Prevalence of visual impairment and refractive errors among different ethnic groups in schoolchildren in Turpan, China

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Running head:

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Abstract

Background: There is currently limited information about ethnic differences in myopia prevalence within mainland China, especially in rural or semi-rural areas. We examined the prevalence of refractive errors, visual impairment and spectacle coverage in school children of varying ethnicity in Turpan, Xinjiang province.

Methods: A community eye care service was provided for 5 schools. Presenting monocular distance and near visual acuity (VA), and ocular alignment were assessed. Retinoscopy and cycloplegic subjective refraction were performed for participants with presenting visual impairment (distance VA >0.3 logMAR; 6/12) or abnormal binocular vision. Questionnaires administered prior to the eye examinations were used to collect information regarding personal lifestyle and parental myopia.

Results: A total of 646 out of 690 (94%) subjects aged 4 to 19 years (11.9±2.6; mean±S.D.) completed the eye examination. 382 (59%) of participants were Uyghur ethnicity, followed by Han, 176 (27%) and Hui, 74 (12%). The mean age of Uyghur, Han and Hui students was 12.3 ±2.7, 11.4 ±2.6 and 11.4 ±2.3 years respectively, in which the Uyghur students were significantly older than the Han and Hui students ($F(3,631)=5.58$ $p<0.001$). In total, 170 (27%) and 85 (13%) subjects failed the screening examination for one eye or both eyes, respectively. The prevalence of presenting visual impairment was not significantly different among the ethnic groups ($p=0.26$). After cycloplegic refraction, most subjects' VA (98%) improved to <0.3 logMAR. The prevalence of "clinically-significant myopia" (≤−0.50 dioptres) was 27%, 18% and 13% in Han, Hui and Uyghur children, respectively ($p<0.001$). In contrast, Uyghur students had the highest prevalence of astigmatism (Uyghur 12%, Han 5%, Hui 4%). The overall spectacle coverage was 36%, while spectacle coverage among ethnic groups were

similar (Han, 41%; Uyghur, 32%; Hui, 41%; χ^2=2.23, df=2, p=0.33).

Conclusion: The prevalence of clinically significant myopia varied markedly with ethnicity in school children sampled from a semi-rural region of mainland China (Han > Hui > Uyghur). As reported previously, uncorrected/under-corrected refractive error was the main cause of presenting visual impairment.

Introduction

According to World Health Organization, about 90% of cases of visual impairment are found in developing countries, and 80% are preventable,[1] with uncorrected refractive error the major cause. Recent epidemiology studies suggest the prevalence of myopia in Chinese children can be as high as 80% in certain regions.[2] However, most of these studies have investigated individuals of Han Chinese ethnicity, the predominant ethnic group in China.[3-9] Data on the prevalence of visual impairment and refractive errors of other ethnic groups in China are limited. Due to the differences in cultural and family lifestyle, as well as genetic difference between Uyghur and Han, we hypothesized that the distribution of refractive errors in Chinese subjects may differ with ethnicity. This study examined the prevalence of visual impairment and refractive errors in school-age children from three different ethnic groups living in the same region.

Turpan is a rural area in Xinjiang province, North-west China, and is home to three main ethnic groups, the Uyghur, Han and Hui. As part of a community eye care project designed to provide spectacles for school children in Turpan, we sought to determine whether ethnicity was a major determinant of myopia prevalence in a region expected to have a relatively low level of myopia.

Methods

Study population

Our project was aimed to provide eye care service for students from primary to junior secondary – an age group that was vulnerable for significant changes in refractive errors. We analyzed cross-sectional data collected during the provision of a community eye care service to five schools (three primary and two secondary schools) in Turpan. All tests were conducted by optometrists and optometry students. Participants

completed questionnaires prior to the eye examination. The questionnaires included items that ascertained satisfaction with current vision, time spent indoors/outdoors, and the refractive status of parents. Informed consent was obtained from the parents/guardians of the participating students. The study followed the tenets of the Declaration of Helsinki.

Examinations

Visual acuity and ocular motility assessment

The workflow of the examination is summarized in **Figure 1**. For students wearing glasses, their prescriptions were checked by focimeter. All students' presenting monocular distance (3 m) and near (40 cm) visual acuity (VA) was assessed using a logMAR chart with Tumbling-E optotypes on illuminated test charts (approximately 480 lux). Tumbling-E optotypes were used in this study because some ethnic students might not know alphabets or numbers. During the acuity measure, students were asked to use their fingers to indicate the direction of the Tumbling-E until 3 consecutive letters could not be resolved accurately. The VA testing was carried out by four examiners and VA was measured by-letter scoring method. Ocular alignment was assessed at distance (4 m) and near (40 cm) using the cover test with subjects' habitual correction. Those with presenting distance VA in either eye worse than 6/12 (0.3 logMAR), heterotropia, or restricted motility underwent cycloplegic refraction and an ocular health examination, as described below.

Cycloplegic refraction and ocular health assessment

Cycloplegic refraction was performed 30 minutes after instillation of 1 drop each of 0.5% phenylephrine and 0.5% tropicamide. Cycloplegia was confirmed when the pupil size was 6 mm or larger without any light reflex. Cycloplegic refraction was carried by

retinoscopy followed by subjective refraction (sphere and Jackson cross-cylinder). External and internal ocular health was assessed using slit lamp biomicroscopy and direct ophthalmoscope respectively. Spectacles were prescribed for participants whose distance VA improved (by at least 1 line) after subjective refraction.

Definitions

Mean spherical equivalent (MSE) refractive error was calculated as sphere power plus half of the cylinder power. In line with the definitions adopted in other studies, [2,9,10] myopia was defined as SE refraction of ≤−0.50 diopter (D), while hyperopia was defined as SE refraction of ≥+2.00D. Emmetropia was defined as SE between >-0.50 and <2.00D and astigmatism of less than 0.75D. Given that subjective refraction was only conducted for students failing the distance acuity in either eye, we made an assumption that the eyes with presenting unaided distance VA of 6/12 (0.3 logMAR) or better had non-clinically significant refractive errors. For students whose presenting aided distance VA was 6/12 (0.3 logMAR) or better, MSE of their spectacles were categorised based on the definitions of ametropia. Unlike other epidemiology studies, "clinical significant myopia" was used to determine the prevalence of participants with myopic MSE and visual acuity worse than 6/12 (0.3 logMAR) in either eye. Participants were classified as myopic if either eye was myopic.[2,9-11] Bilateral hyperopes and subjects with one hyperopic and one emmetropic eye were categorized as hyperopic. Astigmatism was defined as cylinder power of 0.75D or more. Visual impairment was defined as presenting VA worse than 0.30 logMAR in one eye or both eyes.[12-14]

"Met need'' was defined as the number of students who had refractive errors and were corrected (by their current spectacles), while "unmet need" was defined as the number of students who had refractive errors but were uncorrected (i.e. VA was failed

in either eye who had no glasses) / under-corrected (i.e. VA was failed even with glasses). Spectacle coverage (%) was calculated as follow: [15]

Spectacle coverage (%) = [met need/ (met need + unmet need)] X 100%

Statistical Analysis

Statistical analysis of the data was carried out using the Predictive Analytic Software (PASW19.0, SPSS Inc., Chicago, IL, USA). Chi-square (χ^2) tests Mann-Whitney U test and Kruskal-Wallis one-way analysis of variance were applied to assess the effects of ethnicity and gender on visual acuity, refractive error, lifestyle and parental refractive status. Prevalence of refractive errors, strabismus and spectacle coverage was calculated and compared among the ethnic groups. Univariate logistic regression was used to explore the predictors of refractive errors including parental refractive status, time spent indoors, and time spent outdoors. Predictors of strabismus were explored including ethnicity, gender, myopia prevalence, hyperopic prevalence and astigmatism prevalence and refractive errors. Model terms that were statistically significant at the 0.1 level were entered into a multivariate logistic regression to evaluate their independent effects. A p-value less than 0.05 was considered as statistically significant.

Results

Characteristics of study population

Among the recruited 690 students, 646 (94%) students from 5 schools aged 4 to 19 years (mean ± SD; 11.9 ± 2.6 years) completed the eye examination. **Table 1** summarizes the demographic information, time spent on different tasks, and refractive error findings. The major ethnic group was Uyghur (382 students, 59%),

followed by Han (176 students, 27%), Hui (74 students, 12%) and others (14 students, 2%). Given that very few students (n=14) were classified as “other”, this ethnic group was excluded in further analyses, leaving a total of 632. The mean age of Uyghur, Han and Hui students was 12.3 ±2.7, 11.4 ±2.6 and 11.4 ±2.3 years respectively, in which the Uyghur students were significantly older than the Han and Hui students ($F(3,631)=5.58$ $p<0.001$). Of the 632 examined students, 76% students reported dissatisfaction with their current habitual vision. However, only 42% had ever had an eye examination.

The majority of students spent more time on indoor than outdoor activities (3-5 hours indoors VS. 1-3 hours outdoors). Interestingly, Hui students spent significantly fewer hours indoors compared with Han and Uyghur ($\chi^2=14.9$, df=6, $p=0.02$). In total, 15% of subjects reported at least one parent having myopia, however this was approximately twice as common for Han participants (24%) than the other major ethnic groups (Hui, 11%; Uyghur, 15%; $\chi^2=17.9$, df=2, $p<0.001$).

Visual acuity and cycloplegic refraction

All students were asked to bring their own spectacles to the school on the day of the eye examination, regardless whether they wore them or use them. Among, the one hundred and thirty-five students (21%) reported having spectacles, 94% students brought their spectacles for the examination. However, only 40% of the students wore the spectacles at school on a regular basis. Presenting distance VA was 0.16 ± 0.23 and 0.15 ± 0.22 logMAR, while presenting near VA was 0.08 ± 0.19 and 0.06 ± 0.18 logMAR for right and left eyes, respectively. Subnormal distance vision was found in 170 students (27%) and 85 students (13%) for one eye, and both eyes, respectively. The prevalence of subnormal presenting VA was not significantly different among ethnical

groups (χ^2=1.3, df=2, p=0.26 for unilateral impairment; χ^2=4.7, df=2, p=0.09 for bilateral impairment).

Best-corrected distance VA (after cycloplegic refraction) was 0.08 ± 0.17 and 0.08 ± 0.16 logMAR for right and left eyes, respectively. There were 16 (3%) and 9 students (1%) with unilateral and bilateral visual impairment uncorrectable by spectacles. The causes of bilateral visual impairment included amblyopia (2 students), ocular diseases (2 students had bilateral congenital cataract and 1 student had suspected macular dystrophy, Table 2) and unidentifiable visual problems (4 students).

A total of 85 students' current spectacles (13%) "met need" with appropriate prescription (95% CI: 11%–16%). In contrast, new spectacles were required for 150 participants (i.e. unmet need), accounting for 24% of the recruited population (95% CI: 21%–27%). The overall spectacle coverage was 36%, while spectacle coverage among ethnic groups were similar (Han, 41%; Uyghur, 32%; Hui, 41%; χ^2=2.23, df=2, p=0.33) (Table 1).

Prevalence and determinants of clinically significant refractive error

Cycloplegic MSE varied with age, from a median of -0.50 D in 4-8 year-olds to -0.70 D in 15-19 year-olds (right eyes; χ^2=4.5, df=7, p=0.73, Figure 2). The median MSE was -1.00D and -1.38D in girls and boys respectively (Mann-Whitney U=1454, p=0.20). The prevalence of myopia varied significantly with ethnicity: Han 27%; Hui 18%; Uyghur 13%, respectively (χ^2=19.4, df=3, p<0.001; Table 1). After adjusting for age, gender, parents' refractive status, time spent outdoors and time spent indoors, the odds ratios (OR) for myopia in Uyghur VS. Han children was 0.36 (95% CI: 0.23-0.58; p<0.001) and in Hui VS. Han children was 0.60 (95% CI: 0.30-1.21; p=0.15).

As shown in Figure 3, the median MSE in Uyghur students (-0.38D) was significantly less myopic/more hyperopic than in Han (-1.50D) and Hui students (-1.25D) (both p<0.001). In contrast, Uyghur students were likely to have astigmatism (OR=2.01; 95% CI: 0.94-4.30) and hyperopia (OR=3.14; 95% CI: 0.91-10.84) than Han students, although barely insignificant after adjustment (Table 1).

Ocular abnormalities

Tropia was found in 76 (12%) students: 36 (6%) at distance and 72 (11%) at near. Exotropia was the most common form (56% and 79% for distance and near, respectively). Nystagmus was presented in 6 (1%) students. The prevalence of ocular misalignment was not significantly different across ethnic groups (p=0.17 and 0.27 for distance and near misalignment respectively). The gender (p=0.04) and refractive errors (P=0.01) were significant predictors for distant ocular misalignment, while astigmatism prevalence (P<0.001) and gender (P=0.01) were significant predictors for near ocular misalignment. The anterior and posterior segment abnormalities observed during the vision assessment are listed in Table 2.

Discussion

Reduced presenting VA due to refractive error and spectacle coverage

To minimize the adverse impact of poor vision on students' academic performance, early detection and management of visual impairment is important.[16-19] Our study found that 13% students' presenting VA in both eyes was worse than 6/12 (0.3 logMAR), with no significant difference among different ethical groups. After cycloplegic refraction, 98% of students' VA improved to better than 6/12 (0.3 logMAR). Thus, in line with previous studies,[1,20] uncorrected refractive errors were the leading

cause of visual impairment in these school-age students in Turpan. This type of vision problem can easily be managed by prescribing a pair of suitable spectacles. In our study, the overall spectacle coverage was only 36%, where 150 pairs of new spectacles were prescribed and dispensed such that students could benefit from refractive correction. Sixty four percent semi-rural students with refractive errors did not own spectacles or have accurate spectacles. Our finding was comparable to another large-scale epidemiology study by Congdon and colleagues[21] where 62% rural Chinese children did not have appropriate correction.

The prevalence of visual impairment reported in our finding was slightly higher than that reported in urban regions in China such as Guangzhou (10%),[2] but lower than that reported in another rural area (17%).[10] Two plausible reasons may explain the discrepancy. First, 75% students were not satisfied with their current visual status through self-reported questionnaire, but less than half of them sought eye examination to address their concern. This could be because of participants or their parents' poor awareness and recognition of visual problems, as well as low affordability or accessibility of eye examination or spectacles.[22,23] Second, only 40% students with prescribed spectacles actually wore them on regular basis. Surprisingly, some students with significant myopia (e.g. >-4.00D) chose not to wearing their spectacles constantly, mainly because of the stigma attached to wearing glasses or mistaken belief that wearing glasses made eyes deteriorate even faster.[10,21,23-25] Hence, regular arrangement of vision screening and school health programs is essential to raise students' awareness of eye care and educate the importance of appropriate refractive corrections. Despite a high percentage of dissatisfaction of participants' habitual vision (75%), only 27% students had subnormal distance vision in either eye. It is possible that other visual factors such as contrast sensitivity, visual

field, and stereo-acuity that were not measured in our study, may affect participants' self-perceived vision satsisfaction.[26] In addition, quality of learning environment such as adequacy of lighting or sources of glare in the classroom may affect the students' satisfaction level on vision.

Different prevalence of clinically-significant myopia in ethnic minority

The prevalence of myopia is high in eastern Asian children and has increased in recent generations.[27,28] Unlike other epidemiology studies,[2,9,10,22] our study determined the prevalence of "clinically-significant myopia", where cycloplegic refraction was only conducted for students who failed the distance VA. This would underestimate the prevalence of myopia comparing with other studies.[2,4,9,10,22] Despite this limited definition on estimating the prevalence of myopia, it did disclose marked ethnic differences: Han students were 2.6 times and 1.8 time more likely to be myopic than Ugyhur and Hui children, respectively. Uyghur students had lower myopia prevalence despite they were approximately one year older, suggesting that the actual ethnical-differences in prevalence may be even greater. Although our participants were recruited based on convenience sampling, the significant ethnical difference in myopia prevalence was unlikely due to the bias in ethnical minority attending schools. In recent years, Ministry of Education of Mainland China has allocated much resource to implement nine-year free and compulsory education.[29] According to the official figures, the students' enrollment rate for primary and secondary junior in Turpan was nearly 100%.[30] The ethnic distribution in our sampled population was comparable with those reported in the government official figures where the Turpan population structure comprised 69% Uyghur, 25% Han and 6% Hui.[31] Hence, result from our study provided preliminary evidences in the ethnic differences in school-age students' prevalence of clinically-significant myopia.

Turpan is a county-level city with a population density of only 16.0 per square kilometer.[31] It is categorized as a semi-rural region. Previous studies suggested that children living in rural areas spend less time indoors and on near-work than those living in urban areas.[32,33] Greater outdoor activity is associated with reduced myopia incidence and possibly progression rate.[34-37] Here, time spent indoors was positively associated with myopia, but time spent outdoors and near work had no association with myopia. Owing to the limited information on the actual amount of time spending on different tasks per day, analysis on the effect of near work and outdoor activities on refractive errors could not be examined.

Refractive status in Uyghur students

In previous surveys, children of Han Chinese ethnicity have shown a higher prevalence of myopia compared to European and Malay children living in the same region[38-41] suggesting that Chinese children may be more susceptible to myopia than Caucasian children. The Uyghur are a group of Turkish origin living in Eastern and Central Asia, with ancestry from both East Asians and Europeans.[42] This genetic contribution from European ancestry may therefore be a cause of the lower prevalence of myopia we observed in Uyghur students, however lifestyle factors could also explain our findings. Despite the likely misreporting of parental myopia due to ascertainment by a questionnaire, the same pattern of ethnicity-related myopia prevalence was also apparent in the parents ($p<0.001$; Table 1). This implies that the cause of the difference is not of recent origin.

The higher prevalence of astigmatism in the Uyghur children was surprising in light of their lower myopia prevalence, since myopia and astigmatism typically co-occur.[43,44]

However, other ethnic groups, such as Native Americans, have been found to show a high prevalence of astigmatism.[45]

Prevalence of strabismus

The prevalence of tropia in our study was higher comparing with other studies in China.[2,10,46,47] Our results showed that refractive errors could be correlated with distant ocular misalignment. In addition, male in this cohort was more susceptible to have ocular misalignment in both distant and near. Previous studies have shown that uncorrected refractive errors could result in exo-deviation.[48] Yet, given the limited demographic information was available (e.g. birth history or family history of strabismus or amblyopia were not collected), Further investigation was needed for higher prevalence of strabismus.

Limitations

To our knowledge, this is the first study reporting the ethnicity-related differences in the prevalence of refractive error and visual impairment, and spectacle coverage of school children in a rural region of mainland China. However, there were several limitations to our study. First, this was a community project, which aimed to provide eye care services to students in rural areas in China, and hence schools were not recruited via random sampling and the number of participants was lower than would have been ideal. Thus, our findings may not represent the true prevalence of visual impairment and myopia in Turpan, but provide preliminary evidences in the ethnic differences in prevalence of clinically-significant myopia in Turpan students. Second, cycloplegic refraction was only conducted for students who failed the distance VA test. Therefore, some students who passed the VA might have a low level of myopia (e.g. between -0.50 and -1.00D), underestimating the overall prevalence of myopia in this

population. Third, the questionnaire collected only limited information about the amount of time spent indoors, outdoors, performing near-work, and parental refractive status, which limited our ability to assess associations of other factors and students' myopia development. Without a standardized questionnaire quantifying the hours of the outdoor, indoor and near work activities per day for each student, associations between outdoor activity and near work and prevalence of myopia cannot be made.

Conclusion

In this study, preliminary evidences were provided that the prevalence of refractive errors was different among ethnic minorities. Uyghur school children from North West China had a lower prevalence of myopia compared to their Han and Hui peers. However, factors associated with the lower prevalence of myopia in particular in Uyghur children need further population-based investigation.

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Table 1. Demographic distribution, self-reported time spending on different activities, distribution of refractive errors

			Han	Uyghur	Hui	P-value	Adjusted Odds ratios* (95% CI) P-value	
							Uyghur	Hui
No. of Participants (%)	Male		74 (42%)	165 (43%)	30 (41%)	0.90	--	--
	Female		102 (57%)	217 (57%)	44 (60%)		--	--
	Total		176 (27%)	382 (59%)	74 (12%)		--	--
Age	Mean (SD)		11.4 (2.5)	12.3 (2.7)	11.4 (2.3)	0.001	--	--
Spectacle coverage (%)			34/83 (41%)	39/123 (32%)	12/29 (41%)	0.33	--	--
Parental myopia (%)			43/176 (24%)	40/376(11%)	11/74 (15%)	<0.001	0.36(0.22-0.59) P<0.001	0.50(0.24-1.05) P=0.07
Lifestyle factor (%)	Indoor	< 1 hours	39/172 (23%)	54/370 (15%)	19/73 (26%)	0.02	--	--
		1 - 3 hours	66/172 (38%)	129/370 (35%)	30/73 (41%)		--	--
		3 - 5hours	63/172 (37%)	171/370 (46%)	23/73 (32%)		--	--
		> 5 hours	4/172 (2%)	16/370 (4%)	1/73 (1%)		--	--
	Outdoor	< 1 hours	37/172 (21%)	80/370 (22%)	19/74 (26%)	0.51	--	--
		1 - 3 hours	104/172 (59%)	238/370 (64%)	44/74 (60%)		--	--
		3 - 5hours	30/172 (17%)	48/370 (13%)	9/74 (12%)		--	--
		> 5 hours	5/172 (3%)	4/370 (1%)	2/74 (3%)		--	--
	Near work	< 1 hours	70/173 (41%)	103/371 (28%)	21/73 (26%)	0.08	--	--
		1 - 3 hours	77/173 (45%)	215/371 (58%)	43/73 (41%)		--	--
		3 - 5hours	21/173 (37%)	45/371 (12%)	7/73 (32%)		--	--

		> 5 hours	5/173 (2%)	8/371 (2%)	2/73 (1%)	--	--
Prevalence of refractive error (%)	Myopia		48/176 (27%)	48/382 (13%)	13/74 (18%)	<0.001	0.36 (0.23-0.58) P<0.001	0.60(0.30-1.21) P=0.15
	Hyperopia		3/176 (2%)	25/382 (7%)	1/74 (1%)	0.02	3.14 (0.91-10.84) P=0.07	0.79 (0.08-7.75) P=0.84
	Astigmatism		9/176 (5%)	44/382 (12%)	3/74 (4%)	0.02	2.01 (0.94-4.30) P=0.07	0.78 (0.20-2.99) P=0.78
Tropia (%)	Distant		11/176 (6%)	23/382 (6%)	2/74 (3%)	0.49	0.96 (0.49-2.02) P=0.92	0.42 (0.09-1.93) P=0.26
	Near		16/176 (9%)	46/382 (12%)	10/74 (14%)	0.49	1.37 (0.75-2.49) P=0.30	1.56 (0.67-3.67) P=0.30

The percentages were calculated based of three major ethnic groups. Very small proportion of spectacle information was missing for analysis.

* Odds ratios were computed with reference to the Han ethnic group.

Table 2. Summary of causes of visual impairment according to presenting distance visual acuity

Causes	Unilateral	Bilateral	Total
Myopia	38	60	98
Hyperopia	19	8	27
Astigmatism	7	3	10
Refractive amblyopia	8	2	10
Strabismic amblyopia	1	0	1
Cataract	5	2	7
Suspected macular problem	0	1	1
Unknown	2	4	4

Two subjects had myopia in one eye, where one eye's visual acuity could not improve to 6/12.

Figure 1. Workflow of eye examination.

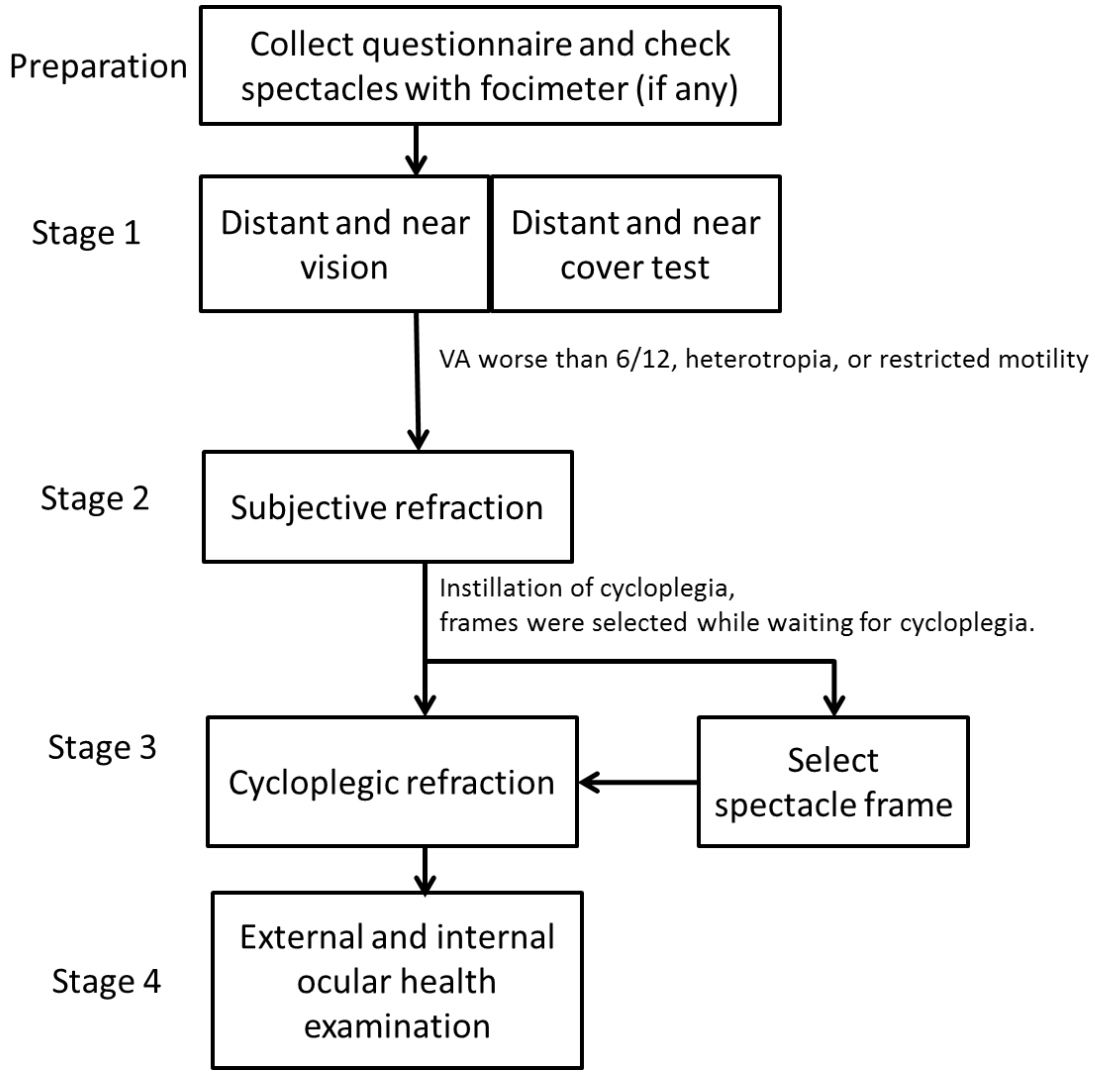
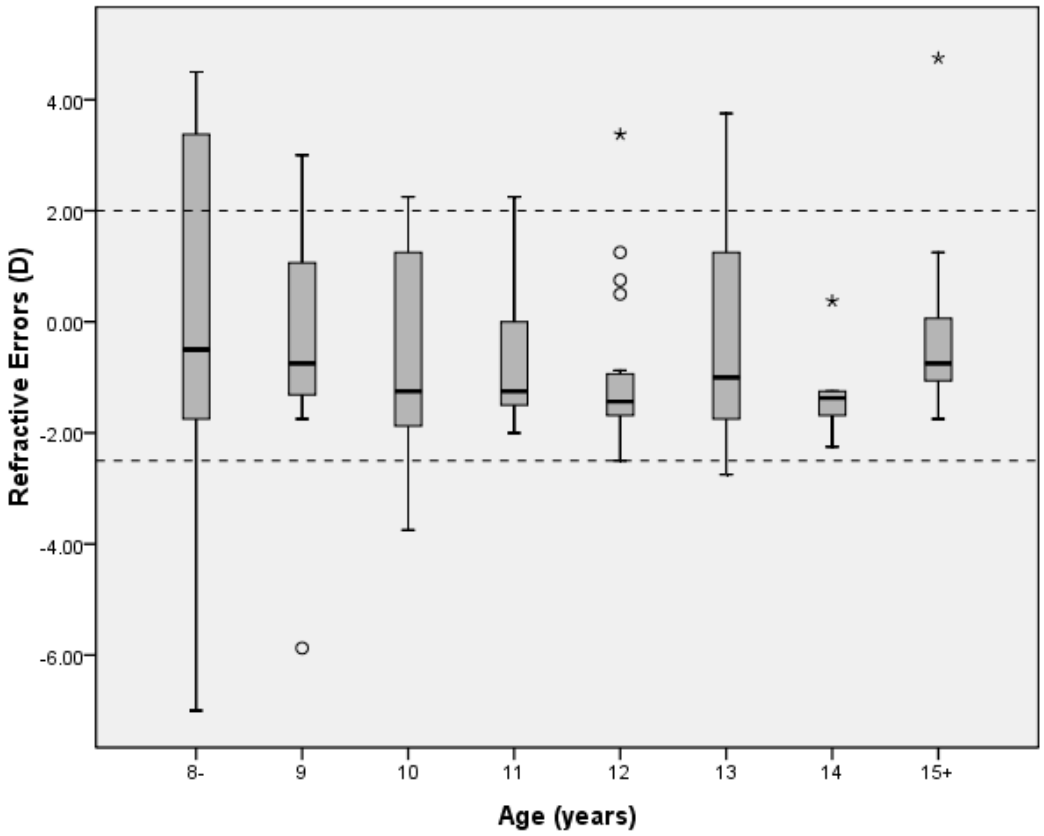
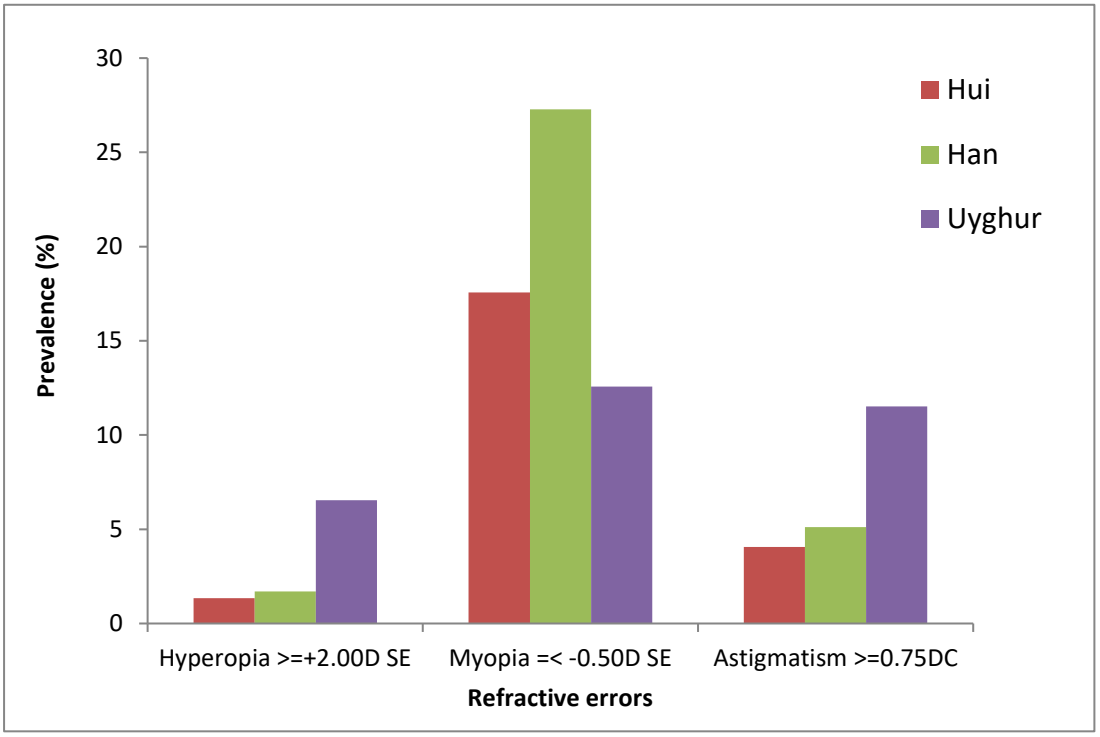


Figure 2. Distribution of mean spherical equivalent refractive error (cycloplegic refraction) in right eye by age.



Given that there were very few students who were younger than 9 or older than 14 years old, they were combined into the groups of "8-" and "15+". Upper and lower horizontal dash lines at +2.00D and -0.50D represent the definitions for hyperopia and myopia respectively. Each box represents the interquartile range of the age-specific distribution of refractive errors, with a median bar within the box. "*" and "o" represent the extremes and outliers respectively for the refractive errors in that specific age group.

Figure 3. Prevalence of refractive errors by ethnic groups.



References

(1) World Health Organisation. Global data on visual impairment - 2010. http://www.who.int/blindness/publications/globaldata/en/ (accessed on 31 Aug 2014)

(2) He M, Zeng J, Liu Y, Xu J, Pokharel GP & Ellwein LB. Refractive error and visual impairment in urban children in southern china. *Invest Ophthalmol Vis Sci* 2004;45: 793-799.

(3) Zhuang W, Yang P, Li Z*, et al*. Association of insulin-like growth factor-1 polymorphisms with high myopia in the Chinese population. *Mol Vis* 2012;18: 634-644.

(4) Lu B, Congdon N, Liu X*, et al*. Associations between near work, outdoor activity, and myopia among adolescent students in rural China: the Xichang Pediatric Refractive Error Study report no. 2. *Arch Ophthalmol* 2009;127: 769-775.

(5) Chan KY, Cheung SW & Cho P. Corneal parameters of six- to 12-year-old Chinese children. *Clin Exp Optom* 2012;95: 160-165.

(6) Sharma A, Congdon N, Gao Y*, et al*. Height, stunting, and refractive error among rural Chinese schoolchildren: the See Well to Learn Well project. *Am J Ophthalmol* 2010;149: 347-353.e1.

(7) Zhang M, Congdon N, Li L*, et al*. Myopia, spectacle wear, and risk of bicycle accidents among rural Chinese secondary school students: the Xichang Pediatric Refractive Error Study report no. 7. *Arch Ophthalmol* 2009;127: 776-783.

(8) Zhang M, Li L, Chen L*, et al*. Population density and refractive error among Chinese children. *Invest Ophthalmol Vis Sci* 2010;51: 4969-4976.

(9) He M, Zheng Y & Xiang F. Prevalence of myopia in urban and rural children in mainland China. *Optom Vis Sci* 2009;86: 40-44.

(10) He M, Huang W, Zheng Y, Huang L & Ellwein LB. Refractive error and visual impairment in school children in rural southern China. *Ophthalmology* 2007;114: 374-382.

(11) Fan DS, Lam DS, Lam RF*, et al*. Prevalence, incidence, and progression of myopia of school children in Hong Kong. *Invest Ophthalmol Vis Sci* 2004;45: 1071-1075.

(12) Foran S, Mitchell P & Wang JJ. Five-year change in visual acuity and incidence of visual impairment: the Blue Mountains Eye Study. *Ophthalmology* 2003;110: 41-50.

(13) Attebo K, Mitchell P & Smith W. Visual acuity and the causes of visual loss in Australia: the Blue Mountains Eye Study. *Ophthalmology* 1996;103: 357-364.

(14) Willis JR, Jefferys JL, Vitale S & Ramulu PY. Visual impairment, uncorrected refractive error, and accelerometer-defined physical activity in the United States. *Arch Ophthalmol* 2012;130: 329-335.

(15) Naidoo KS, Jaggernath J, Martin C*, et al*. Prevalence of presbyopia and spectacle coverage in an African population in Durban, South Africa. *Optom Vis Sci* 2013;90: 1424-1429.

(16) Maples W. A comparison of visual abilities, race and socio-economic factors as predictors of academic achievement. *J Behav Optom* 2001;12: 60-65.

(17) Toledo CC, Paiva A, Camilo GB, Maior MRS, Leite ICG & Guerra MR. Early detection of visual impairment and its relation to academic performance. *Rev Assoc Med Bras* 2010;56: 415-419.

(18) Krumholtz I. Results from a pediatric vision screening and its ability to predict academic performance. *Optometry* 2000;71: 426-430.

(19) Maples W. Visual factors that significantly impact academic performance. *Optometry* 2003;74: 35-49.

(20) Resnikoff S, Pascolini D, Mariotti SP & Pokharel GP. Global magnitude of visual impairment caused by uncorrected refractive errors in 2004. *Bull World Health Organ* 2008;86: 63-70.

(21) Congdon N, Zheng M, Sharma A*, et al*. Prevalence and determinants of spectacle nonwear among rural Chinese secondary schoolchildren: the Xichang Pediatric Refractive Error Study Report 3. *Arch Ophthalmol* 2008;126: 1717-1723.

(22) He M, Xu J, Yin Q & Ellwein LB. Need and challenges of refractive correction in urban Chinese school children. *Optom Vis Sci* 2005;82: E229.

(23) Odedra N, Wedner SH, Shigongo ZS, Nyalali K & Gilbert C. Barriers to spectacle use in Tanzanian secondary school students. *Ophthalmic Epidemiol* 2008;15: 410-417.

(24) Holguin AMC, Congdon N, Patel N*, et al*. Factors associated with spectacle-wear compliance in school-aged Mexican children. *Invest Ophthalmol Vis Sci* 2006;47: 925-928.

(25) Li L, Song Y, Liu X*, et al*. Spectacle acceptance among secondary school students in rural China: the Xichang Pediatric Refractive Error Study (X-PRES)--report 5. *Invest Ophthalmol Vis Sci* 2008;49: 2895-2902.

(26) El-Gasim M, Munoz B, West SK & Scott AW. Associations between self-rated vision score, vision tests, and self-reported visual function in the Salisbury Eye Evaluation Study. *Invest Ophthalmol Vis Sci* 2013;54: 6439-6445.

(27) Matsumura H & Hirai H. Prevalence of myopia and refractive changes in students from 3 to 17 years of age. *Surv Ophthalmol* 1999;44: S109-S115.

(28) Xiang F, He M, Zeng Y, Mai J, Rose K & Morgan I. Increases in the prevalence of reduced visual acuity and myopia in Chinese children in Guangzhou over the past 20 years. *Eye (Lond)* 2013; 27:1353-8.

(29) Xinhua News Agency. China to Popularize Nine-year Compulsory Education. http://www.china.org.cn/english/2006/Feb/159585.htm (accessed on 01 Nov 2014)

(30) Turpan elementary and middle school-age children enrollment rate reached 100%. http://www.tlf.gov.cn/info/360/77412.htm (accessed on 01 Nov 2014)

(31) Turpan. http://zh.wikipedia.org/wiki/%E5%90%90%E9%B2%81%E7%95%AA%E5%9C%B0%E5%8C%BA (accessed on 01 Nov 2014)

(32) Guo Y, Liu LJ, Xu L*, et al*. Outdoor activity and myopia among primary students in rural and urban regions of Beijing. *Ophthalmology* 2013;120: 277-283.

(33) Saw SM, Hong RZ, Zhang MZ*, et al*. Near-work activity and myopia in rural and urban schoolchildren in China. *J Pediatr Ophthalmol Strabismus* 2001;38: 149-155.

(34) Low W, Dirani M, Gazzard G*, et al*. Family history, near work, outdoor activity, and myopia in Singapore Chinese preschool children. *Br J Ophthalmol* 2010;94: 1012-1016.

(35) Rose KA, Morgan IG, Ip J*, et al*. Outdoor activity reduces the prevalence of myopia in children. *Ophthalmology* 2008;115: 1279-1285.

(36) Guggenheim JA, Northstone K, McMahon G*, et al*. Time outdoors and physical activity as predictors of incident myopia in childhood: a prospective cohort study. *Invest Ophthalmol Vis Sci* 2012;53: 2856-2865.

(37) Wu PC, Tsai CL, Wu HL, Yang YH & Kuo HK. Outdoor activity during class recess reduces myopia onset and progression in school children. *Ophthalmology* 2013;120: 1080-1085.

(38) Saw SM, Goh PP, Cheng A, Shankar A, Tan DT & Ellwein LB. Ethnicity-specific prevalences of refractive errors vary in Asian children in neighbouring Malaysia and Singapore. *Br J Ophthalmol* 2006;90: 1230-1235.

(39) Ip JM, Rose KA, Morgan IG, Burlutsky G & Mitchell P. Myopia and the urban environment: findings in a sample of 12-year-old Australian school children. *Invest Ophthalmol Vis Sci* 2008;49: 3858-3863.

(40) Kleinstein RN, Jones LA, Hullett S*, et al*. Refractive error and ethnicity in children. *Arch Ophthalmol* 2003;121: 1141-1147.

(41) Pan CW, Ramamurthy D & Saw SM. Worldwide prevalence and risk factors for myopia. *Ophthalmic Physiol Opt* 2012;32: 3-16.

(42) Xu S, Huang W, Qian J & Jin L. Analysis of genomic admixture in Uyghur and its implication in mapping strategy. *Am J Hum Genet* 2008;82: 883-894.

(43) Kee C. Astigmatism and its role in emmetropization. *Exp Eye Res* 2013;114: 89-95.

(44) Guggenheim JA & Farbrother JE. The association between spherical and cylindrical component powers. *Optom Vis Sci* 2004;81: 62-63.

(45) Mohindra I & Nagaraj S. Astigmatism in Zuni and Navajo indians. *Am J Optom Physiol Opt* 1977;54: 121-124.

(46) Guo Y, Liu LJ, Xu L*, et al*. Visual impairment and spectacle use in schoolchildren in rural and urban regions in Beijing. *Eur J Ophthalmol* 2014;24: 258-64

(47) Lin S, Congdon N, Yam JC, Huang Y, Qiu K, Ma D, Chen B, Li L, Zhang M. Alcohol use and positive screening results for depression and anxiety are highly prevalent among Chinese children with strabismus. Am J Ophthalmol. 2014;157:894-900

(48) Von Noorden GK & Campos EC. Binocular vision and ocular motility: theory and management of strabismus. *St.Louis, MO: Mosby* 2002.