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Title page

Normative visual acuity in Chinese preschoolers aged 36 to < 48 months as measured with the linear HOTV chart

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Synopsis

The 5th percentile of the normative uncorrected visual acuity distribution in Chinese children aged 36 to < 48 months were 20/40, which could be used as a referral cutoff to detect amblyopia cases.

ABSTRCT

Objectives To document population-based normative data for uncorrected visual acuity (UCVA) in Chinese preschoolers aged 36 to < 48 months without any sight-affecting abnormalities and to evaluate its effectiveness for vision referral.

Methods In a population-based cohort of children in the Yuhuatai Pediatric Eye Disease Study (YPEDS), UCVA was measured by using the linear HOTV chart, followed by other ocular examinations. Reference population was defined as children without ophthalmic abnormalities or refractive error. Normative UCVA was obtained from the reference population. The UCVA referral cutoff was defined as the lowest 5th percentile of the normative distribution of UCVA.

Results The analysis cohort consisted of 1606 Chinese preschoolers aged 36 to < 48 months. Among them, a total of 791 children were included in the reference population. The 5th, 50th, and 95th percentiles of the UCVA distribution in the reference population were 20/40, 20/32, and 20/25, respectively. UCVA improved with increasing age ($p < 0.0001$), but worsen if prematurity was presented ($p = 0.041$). Using the 5th percentile UCVA cutoff from the reference population generated referral rates of 26.9% in the general population, and detected more than 86% of amblyopia cases.

Conclusions We propose that UCVA no better than 20/40 measured by linear HOTV chart should be a referral cutoff for Chinese preschoolers aged 36 to < 48 months. Most amblyopia cases can be identified with this age-specific and chart-specific UCVA cutoff.

Strengths and limitations of this study

- This is a population-based study, comprising 1606 preschoolers aged 36 to < 48 months.
- Normative uncorrected visual acuity was obtained from 791 children without any sight-affecting abnormalities among the population-based cohort.
- The linear HOTV chart, which was recommended when measuring visual acuity in 3- and 4-year-old children, was used in the study.
- Only children with suspected abnormities underwent cycloplegic refraction, which may impact the detection of sight-affecting refractive errors.
- 11.1% children were not testable when doing the HOTV test and were excluded from the analysis.

INTRODUCTION

Accurate and timely determination of visual acuity (VA) is the basis of clinical management of many ocular conditions in children.[1] The American Academy of Pediatrics (AAP) recommended that objective evaluation of VA be initiated by 3 years of age.[2] Unfortunately, because of the different charts used in different countries and the developing visual and cognitive systems, normative VA levels in children of preschool age are not uniform internationally.[3-5] This makes it difficult to accurately set referral criteria for vision screening and to effectively monitor and manage eye conditions, requiring the development of age-specific and chart-specific normative VA.

For ensuring measures accurately reflect what could be expected in healthy eyes, VA norms need to be established on the basis of normative data, obtained by studying reference populations of children who do not have sight-affecting ocular conditions. Normative data of this kind have been reported in the Multi-Ethnic Pediatric Eye Disease Study (MEPEDS),[6] and the Sydney Pediatric Eye Disease Study (SPEDS).[7] The samples of preschool children were African American and Hispanic in MEPEDS, and predominantly European Caucasian in SPEDS. Given that ethnicity and socio-economic status have potential effects on the level of VA measured, population-specific norms still need to be established for Chinese preschoolers.[6, 8-9]

In China, only the Shenzhen Kindergarten Eye Study (SKES) provided population-based normative data for VA in children 3 to 6 years old.[10] However, in SKES, VA was measured by the Early Treatment Diabetic Retinopathy Study (ETDRS) Tumbling E chart, which is commonly used in children aged $5\frac{1}{2}$ years and older but too difficult for younger children to complete.[11] The HOTV or Lea Symbols chart tests were recommended by AAP when measuring VA in 3- and 4-year-old children.[12]

This report aims to provide the population-based normative distribution of monocular uncorrected VA (UCVA) and interocular differences (IOD) in UCVA in Chinese children aged 36 to < 48 months by using the linear HOTV chart, and explore

appropriate UCVA criteria for referral of cases of suspected amblyopia and refractive error. This analysis is part of the Yuhuatai Pediatric Eye Disease Study (YPEDS).

METHODS

Study population

YPEDS is an ongoing prospective population-based vision screening study, with the specific aims of establishing a systematic database on refraction, visual acuity, ocular biometric parameters, ocular position and other ophthalmic measures, exploring the development rule of vision, and estimating the burden of common pediatric ocular disorders of preschool children.[13] All of the children, who resided in Yuhuatai District, were born between September 2011 and August 2012, and were about to enter a kindergarten in Yuhuatai District, were invited to participate in YPEDS and to undergo a further vision examination in addition to a compulsory health examination. The data presented in this paper were obtained from July 2015 to August 2015, when these children were 36 to < 48 months old.

This study was approved by the Ethics Committee of Nanjing Medical University and followed the tenets of the Declaration of Helsinki. Written informed consent was obtained from the parents or legal representatives of all the participating children.

Ocular examinations

A detailed parental interview was conducted, including questions regarding parental education level, monthly family income, employment of parent, history of pregnancy and delivery, parental history of smoking and drinking during pregnancy, and so on. Comprehensive eye examinations included distance VA, ocular alignment and motility, non-cycloplegic refractive error measurement, anterior segment examination, fundus evaluation and ocular biometric parameters.

Monocular distance UCVA measurements were attempted, first in the right eye, and then in the left, at 3 m by using a linear HOTV logMAR chart (GOOD-LITE, USA). A similar, standardized approach to the Amblyopia Treatment Study (ATS) HOTV VA testing protocol was adapted.[14] An initial screening phase determined an approximate threshold acuity, and then was followed by a first threshold determination phase, a reinforcement phase, and a second threshold determination phase. The best VA obtained from each of the two threshold phases was recorded as

the final VA. VA scores were measured in 0.1 logMAR increments from 20/125 to 20/8.

Non-cycloplegic refraction was performed with the table-mounted autorefractor (R-F10, Cannon, Tokyo, Japan), photorefraction (PlusoptiX GmbH, Nuremberg, Germany) and retinoscopy. Cycloplegic refraction was performed in any of the following conditions: (1) spherical equivalent refraction (SER) obtained from any of the non-cycloplegic refraction measurements was ≤ -0.50 D in either eye, ≥ +1.25 D in either eye, or showed a difference ≥ 0.75 D interocularly; (2) cylindrical diopter obtained from any of the non-cycloplegic refraction measurements was ≥ 0.75 D in either eye; (2) UCVA was < 20/40 (logMAR 0.3) in either eye, or ≥ 2-line IOD; (3) abnormal results in the examinations of ocular alignment and motility, anterior segment examination or fundus evaluation were found. Two drops of 1.0% cyclopentolate (Cyclogyl, Alcon, Belgium) were instilled five minutes apart, with a third drop administered 20 minutes later. Cycloplegia was then evaluated after an additional 15 minutes. Cycloplegia was considered complete if a pupillary light reflex was absent. If a light reflex was still detected, another drop of cyclopentolate was administered, and the light reflex was evaluated again after 15 minutes. Cycloplegic refraction was performed with the table-mounted autorefractor (R-F10, Cannon, Tokyo, Japan). Subjective refraction was then assessed monocularly according to the cycloplegic refraction values. The best-corrected VA (BCVA) was recorded based on monocular subjective refraction, using the same protocol and VA chart as the UCVA measurements.

Definitions

The criteria of refractive errors were based on the cycloplegic refraction values: myopia was defined as SER ≤ -0.50 D in either eye; hyperopia was defined as SER ≥ +2.00 D in either eye; astigmatism was defined as a cylindrical refractive error ≥ 0.75 D; anisometropia was defined as an SER difference ≥ 2.00 D interocularly.

To be comparable with SKES, two definitions of amblyopia were also adopted in the present report (Table 1): (1) the American Academy of Ophthalmology (AAO)

amblyopia Preferred Practice Pattern (PPP);[15] (2) the Chinese Ophthalmology Society (COS) guidelines.[16]

Table 1. The two definitions of amblyopia in preschoolers aged 36 to < 48 months*

AAO Definition		COS Definition
Unilateral amblyopia	**Bilateral amblyopia**	**Amblyopia**
BCVA ≥ 2-line IOD	BCVA < 20/50 in either eye	BCVA ≥ 2-line IOD or < 20/40 in either eye

*Amblyopia risk factors should be identified when diagnosing amblyopia.

Inclusion and exclusion criteria

Only Chinese children aged 36 to < 48 months able to complete monocular UCVA testing in both eyes were included in the analysis and considered as the general study population. The reference population was defined as the children without sight-affecting ocular conditions, including myopia, hyperopia, astigmatism, anisometropia, amblyopia, strabismus, nystagmus, visual axis occlusion, or other anterior segment or fundus abnormalities capable of causing visual impairment.

Statistical analysis

UCVA outcomes were recorded continuously as mean logMAR UCVA or mean logMAR IOD in UCVA and dichotomously as the proportion of children achieving a particular level of UCVA or IOD. The UCVA for right and left eyes in the reference population were highly correlated (Pearson's correlation = 0.721, $p < 0.01$), thus right eye UCVA was used to report the distribution of UCVA. The UCVA cutoff for referral was defined as the lowest 5th percentile of the normative distribution of UCVA. Effectiveness in referral for amblyopia or refractive error using the estimated UCVA cutoff was than calculated. Multiple linear regression was used to assess associations of logMAR UCVA with age, gender, and other potential risk factors. All analyses were performed by using SPSS 22.0 (IBM, China) and a 0.05 significance level.

RESULTS

Study population

A total of 2,300 preschoolers were enrolled in this study, and 1,806 participated in the UCVA test (78.5% responses rate), among which 1,606 (88.9%) were testable in both eyes and considered as the general population. According to the definition outlined in the methods, 791 (49.3%) children were classified as the reference population. Table 2 shows the demographic characteristics of the reference and general population. Boys constituted 53.5% of the reference population and 52.5% of the general population. There was no statistically significant sex difference in the mean age of the reference population (P = 0.277) and the general population (P= 0.607).

Table 2. Demographic and UCVA distribution of the reference and general population

	The reference population (n=791)	The general population (N=1606)
Gender, n		
Male	423	843
Female	368	763
Age in months, mean ± SD		
All	41.1 ± 3.4	41.0 ± 3.4
Male	41.2 ± 3.4	41.0 ± 3.4
Female	41.0 ± 3.3	40.9 ± 3.3

UCVA outcomes

Table 3 presents the distributions of UCVA in the reference population. About 60% of the measured monocular UCVAs fell in the category of 20/32. The 5th, 50th, and 95th percentiles fell in the UCVA categories of 20/40, 20/32, and 20/25, respectively.

Table 3. Distribution of UCVA and IOD in the reference population

	n (%)
LogMAR UCVA (Snellen equiv.)	
0.6 (20/80)	1 (0.1)
0.5 (20/63)	2 (0.3)
0.4 (20/50)	6 (0.8)
0.3 (20/40)	106 (13.4)*
0.2 (20/32)	478 (60.4)*
0.1 (20/25)	170 (21.5)*
0 (20/20)	27 (3.4)
-0.1 (20/16)	1 (0.1)
UCVA IOD, lines (LogMAR equiv.)	
0 (0.0)	595 (75.2)
1 (0.1)	181 (22.9)
2 (0.2)	14 (1.8)
3 (0.3)	1 (0.1)

*The 5th, 50th, and 95th percentiles fell in the UCVA categories of 20/40, 20/32, and 20/25, respectively.

Age-specific and gender-specific mean logMAR UCVA levels for the right eye in the reference population are shown in Table 4. A multivariate linear regression model including age and gender showed that UCVA improved with increasing age ($p < 0.0001$), but had no association with gender ($p = 0.892$). Risk factors adjusted for age and adjusted for age and gender for UCVA in the reference population are shown in Table 5. Only prematurity was significantly associated with poorer UCVA after adjustment for age ($p = 0.040$), or adjusted for age and gender ($p = 0.041$).

Table 4. Mean logMAR UCVA and IOD in reference generation, by age and by gender

	n	Mean UCVA (SD)	Mean absolute UCVA IOD (SD)

All	791	0.19 (0.07)	0.03 (0.05)
Age in months			
36 to <42	438	0.19 (0.08)	0.03 (0.05)
42 to <48	353	0.18 (0.07)	0.02 (0.04)
Gender			
Male	423	0.19 (0.08)	0.03 (0.05)
Female	368	0.19 (0.07)	0.02 (0.05)

Table 5. Risk factors adjusted for age and adjusted for age and gender for UCVA in the reference population

Associated factors	Adjusted for age	Adjusted for age and gender		
	p value	β coefficient	r^2	p value
Prematurity <37 weeks	**0.040**	0.082	0.032	**0.041**
Low birth weight <2500 g	0.163	0.054	0.028	0.163
Maternal smoking during pregnancy	0.770	0.012	0.023	0.758
Maternal drinking during pregnancy	0.264	-0.042	0.024	0.270
Parental tertiary education (University or College)	0.755	-0.012	0.024	0.754
Monthly family income	0.685	-0.019	0.016	0.689
Employment of one parent	0.501	-0.028	0.030	0.506
Employment of both parents	0.791	0.011	0.029	0.798

75.2% children in the reference population achieved equal vision in both eyes and only 1.9% had an IOD of two or more lines (≥ 0.2 logMAR) (Table 3). Table 4 shows mean absolute logMAR UCVA IOD in the reference population, by age and by gender. A multivariate linear regression model including age and gender showed that absolute UCVA IOD decreased with increasing age (p = 0.014), but had no association with gender (p = 0.227).

The mean non-absolute logMAR UCVA IOD (right eye minus left eye logMAR VA) in the reference population was 0.0023, with no significantly difference from zero (p = 0.251), indicating no influence of the order in which the eyes were tested on UCVA.

Effectiveness of the UCVA and UCVA IOD referral cutoffs

Using the 5th percentile UCVA cutoff from the reference population (defined as UCVA ≤ 20/40) would generate referral rates of 26.9% (432 cases) in the general population. Table 6 shows the effectiveness in terms of sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) in referral for refractive errors or amblyopia using the current UCVA cutoff. A total of 39.5% (301/762) of cases with any refractive error were detected, with a specificity of 84.5%. For amblyopia using the AAO definition, the sensitivity and specificity were 86.2% (25/29) and 74.2% (1170/1577), respectively, which are similar to the findings when using the COS amblyopia definition (86.7% and 74.2%).

Table 6. Effectiveness in Referral for Refractive Errors or Amblyopia Using the lowest 5th Percentile UCVA Cutoff Criteria

	Sensitivity, n/N (%)	Specificity, n/N (%)	PPV, n/N (%)	NPV, n/N (%)
Refractive Errors				
Myopia	112/319 (35.1)	967/1287 (75.1)	112/432 (25.9)	967/1174 (82.4)
Hyperopia	43/84 (51.2)	1133/1522 (74.4)	43/432 (10.0)	1133/1174 (96.5)
Astigmatism	252/518 (48.6)	908/1088 (83.5)	252/432 (58.3)	908/1174 (77.3)
Anisometropia	26/59 (44.1)	1141/1547 (73.8)	26/432 (6.0)	1141/1174 (97.2)
Amblyopia				
AAO Definition				
Unilateral Amblyopia	11/14 (78.6)	1171/1601 (73.1)	11/432 (2.5)	1171/1174 (99.7)
Bilateral Amblyopia	14/15 (93.3)	1173/1591 (73.7)	14/432 (3.2)	1173/1174 (99.9)
COS Definition	26/30 (86.7)	1170/1576 (74.2)	26/432 (6.0)	1170/1174 (99.7)

When using the UCVA IOD of two or more lines as the criterion, only 4.3% (69 cases) of the general population would be referred. According to the AAO definition, this criterion detected 20.7% (6/29) of cases with any amblyopia, and 28.6% (4/14) of cases with unilateral amblyopia. For amblyopia using the COS definition, 26.7% (8/30) of cases with amblyopia were detected using such criterion.

DISCUSSION

In China, SKES was the only population-based investigation of UCVA normative distribution in Chinese preschoolers before our study.[10] In order to be comparable with SKES and also to ensure that children with sight-affecting ocular conditions were excluded, we used the same stringent definition of the "reference population" as SKES. However, the lowest 5th percentile in our reference population, falling in the UCVA category of 20/40, was two lines better than this found in the 3-year-old reference population in SKES (20/63). In addition, the 50th percentile in our reference population was one line better than this in SKES (20/32 vs. 20/40). Two reasons might contribute to the differences between our study and SKES. First, we measured the UCVA using the HOTV chart, which is recommended and commonly used in Western countries for young children,[6-7, 12] while SKES used the ETDRS Tumbling E chart which is harder for young children.[17-19] Second, smaller sample size of the 3-year-old children (51 cases) in the reference population of SKES might have a significant influence on the results of UCVA normative distribution.

We are unable to compare the mean logMAR UCVA in our study with that in SKES as SKES didn't calculate this. When our mean logMAR UCVA is compared to this obtained from the African American and Hispanic children without sight-affecting abnormalities in MEPEDS, the mean logMAR UCVA in our reference population is very close to this established in the MEPEDS 36- to 47-month-old children using the ATS HOTV (0.19 vs. 0.17 logMAR).[6] If compared to the results obtained from the European Caucasian and Asian children without sight-affecting abnormalities in SPEDS, the mean logMAR UCVA in our reference population is close to one line worse than this tested with the ATS HOTV in SPEDS (0.19 vs. 0.09 logMAR for children aged 36 to <42 months; 0.18 vs. 0.07 for 42 to <48 months), and similar to this tested with the linear ETDRS or HOTV logMAR chart (0.19 vs. 0.22 logMAR for children aged 36 to <42 months; 0.18 vs. 0.16 for 42 to <48 months).[7] However, the significances of such comparisons are not very clear, because that the ATS HOTV VA test is quite different from the linear HOTV logMAR chart that we used, and SPEDS

didn't specify the mean logMAR UCVA when only using linear HOTV logMAR chart.

We found improvement in UCVA with increasing age, as has been reported in several studies despite different charts used.[6-7, 10,18,20] Gender was not associated with UCVA both in our sample and SPEDS, opposite to that reported in MEPEDS.[6-7] As for risk factors of UCVA, prematurity was related with worse UCVA in our reference population, which was consistent with the finding in SPEDS. However, socio economic status (SES) factors, such as the employment status of parents and family income, which were significantly associated with UCVA in MEPEDS and SPEDS, showed no associations with UCVA in our study. In addition, maternal smoking during pregnancy, which was related with slightly better UCVA in SPEDS, had no relationship with UCVA in our study.

As the penalty for missing one amblyopia case is a lifetime disability and treatment exists, the UCVA referral cutoff for amblyopia should target high sensitivity, while the specificity should be high enough not to put immense load on ophthalmologists.[21-22] The sensitivity of detecting amblyopia by using the UCVA referral cutoff in our study (UCVA ≤ 20/40 at age 36 to < 48 months), was as high as 86%, and at the same time, the specificity was high enough (74.2%). On the other hand, this cutoff only identified a total of 39.5% refractive errors, even though the overall specificity was high (84.5%). The sensitivity in detecting myopia was not good in our study (35.1%), lower than hyperopia (51.2), astigmatism (48.6%), and anisometropia (44.1%). In SKES, even though a high sensitivity (83.3%) in detecting myopia was observed in all 3- to 6-year-old preschoolers, it's not available to calculate the sensitivity in detecting myopia in 3-year-old children because of no presence of myopia in this age group. And for all refractive errors in 3-year-old children in SKES, the overall sensitivity was only 8.6%. Therefore, only using the UCVA cutoff as referral criterion might be difficult to detect refractive errors in 3-year-old children, and additional refraction examination might be necessary for vision screening.

The normative distribution of UCVA IOD in our study was consistent with that in SKES, with most children achieving equal vision in both eyes. No effect of gender or testing order on IOD was observed in our study, which was consistent with MEPED. However, we found that absolute UCVA IOD decreased with increasing age of month in our sample, which was not consistent with the findings in 30- to 72-month-old children in MEPED. The reason of this difference might be that, in MEPED, equal vision in both eyes in older children hided the effect of age on UCVA IOD in younger children.

When using UCVA IOD of two or more lines as the criterion, approximately 4% in the general population would be referred in both of SKES and our study. The sensitivity of using this criterion alone for detecting amblyopia, including unilateral amblyopia, was very low in our study, similar to the results in SKES.

To our knowledge, the present study is the first to provide population-based HOTV-specific normative UCVA data in Chinese preschoolers aged 36 to < 48 months without significant refractive error or other ophthalmic abnormalities. However, there are several limitations in the present study. Because that young children are very afraid of using eye drops, which makes cycloplegia difficulty and unacceptable for parents, only children with suspected abnormities underwent cycloplegic refraction in our study. Even though not all children had refraction results under cycloplegia, we adopted stringent criteria to identify children who needed cycloplegic refraction, which could effectively detect sight-affecting refractive errors. 11.1% children were not testable when doing the HOTV test and were excluded from the analysis, which may influence the normative UCVA distribution. However, the testability in our study was at an average level of published reports,[6, 10] and difficulty to increase further in young children.

In conclusion, our study suggests that Chinese preschoolers aged 36 to < 48 months with UCVA no better than 20/40 measured by linear HOTV chart should be referred for further ophthalmic examinations. Most amblyopia cases can be identified with this age-specific and chart-specific UCVA cutoff.

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Contributors Conceived and designed the experiments: HL, HZ, DH and QS. Performed the experiments: HZ, DH, QS, HD, JB, JC, YW, XZ, JW and XL. Analyzed the data: HZ, DH, QS and XC. Contributed reagents/materials/analysis tools: HL, HZ, DH, HD, JB, JC, and XC. Wrote the paper: HL, HZ, DH, QS, XC, HD, JB, JC, YW, XZ, JW and XL.

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Title page

Normative visual acuity in Chinese preschoolers aged 36 to < 48 months as measured with the linear HOTV chart: the Yuhuatai Pediatric Eye Disease Study

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ABSTRCT

Objectives To document population-based normative data for uncorrected visual acuity (UCVA) in Chinese preschoolers aged 36 to < 48 months without any sight-affecting abnormalities and to evaluate its effectiveness for vision referral.

Methods In a population-based cohort of children in the Yuhuatai Pediatric Eye Disease Study (YPEDS), UCVA was measured by using the linear HOTV chart, followed by other ocular examinations. Reference population was defined as children without ophthalmic abnormalities or refractive error. Normative UCVA was obtained from the reference population. The UCVA referral cutoff was defined as the lowest 5th percentile of the normative distribution of UCVA.

Results The analysis cohort consisted of 1606 Chinese preschoolers aged 36 to < 48 months. Among them, a total of 791 children were included in the reference population. The 5th, 50th, and 95th percentiles of the UCVA distribution in the reference population were 20/40, 20/32, and 20/25, respectively. UCVA improved with increasing age ($p < 0.0001$), but worsen if prematurity was presented ($p = 0.041$). Using the 5th percentile UCVA cutoff from the reference population generated referral rates of 26.9% in the general population, and detected more than 86% of amblyopia cases.

Conclusions We propose that UCVA no better than 20/40 measured by linear HOTV chart should be a referral cutoff for Chinese preschoolers aged 36 to < 48 months. Most amblyopia cases can be identified with this age-specific and chart-specific UCVA cutoff.

Strengths and limitations of this study

- This is a population-based study, comprising 1606 preschoolers aged 36 to < 48 months.
- Normative uncorrected visual acuity was obtained from 791 children without any sight-affecting abnormalities among the population-based cohort.
- The linear HOTV chart, which was recommended when measuring visual acuity in 36- and 48-month-old children, was used in the study.
- Only children with suspected abnormities underwent cycloplegic refraction, which may impact the detection of sight-affecting refractive errors.
- 11.1% children were not testable when doing the HOTV test and were excluded from the analysis.

INTRODUCTION

Accurate and timely determination of visual acuity (VA) is the basis of clinical management of many ocular conditions in children.[1] The American Academy of Pediatrics (AAP) recommended that objective evaluation of VA be initiated by 36 months of age.[2] Unfortunately, because of the different charts used in different countries and the developing visual and cognitive systems, normative VA levels in children of preschool age are not uniform internationally.[3-5] This makes it difficult to accurately set referral criteria for vision screening and to effectively monitor and manage eye conditions, requiring the development of age-specific and chart-specific normative VA.

For ensuring measures accurately reflect what could be expected in healthy eyes, VA norms need to be established on the basis of normative data, obtained by studying reference populations of children who do not have sight-affecting ocular conditions. Normative data of this kind have been reported in the Multi-Ethnic Pediatric Eye Disease Study (MEPEDS),[6] and the Sydney Pediatric Eye Disease Study (SPEDS).[7] The samples of preschool children were African American and Hispanic in MEPEDS, and predominantly European Caucasian in SPEDS. Given that ethnicity and socio-economic status have potential effects on the level of VA measured, population-specific norms still need to be established for Chinese preschoolers.[6-9]

In China, only the Shenzhen Kindergarten Eye Study (SKES) provided population-based normative data for VA in children 36 to 72 months old.[10] However, in SKES, VA was measured by the Early Treatment Diabetic Retinopathy Study (ETDRS) Tumbling E chart, which is commonly used in children aged 66 months and older but too difficult for younger children to complete.[11] The HOTV or Lea Symbols chart tests were recommended by AAP when measuring VA in 36- and 48-month-old children.[12]

This report aims to provide the population-based normative distribution of monocular uncorrected VA (UCVA) and interocular differences (IOD) in UCVA in Chinese children aged 36 to < 48 months by using the linear HOTV chart, and explore

appropriate UCVA criteria for referral of cases of suspected amblyopia and refractive error. This analysis is part of the Yuhuatai Pediatric Eye Disease Study (YPEDS).

METHODS

Study population

YPEDS is an ongoing prospective population-based vision screening study, with the specific aims of establishing a systematic database on refraction, visual acuity, ocular biometric parameters, ocular position and other ophthalmic measures, exploring the development role of vision, and estimating the burden of common pediatric ocular disorders of preschool children.[13] All of the children, who resided in Yuhuatai District, were born between September 2011 and August 2012, and were about to enter a kindergarten in Yuhuatai District, were invited to participate in YPEDS and to undergo a further vision examination in addition to a compulsory health examination. The data presented in this paper were obtained from July 2015 to August 2015, when these children were 36 to < 48 months old.

This study was approved by the Ethics Committee of Nanjing Medical University and followed the tenets of the Declaration of Helsinki. Written informed consent was obtained from the parents or legal representatives of all the participating children.

Ocular examinations

A detailed parental interview was conducted, including questions regarding parental education level, monthly family income, employment of parent/s, history of pregnancy and delivery, and parental history of smoking and drinking during pregnancy. Comprehensive eye examinations included distance VA, ocular alignment and motility, non-cycloplegic refractive error measurement, anterior segment examination, fundus evaluation by indirect ophthalmoscopy and ocular biometric parameters.

Monocular distance UCVA measurements were attempted, first in the right eye, and then in the left, at 3 m by using a retroilluminated (ESV1200 Illuminated Cabinet, GOOD-LITE, USA) linear HOTV logMAR chart (600017, GOOD-LITE, USA) with matching letter card. VA scores were measured in 0.1 logMAR increments from 20/100 to 20/16. A similar, standardized approach to the Amblyopia Treatment Study (ATS) HOTV VA testing protocol was adapted:[14]

1) **Screening**

Patch the eye not being tested. Project a 20/100 optotype. If correct, go down a logMAR level and again show a single optotype. Continue through 20/20 with 1 letter per level until an incorrect response.

2) **Phase 1**

Move up 2 letter sizes from the letter size with the incorrect response in screening up to maximum size of 20/100.

- Present 4 new letters (if first 3 new letters are correct, then the fourth does not need to be tested; as soon as 2 letters are missed, testing of a level stops).
- If less than 3 letters are correct, proceed to the next largest size and so on until 3 of 4 are correct. When 3 of 4 are correct, proceed to "reinforcement". If 20/100 is failed, stop testing.
- If 3 letters are correct, repeat on next smallest optotype. Continue to move to smaller optotypes as long as first 3 or 3 of 4 are correct. If 20/16 is passed, test is over. When 2 letters on a level are missed, stop and move to "reinforcement".

3) **Reinforcement**

Move up 3 level from the level missed in phase 1 and show 3 successively smaller single letters. If the patient fails phase 1 at 20/63 or 20/80, show three 20/100 letters but still start phase 2 at the level failed in phase 1. Whether or not all 3 are correct in reinforcement, proceed to phase 2.

4) **Phase 2**

Retest the last level failed in phase 1. Continue the test by the same procedure as described for phase 1, with the exception that if 2 letters are missed, testing stops.

5) **Recording Visual Acuity**

Acuity is the smallest letter size (level) passed in phase 1 or phase 2.

Non-cycloplegic refraction was performed with the table-mounted autorefractor (R-F10, Cannon, Tokyo, Japan), photorefraction (PlusoptiX GmbH, Nuremberg,

Germany) and retinoscopy. Cycloplegic refraction was performed in any of the following conditions: (1) spherical equivalent refraction (SER) obtained from any of the non-cycloplegic refraction measurements was ≤ -0.50 D in either eye, ≥ +1.25 D in either eye, or showed a difference ≥ 0.75 D interocularly; (2) cylindrical diopter obtained from any of the non-cycloplegic refraction measurements was ≥ 0.75 D in either eye; (3) UCVA was < 20/40 (logMAR 0.3) in either eye, or ≥ 2-line IOD; (4) abnormal results in the examinations of ocular alignment and motility, anterior segment examination or fundus evaluation were found. Two drops of 1.0% cyclopentolate (Cyclogyl, Alcon, Belgium) were instilled five minutes apart, with a third drop administered 20 minutes later. Cycloplegia was then evaluated after an additional 15 minutes. Cycloplegia was considered complete if a pupillary light reflex was absent. If a light reflex was still detected, another drop of cyclopentolate was administered, and the light reflex was evaluated again after 15 minutes. Cycloplegic refraction was performed with the table-mounted autorefractor (R-F10, Cannon, Tokyo, Japan). Subjective refraction was then assessed monocularly according to the cycloplegic refraction values. The best-corrected VA (BCVA) was recorded based on monocular subjective refraction, using the same protocol and VA chart as the UCVA measurements.

Definitions

The criteria of refractive errors were based on the cycloplegic refraction values: myopia was defined as SER ≤ -0.50 D in either eye; hyperopia was defined as SER ≥ +2.00 D in either eye; astigmatism was defined as a cylindrical refractive error ≥ 0.75 D; anisometropia was defined as an SER difference ≥ 2.00 D interocularly.

To be comparable with SKES, two definitions of amblyopia were adopted in the present report. Amblyopia risk factors should be identified when diagnosing amblyopia in each of the definitions: (1) the American Academy of Ophthalmology (AAO) amblyopia Preferred Practice Pattern (PPP) guidelines define unilateral amblyopia in preschoolers aged 36 to < 48 months as an IOD of greater than or equal to two lines of BCVA, and bilateral amblyopia as BCVA less than 20/50 in either

eye;[15] (2) the Chinese Ophthalmology Society (COS) guidelines define amblyopia in preschoolers aged 36 to < 48 months as an IOD of greater than or equal to two lines of BCVA or BCVA less than 20/40 in either eye.[16]

Inclusion and exclusion criteria

Only Chinese children aged 36 to < 48 months able to complete monocular UCVA testing in both eyes and without neurological problems were included in the analysis and considered as the general study population. The reference population was defined as the children without sight-affecting ocular conditions, including myopia, hyperopia, astigmatism, anisometropia, amblyopia, strabismus, nystagmus, visual axis occlusion, or other anterior segment or fundus abnormalities capable of causing visual impairment.

Statistical analysis

UCVA outcomes were recorded continuously as mean logMAR UCVA or mean logMAR IOD in UCVA and dichotomously as the proportion of children achieving a particular level of UCVA or IOD. The UCVA for right and left eyes in the reference population were highly correlated (Pearson's correlation = 0.721, $p < 0.01$), thus right eye UCVA was used to report the distribution of UCVA. The UCVA cutoff for referral was defined as the lowest 5th percentile of the normative distribution of UCVA. Effectiveness in referral for amblyopia or refractive error using the estimated UCVA cutoff was then calculated. Multiple linear regression was used to assess associations of logMAR UCVA with age, gender, and other potential risk factors. All analyses were performed by using SPSS 22.0 (IBM, China) and a 0.05 significance level.

RESULTS

Study population

A total of 2,300 preschoolers were enrolled in this study, and 1,806 participated in the UCVA test (78.5% responses rate), among which 1,606 (88.9%) were testable in both eyes and considered as the general population. According to the definition outlined in the methods, 791 (49.3%) children were classified as the reference population. Boys constituted 53.5% of the reference population and 52.5% of the general population. There was no statistically significant sex difference in the mean age of the reference population (P = 0.277) and the general population (P= 0.607).

UCVA outcomes

Table 1 presents the distributions of UCVA in the reference population. About 60% (478 out of 791) of the measured monocular UCVAs fell in the category of 20/32. The 5th, 50th, and 95th percentiles fell in the UCVA categories of 20/40, 20/32, and 20/25, respectively.

Table 1. Distribution of UCVA and IOD in the reference population

	n (%)
LogMAR UCVA (Snellen equiv.)	
0.6 (20/80)	1 (0.1)
0.5 (20/63)	2 (0.3)
0.4 (20/50)	6 (0.8)
0.3 (20/40)	106 (13.4)*
0.2 (20/32)	478 (60.4)*
0.1 (20/25)	170 (21.5)*
0 (20/20)	27 (3.4)
-0.1 (20/16)	1 (0.1)
UCVA IOD, lines (LogMAR equiv.)	
0 (0.0)	595 (75.2)
1 (0.1)	181 (22.9)

2 (0.2)	14 (1.8)
3 (0.3)	1 (0.1)

*The 5th, 50th, and 95th percentiles fell in the UCVA categories of 20/40, 20/32, and 20/25, respectively.

Age-specific and gender-specific mean logMAR UCVA levels for the right eye in the reference population are shown in Table 2. A multivariate linear regression model including age and gender showed that UCVA improved with increasing age ($p < 0.0001$), but had no association with gender ($p = 0.892$). Risk factors adjusted for age and adjusted for age and gender for UCVA in the reference population are shown in Table 3. Only prematurity was significantly associated with poorer UCVA after adjustment for age ($p = 0.040$), or adjusted for age and gender ($p = 0.041$).

Table 2. Mean logMAR UCVA and IOD in reference generation, by age and by gender

	n	Mean UCVA (SD)	Mean absolute UCVA IOD (SD)
All	791	0.19 (0.07)	0.03 (0.05)
Age in months			
36 to <42	438	0.19 (0.08)	0.03 (0.05)
42 to <48	353	0.18 (0.07)	0.02 (0.04)
Gender			
Male	423	0.19 (0.08)	0.03 (0.05)
Female	368	0.19 (0.07)	0.02 (0.05)

75.2% (595 out of 791) children in the reference population achieved equal vision in both eyes and only 1.9% had an IOD of two or more lines (≥ 0.2 logMAR) (Table 1). Table 2 shows mean absolute logMAR UCVA IOD in the reference population, by age and by gender. A multivariate linear regression model including age and gender showed that absolute UCVA IOD decreased with increasing age (p = 0.014), but had no association with gender (p = 0.227).

The mean non-absolute logMAR UCVA IOD (right eye minus left eye logMAR VA) in the reference population was 0.0023, with no significantly difference from zero (p = 0.251), indicating no influence of the order in which the eyes were tested on UCVA.

Table 3. Risk factors adjusted for age and adjusted for age and gender for UCVA in the reference population

Associated factors	Adjusted for age	Adjusted for age and gender		
	p value	β coefficient	r^2	p value
Prematurity <37 weeks	**0.040**	0.082	0.032	**0.041**
Low birth weight <2500 g	0.163	0.054	0.028	0.163
Maternal smoking during pregnancy	0.770	0.012	0.023	0.758
Maternal drinking during pregnancy	0.264	-0.042	0.024	0.270
Parental tertiary education (University or College)	0.755	-0.012	0.024	0.754
Monthly family income	0.685	-0.019	0.016	0.689
Employment of one parent	0.501	-0.028	0.030	0.506
Employment of both parents	0.791	0.011	0.029	0.798

Effectiveness of the UCVA and UCVA IOD referral cutoffs

Using the 5th percentile UCVA cutoff from the reference population (defined as UCVA ≤ 20/40) would generate referral rates of 26.9% (432 cases) in the general population. Table 4 shows the effectiveness in terms of sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) in referral for refractive

errors or amblyopia using the current UCVA cutoff. A total of 39.5% (301/762) of cases with any refractive error were detected, with a specificity of 84.5% (713/844). For amblyopia using the AAO definition, the sensitivity and specificity were 86.2% (25/29) and 74.2% (1170/1577), respectively, which are similar to the findings when using the COS amblyopia definition (86.7% and 74.2%).

Table 4. Effectiveness in Referral for Refractive Errors or Amblyopia Using the lowest 5th Percentile UCVA Cutoff Criteria

	Sensitivity, n/N (%)	Specificity, n/N (%)	PPV, n/N (%)	NPV, n/N (%)
Refractive Errors				
Myopia	112/319 (35.1)	967/1287 (75.1)	112/432 (25.9)	967/1174 (82.4)
Hyperopia	43/84 (51.2)	1133/1522 (74.4)	43/432 (10.0)	1133/1174 (96.5)
Astigmatism	252/518 (48.6)	908/1088 (83.5)	252/432 (58.3)	908/1174 (77.3)
Anisometropia	26/59 (44.1)	1141/1547 (73.8)	26/432 (6.0)	1141/1174 (97.2)
All	301/762 (39.5)	713/844 (84.5)	301/432 (69.7)	713/1174 (60.73)
Amblyopia				
AAO Definition				
Unilateral Amblyopia	11/14 (78.6)	1171/1601 (73.1)	11/432 (2.5)	1171/1174 (99.7)
Bilateral Amblyopia	14/15 (93.3)	1173/1591 (73.7)	14/432 (3.2)	1173/1174 (99.9)
All	25/29 (86.2)	1170/1577 (74.2)	25/432 (5.8)	1170/1174 (99.7)
COS Definition	26/30 (86.7)	1170/1576 (74.2)	26/432 (6.0)	1170/1174 (99.7)

When using the UCVA IOD of two or more lines as the criterion, only 4.3% (69 cases) of the general population would be referred. According to the AAO definition, this criterion detected 20.7% (6/29) of cases with any amblyopia, and 28.6% (4/14) of cases with unilateral amblyopia. For amblyopia using the COS definition, 26.7% (8/30) of cases with amblyopia were detected using such criterion.

DISCUSSION

In China, SKES was the only population-based investigation of UCVA normative distribution in Chinese preschoolers before our study.[10] In order to be comparable with SKES and also to ensure that children with sight-affecting ocular conditions were excluded, we used the same stringent definition of the "reference population" as SKES. However, the lowest 5th percentile in our reference population, falling in the UCVA category of 20/40, was two lines better than this found in the 36-month-old reference population in SKES (20/63). In addition, the 50th percentile in our reference population was one line better than this in SKES (20/32 vs. 20/40). Two reasons might contribute to the differences between our study and SKES. First, we measured the UCVA using the HOTV chart, which is recommended and commonly used in Western countries for young children,[6-7, 12] while SKES used the ETDRS Tumbling E chart which is harder cognitively for the child to understand and thus affect the threshold acuity that can be achieved by the child.[17-19] Second, smaller sample size of the 36-month-old children (51 cases) in the reference population of SKES might have a significant influence on the results of UCVA normative distribution.

We are unable to compare the mean logMAR UCVA in our study with that in SKES as SKES didn't calculate this. When our mean logMAR UCVA is compared to this obtained from the African American and Hispanic children without sight-affecting abnormalities in MEPEDS, the mean logMAR UCVA in our reference population is very close to this established in the MEPEDS 36- to 47-month-old children using the ATS HOTV (0.19 vs. 0.17 logMAR, respectively).[6] If compared to the results obtained from the European Caucasian and Asian children without sight-affecting abnormalities in SPEDS, the mean logMAR UCVA in our reference population is close to one line worse than this tested with the ATS HOTV in SPEDS (0.19 vs. 0.09 logMAR for children aged 36 to <42 months; 0.18 vs. 0.07 for 42 to <48 months), and similar to this tested with the linear ETDRS or HOTV logMAR chart (0.19 vs. 0.22 logMAR for children aged 36 to <42 months; 0.18 vs. 0.16 for 42 to <48 months).[7] However, the significances of such comparisons are not very clear, because the ATS

HOTV VA test, which uses a single letter surrounded by bars optimally placed at half the optotype height from the letter optotype, is quite different from the linear HOTV logMAR chart that we used, and SPEDS didn't specify the mean logMAR UCVA when only using linear HOTV logMAR chart. The better VA by approximately 1 line (using the ATS HOTV test) found in SPEDS when compared to our study might be due to the following reasons: (1) Non-cycloplegic refraction was performed on part of children in our reference population, which may underdiagnose hyperopia due to accommodative reserves[20-21] and then produce slightly reduced VA in the reference population due to hyperopia; (2) The ATS HOTV is cognitively easier to perform by preschoolers than the linear chart;[22] (3) Leone et al found that East Asian children had significantly poorer VA than their European Caucasian counterparts,[7] which indicated that ethnicity differences might have impacted our findings.

We found improvement in UCVA with increasing age, as has been reported in several studies despite different charts used.[6-7, 10, 18, 23] However, the difference between UCVA in the 36- to <42-month-old children was only 0.01 logMAR worse than the 42- to <48-month-old children (Table 2), which might have no clinical significance. Gender was not associated with UCVA both in our sample and SPEDS, opposite to that reported in MEPEDS.[6-7] As for risk factors of UCVA, prematurity was related with worse UCVA in our reference population, which was consistent with the finding in SPEDS. However, the r^2 value was only 0.032, indicating that the significance of prematurity to UCVA might not be very high. Socio economic status (SES) factors, such as the employment status of parents and family income, which were significantly associated with UCVA in MEPEDS and SPEDS, showed no associations with UCVA in our study. In addition, maternal smoking during pregnancy, which was related with slightly better UCVA in SPEDS, had no relationship with UCVA in our study.

As the penalty for missing one amblyopia case is a lifetime disability and treatment exists, the UCVA referral cutoff for amblyopia should target high sensitivity, while the specificity should be high enough not to put immense load on

ophthalmologists.[24-25] The sensitivity of detecting amblyopia by using the UCVA referral cutoff in our study (UCVA ≤ 20/40 at age 36 to < 48 months), was as high as 86%, and at the same time, the specificity was high enough (74.2%). On the other hand, this cutoff only identified a total of 39.5% refractive errors, even though the overall specificity was high (84.5%). The sensitivity in detecting myopia was not good in our study (35.1%), lower than hyperopia (51.2), astigmatism (48.6%), and anisometropia (44.1%). In SKES, even though a high sensitivity (83.3%) in detecting myopia was observed in all 36- to 72-month-old preschoolers, it's not available to calculate the sensitivity in detecting myopia in 36-month-old children because of no presence of myopia in this age group. And for all refractive errors in 36-month-old children in SKES, the overall sensitivity was only 8.6%. Therefore, only using the UCVA cutoff as referral criterion might be difficult to detect refractive errors in 36-month-old children, and additional refraction examination might be necessary for vision screening.

The normative distribution of UCVA IOD in our study was consistent with that in SKES, with most children achieving equal vision in both eyes. No effect of gender or testing order on IOD was observed in our study, which was consistent with MEPEDS. However, we found that absolute UCVA IOD decreased with increasing age of month in our sample, which was not consistent with the findings in 30- to 72-month-old children in MEPEDS. The reason of this difference might be that, in MEPEDS, equal vision in both eyes in older children concealed the effect of age on UCVA IOD in younger children.

When using UCVA IOD of two or more lines as the criterion, approximately 4% in the general population would be referred in both of SKES and our study. The sensitivity of using this criterion alone for detecting amblyopia, including unilateral amblyopia, was very low in our study, similar to the results in SKES.

To our knowledge, the present study is the first to provide population-based HOTV-specific normative UCVA data in Chinese preschoolers aged 36 to < 48 months without significant refractive error or other ophthalmic abnormalities.

However, there are several limitations in the present study. Because young children are very afraid of using eye drops, which makes cycloplegia difficult and unacceptable for parents, only children with suspected abnormities underwent cycloplegic refraction in our study. Even though not all children had refraction results under cycloplegia, we adopted stringent criteria to identify children who needed cycloplegic refraction, which could effectively detect sight-affecting refractive errors. However, Fotedar et al[20] and Leone et al[21] found that hyperopia and some astigmatism might not be as detectable without cycloplegia, which might impact the findings of our reference population at some degree. 11.1% children were not testable when doing the HOTV test and were excluded from the analysis, which may influence the normative UCVA distribution. However, the testability in our study was at an average level of published reports,[6, 10] which tested VA using the HOTV single surrounded letters, not linear, and difficult to increase further in young children.

In conclusion, our study suggests that Chinese preschoolers aged 36 to < 48 months with UCVA no better than 20/40 measured by linear HOTV chart should be referred for further ophthalmic examinations. Most amblyopia cases can be identified with this age-specific and chart-specific UCVA cutoff.

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Contributors Conceived and designed the experiments: HL, HZ, DH and QS. Performed the experiments: HZ, DH, QS, HD, JB, JC, YW, XZ, JW and XL. Analyzed the data: HZ, DH, QS and XC. Contributed reagents/materials/analysis tools: HL, HZ, DH, HD, JB, JC, and XC. Wrote the paper: HL, HZ, DH, QS, XC, HD, JB, JC, YW, XZ, JW and XL.

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