aged 6 and older, with additional amblyopia risk factors.²⁶ The current referral criteria, with UCVA lower than 20/50 at age 3, lower than 20/40 at age 4, and lower than 20/32 at ages 5 and 6, detect most of the amblyopia cases in the general population. The high prevalence of bilateral amblyopia (5.6%, 27/481) at age 4 is largely due to the VA criteria for defining the condition. Although longitudinal data are not available, the lowered prevalence of bilateral amblyopia at ages 5 (0.6%, 2/320) and 6 (0.3%, 1/188) in this population suggests most of the children identified with bilateral amblyopia at age 4 will have increased their VA over 1 year.

There was less variation with age in IOD, with the referral rate at approximately 4% in the general populations, when the criterion is set at IOD of two or more lines across all ages. The greater stability using such a cutoff is in accordance with previous studies,^{13,22} but this referral criterion missed 80% of the cases diagnosed with amblyopia in the general population, including almost half of the cases with unilateral amblyopia. This could be because an IOD criterion largely excludes cases of bilateral amblyopia, although it also should be noted that the diagnosis of bilateral amblyopia may not, at this age, reliably identify children who need treatment. Another possibility is that an IOD criterion for diagnosis of amblyopia is usually based on BCVA rather than UCVA.^{7,12} The combined criterion of the 95th percentile UCVA cutoff and an IOD of two or more lines further restrict the referral but are not effective in detecting amblyopia either.

Limitations of the current study should be taken into consideration. The study sample was drawn from eight kindergartens in Shenzhen City. Although this is not a population-representative statistically derived sample, the preschools were selected to be geographically representative of the population. Given the generally high enrollment rate in preschools (>90%) in urban China, the preschool population is likely to be quite representative of the age cohort. Moreover, the age-specific SER was very similar to that reported by Lan et al.²⁷ (1.50 ± 0.64 vs. 1.42 ± 0.79 D at age 3, 1.43 ± 0.65 vs. 1.44 ± 0.76 D at age 4, 1.36 ± 0.78 vs. 1.41 ± 0.82 D at age 5, and 1.23 ± 0.85 vs. 1.33 ± 0.70 D at age 6), which was based on a population study with a larger sample size. The biometry data of the current study (not shown in the article) were consistent with the data obtained from our Guangzhou

FIGURE 2. Age-specific normative UCVA thresholds from different studies, defined as 95% UCVA cutoffs in the normative populations. Shenzhen Study, current study, ETDRS multiple-line Tumbling E; Guangzhou Studies, 2012, ETDRS multiple-line Tumbling E (Guo X, Ding X, Morgan IG, He M, unpublished data, 2012); MEPEDS, 2009, HOTV crowded single letter¹³; Sydney Pediatric Eye Disease Study, 2014, ETDRS/HOTV logMAR multiple-line¹⁴; HOTV Norms Study, 2008, HOTV crowded single letter²²; ETDRS Norms Study, 2009, ETDRS multiple-line.²³

outdoor activity study, which showed similar axial length (22.63 ± 0.71 vs. 22.39 ± 0.68 mm) at age 6 (He M, Xiang F, Zeng Y, et al., unpublished results, 2012). However, these preschools were drawn from among the first-class preschools in the area, and the high level of teaching and facilities in these eight kindergartens could account for the high testability observed.

Whenever a new referral criterion is proposed, validations of the effectiveness of detection of refractive error and amblyopia among preschoolers should assess its specificity and sensitivity using gold standard diagnosis of the conditions. Using UCVA testing as a screening tool largely aims to identify clinically significant refractive error and amblyopia.²⁸ However, a gold standard for the diagnosis of amblyopia is lacking because no globally accepted standards are available. We therefore evaluated the effectiveness in referral by using two different criteria for diagnosing amblyopia, which share similar false-positive rates and sensitivity, suggesting the similar effectiveness across these diagnostic criteria.

In conclusion, our findings suggest that using UCVA or IOD alone in vision screening and referral in Chinese preschoolers is somewhat pragmatic, although with potential false-positive cases. We suggest that children with UCVA no better than 20/63 by the age of 3, 20/50 by the age of 4, and 20/40 by the ages of 5 and 6 should be considered for further ophthalmic evaluation. There are particularly marked problems with the diagnosis of bilateral amblyopia at these ages, given that many children may fail on VA criteria simply because of developmental and cognitive limitations. In cases of this kind, follow-up at least annually might help to identify improvements in vision and confirm any abnormalities in visual development.

On the other hand, these findings also pose an interesting question of when do children reach full development of vision, as determined by monocular VA measurements reaching 20/20. Answers to this will be looked into in future studies.

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