Accuracy of Rural Refractionists in Western China

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Purpose. We assessed the prevalence and predictors of inaccurate refractive error among rural refractionists in western China.

Methods. A subset of primary school children with visual acuity (VA) ≤6/12 in ≥1 eye, undergoing subjective refinement by local refractionists after cycloplegic autorefraction in an ongoing population-based study, received repeat refraction by university optometrists for quality control.

Results. Among 502 children (mean age 10.5 years, 53.2% girls), independent predictors of poor (inaccurate by ≥1.0 diopter [D]) refraction by 21 rural practitioners (66.7% with high school or lower education) included hyperopia (odds ratio [OR], 4.2; 95% confidence interval [CI], 2.4–7.3, $P < 0.001$), astigmatism (OR = 3.8; 95% CI, 2.5–5.6; $P < 0.001$) and VA uncorrectable to >6/12 by the rural refractionist (OR = 4.7; 95% CI, 3.1–7.3; $P = < 0.001$). Among 201 children whose vision was uncorrectable in ≥1 eye by the rural refractionists, vision could be improved to >6/12 by the university optometrist in 110 (54.7%). We estimate vision could be so improved in 9.1% of all children refracted by these rural refractionists. A reason for inaccuracy in this setting is the erroneous tendency of rural refractionists to adjust instrument values for accommodation, even under cycloplegia.

Conclusions. Rural refractionists in western China have little formal training and frequently fail to optimize VA among children, even when autorefractors are used. Training is needed emphasizing better use of automated refraction, particularly in children with astigmatism and hyperopia.

Keywords: China, rural, refractionist, refraction, optometrist, accuracy

Chinese children have among the highest rates of myopia in the world,[1,2] and uncorrected refractive error accounts for over 90% of visual impairment in this group.[1,2] Recent reports confirm that access to refractive services in rural populations can reduce the risk of visual impairment significantly.[3] Uncorrected refractive error is associated with decreased self-reported visual function among children,[4] and provision of accurate spectacles can improve children's function.[5]

Despite the high prevalence of reversible visual function loss in rural China associated with children's uncorrected refractive error, little is known about the quality of refractive services available to them. Zhang et al.[6] report that nearly half of spectacles worn by rural Chinese children were inaccurate by ≥1 diopter (D), while nearly one in 10 had inaccuracy of ≥3 D. However, it was not possible to distinguish between problems due to outdated glasses and those from incorrect refraction; furthermore, information on individual refractionists was not collected.

In the course of a randomized controlled trial on the impact of correcting refractive error on children's scholastic performance in rural western China, we carried out quality control testing of the accuracy of refraction performed by rural refractionists on a random, population-based sample of elementary school children. We now report on the accuracy of rural refractionists as compared to optometrists from a tertiary eye hospital, as well as potential patient and caregiver determinants of inaccurate refraction.

Methods

The protocol for this study was approved in full by the Institutional Review Boards at Stanford University (Palo Alto, CA) and the Zhongshan Ophthalmic Center, Sun Yat-sen University (Guangzhou, China). Written permission was received by the local Board of Education in each region, by the principals of all schools, and from the rural refractionists and university optometrists participating in the study. The principals of the Declaration of Helsinki were followed throughout. Methods of the study have been described in detail elsewhere, and are summarized here for reference.[7]

Sampling

A list of primary schools was obtained for all 18 counties in two prefectures, Tianshui Prefecture in Gansu Province and Yulin Prefecture in Shaanxi Province, except for one county in Yulin (eliminated due to small size and inaccessibility). From the list of 435 schools, those having <50 or >150 students in the fourth and fifth grades together ($n = 85$ or 19% of the sample frame) were eliminated to avoid the inefficiency of visiting small schools and the logistical difficulty of being unable to complete screening at a school in a single day. One school from each township in all of the 18 counties in the sample was selected at random, and within each school, one class was chosen in each grade. In total, 10,308 students were selected in 120 schools in Tianshui Prefecture (Gansu) and 9667 from 133 schools in Yulin Prefecture (Shaanxi). Chinese law requires 9 years of compulsory schooling, and primary school attendance rates are high throughout the country. Even in very poor Gansu province, it is estimated that primary school nonattendance is only 2.42% for the entire province, and <5% for Tianshui.[8] Thus, the myopia figures provided here are likely representative of the population as a whole.

Setting

Shaanxi's gross domestic product (GDP) per capita of USD6108 was ranked 14th among China's administrative regions in 2012, and was very similar to that for the country as a whole (USD6091) in the same year,[9] while Gansu was the second-poorest province in the country (per capita GDP USD3100).[9] Yulin prefecture in northern Shaanxi has a per capita GDP, placing it second of all prefectures in the province, exceeding the provincial average by 66%. The population is 99.4% Han Chinese.[10] Tianshui is highly mountainous, and its per capita GDP of USD1359 places it 11th of Gansu's 14 prefectures. The population is 93.1% Han Chinese.[11,12] In summary, Yulin represents a relatively wealthy region in a middle-income province; Tianshui constitutes a poor region of one of China's poorest provinces.

Data Collection

During September and October 2012, children underwent visual acuity (VA) screening by a local team consisting of one nurse and one staff assistant. The VA was tested separately for each eye at a distance of 4 m using Early Treatment Diabetic Retinopathy Study (ETDRS) charts[13] in a well-lighted area of the school. The VA was measured without refractive correction for all children and also with habitually-worn correction for those children having glasses.

Each child started testing from the 6/60 line. If the orientation of at least four of the five optotypes was identified correctly, the child was next examined on the 6/30 line. If one or no optotypes were missed, testing continued at 6/15 and proceeded line by line to 6/6. In case of failure to identify 4 or more optotypes on a line correctly, the line immediately above was tested until the child identified at least four of the five optotypes on a single line. The lowest line read successfully was recorded as the VA for the eye undergoing testing.

A second vision examination was carried out one to two weeks after the first, when the team described above, with the addition of one local refractionist, returned to carry out refraction. The local refractionists each were recruited from private optical shops that provided the bulk of refractive services in the communities selected for the study. Children underwent cycloplegia with a single drop of cyclopentolate 1% after topical anesthesia with one drop of proparacaine hydrochloride 0.5%. A second drop of cyclopentolate was given 10 minutes later, and a third 20 minutes after that if the pupil diameter remained <6 mm and/or if the pupillary reflex still was present. Children then underwent automated refraction (Topcon KR 8900; Topcon, Tokyo, Japan) five times in each eye. The mean was computed automatically, and this value was used as the starting point for subjective refinement by the local refractionist, using loose lenses provided for the purpose.

A third visit to a randomly-selected sample of approximately 1/3 of schools in Shaanxi ($N = 33$) and Gansu ($N = 36$) was carried out one month later as a quality check by a team consisting of experienced optometrists and ophthalmologists from Zhongshan Ophthalmic Center, a large, tertiary eye hospital in Guangdong Province. At this time, VA testing and automated refraction with subjective refinement were carried out per the above protocol on the following children at each school: five children selected at random whose uncorrected VA was ≤6/12 in either eye, but could be corrected to >6/12 in both eyes with refraction, and all students whose VA could not be corrected with refraction to >6/12 in either eye (suspected of amblyopia or other ocular pathology). The university optometrists were not masked to the refractive results from the rural refractionists.

Statistical Methods

To adjust for unequal sampling proportions among children having correctable or uncorrectable vision on refraction by local practitioners in Shaanxi versus Gansu, weighting was used to derive estimates for the complete study population.

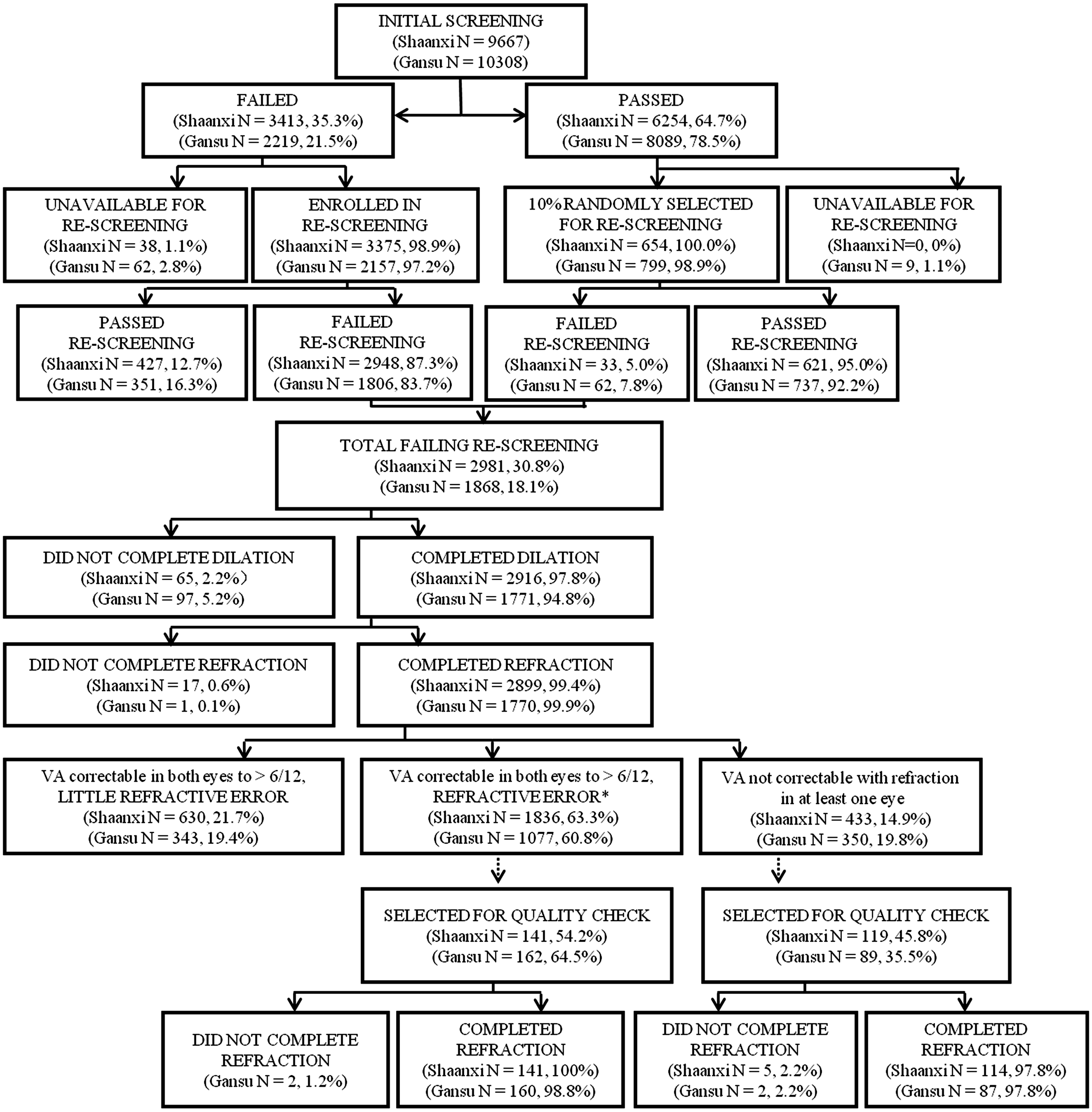
The following formula[14,15] was used to calculate the vector difference in diopters, conventionally positive, between the subjective prescription of the rural refractionist and the subjective prescription of the university optometrist for each eye of each child, as well as the difference in power between automated refraction and the subjective power prescribed by rural refractionists:

$$\text{Vector Dioptric Distance (VDD)} = \text{sqrt}(2) \times \text{sqrt}\left([\text{SE}_1 - \text{SE}_2]^2 + [\text{J0}_1 - \text{J0}_2]^2 + [\text{J45}_1 - \text{J45}_2]^2\right),$$

where SE = spherical equivalent refractive error (sphere + cylinder/2), J0 = –(sphere power/2) × cos(2 × axis), J45 = –(cylinder power/2) × sin(2 × axis).

Characteristics of children and rural refractionists were assessed as potential determinants of inaccurate prescriptions by the rural refractionist, taking the university optometrist as a gold standard. The proportion of prescriptions differing by ≥1 D, ≥2 D, and ≥3 D in the better seeing eye were calculated for each characteristic and compared to the χ^2 test using the Survey features in STATA to account for sampling inequality and clustering effects by rural refractionist. To determine whether rural refractionists tend to give more or less myopic prescriptions than university optometrists, VDD was recorded as negative when the power prescribed by the university optometrist was more negative than that prescribed by the rural refractionist, and the median of VDD using this convention was calculated for each potential determinant of inaccurate prescription.

Simple logistic mixed regression models were used including both eyes of each child to estimate odds ratios (ORs) for different characteristics of the child and the rural refractionist, taking a difference of ≥1 D in prescribed power between the rural refractionist and the university optometrist as cutoff for an inaccurate result. Child and refractionist were included in a random intercept model using the PROC



* correctable spherical equivalent refractive error <=-1.00 D, >=+2.00 D in either eye or astigmatism of >=0.75 D in both eyes

Figure 1. Flow chart of enrollment into the study (Shaanxi and Gansu provinces). All children underwent initial screening of VA carried out by a local team consisting of one nurse and one staff assistant. Failure on this examination was defined by uncorrected VA $\leq$ 6/12 in either eye. A second "rescreening" examination was carried out by the team described above with the addition of a local refractionist one to two weeks after the first examination. A third "quality check" visit at a randomly-selected sample of 1/3 of schools was carried out one month later by a team consisting of experienced optometrists and ophthalmologists from Zhongshan Ophthalmic Center.

GLIMMIX command in SAS to adjust for the correlation between eyes of a student and between children refracted by the same refractionist.[16–18] The effect of the random parts of the model were tested using the likelihood ratio test comparing the pseudo likelihoods of the models with and without the random parts. The effect of the refractionist was not significant, so the results are shown only with adjustments for correlation between the two eyes of a child. Tests of hypotheses for the fixed effects are based on Wald-type tests and the estimated variance-covariance matrix.

All analyses were performed using Stata 12.0 (StataCorp, College Station, TX) and SAS 9.3 (SAS Institute, Cary, NC).

Table 1. Demographic and Clinical Characteristics of 502 Rural Children With Uncorrected VA ≤ 6/12 in One or Both Eyes Participating in the Study

Characteristic	VA Correctable in Both Eyes to >6/12,* N (%) 301, 60.0% of 502	Visual Acuity Not Correctable With Refraction in at Least 1 Eye,* N (%) 201, 40% of 502	Total N (%) 502, 100.0
Age, y			
≤9	61 (20.3)	36 (17.9)	97 (19.3)
10	111 (36.9)	75 (37.3)	186 (37.1)
11	81 (26.9)	61 (30.4)	142 (28.3)
≥12	48 (16.0)	29 (14.4)	77 (15.3)
Sex			
Male	141 (46.8)	94 (46.8)	235 (46.8)
Female	160 (53.2)	107 (53.2)	267 (53.2)
Home province			
Gansu	160 (53.2)	87 (43.3)	247 (49.2)
Shaanxi	141 (46.8)	114 (56.7)	255 (50.8)

* Clinical status per local refractionist.

Results

In Shaanxi, a total of 2899 children with VA ≤ 6/12 in at least one eye underwent refraction by the rural refractionists. In Gansu, the number was 1770. Among these children, 511 were selected to be refracted by university optometrists as part of the quality check process, of whom 9 were excluded because of missing refraction data (Fig. 1). These 502 children form the basis for the remaining analyses except where indicated.

These children had a mean age of 10.5 years (SD 1.2 years), 53.2% ($n = 267$) were girls, and roughly equal numbers were from Shaanxi ($n = 255$, 50.8%; 8.8% of the total sample of 2899) and Gansu ($n = 247$, 49.2%; 14.0% of the total sample of 1770). Among children selected for refraction quality testing, 60.0% ($n = 301$) had VA correctable to >6/12 in both eyes by the rural refractionists, while 40.0% ($n = 201$) could not be corrected with refraction in one or both eyes (Table 1) .These latter children were deliberately over-sampled during quality control testing: vision was uncorrectable in one or both eyes by rural refractionists in 14.9% (433/2899) of all children undergoing refraction in Shaanxi and 19.8% (350/1770) in Gansu.

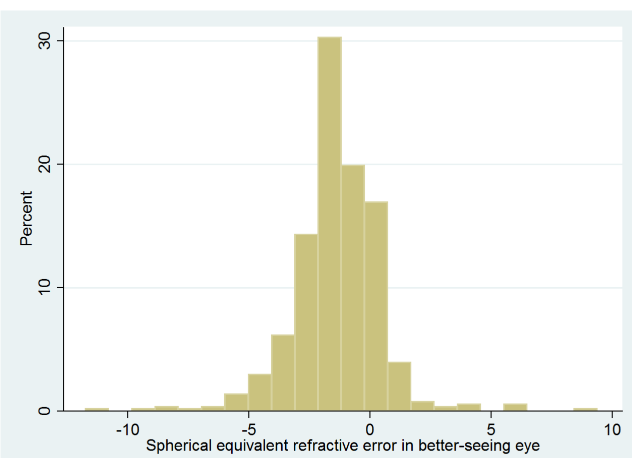


Figure 2. Distribution of spherical equivalent refractive error in the better-seeing eye among 502 rural children with uncorrected VA ≤ 6/12 in at least one eye, according to university optometrists.

Figure 2 shows the distribution of refractive error in the better-seeing eye according to refractive power prescribed by the university optometrists.

Among the 21 rural refractionists enrolled in the study, the mean age was 32.0 years (range, 20–49 years), and 71.4% ($n = 15$) were male. Roughly half each came from Shaanxi ($n = 11$, 52.4%) and Gansu ($n = 10$, 48.6%), and their educational background was modest: 23.8% ($n = 5$) had only a middle school (junior high school) education, 47.6% ($n = 10$) had completed high school, and only 28.6% ($n = 6$) had attended college. Table 2 provides additional information for the refractionists on certification, work experience, professional training, and volume of glasses dispensed monthly.

The 21 rural refractionists each refracted a mean of 24 students (range, 5–46) in the current study, while the mean for the 11 university optometrists was 42 (range, 22–53). In the overall study sample of 3696 students, 23 rural refractionists refracted on average 161 students (range, 30–299).

The median vector diopteric difference between the refractive power in the better-seeing eye (subjective refraction) according to the rural refractionists and university optometrists was –0.4 D (indicating a more myopic refractive power for university optometrists), while 18.4% of eyes differed by an absolute value of ≥1.0 D, 9.5% by ≥2.0 D, and 4.2% ≥3.0 D (Table 2). Though college-educated rural refractionists were roughly twice as likely to have prescriptions inaccurate by ≥2.0 D (12.9% vs. 6.5%, $P < 0.05$) compared to those with only a middle school education, differences in error rates stratifying by refractionist characteristics were otherwise modest (Table 2).

Error rates were relatively low (13.1% ≥1.0 D, 7.5% ≥2.0 D, 2.6% ≥3.0D) among children having myopia (≤–0.5 D, $n = 3096$), but were significantly ($P < 0.001$) higher among hyperopic (≥+0.5 D, $n = 226$) children (55.4% ≥1.0 D, 32.1% ≥2.0 D, and 21.9% ≥3.0 D, Table 3). Error rates also were significantly higher for children with astigmatism (≥0.5 D, $n = 750$): 40.5% ≥1.0 D of error versus 12.8% among children without astigmatism ($P < 0.001$). Likewise, having VA not correctable to ≥6/12 was an important predictor of poor refractive accuracy: nearly half (45.9%) of such children had ≥1.0 D of inaccuracy, versus 11.1% of children among whom VA could be corrected ($P < 0.001$). In all cases, a greater tendency towards more myopic refractive error by the university optometrists was present among children at greater risk for inaccurate results. Children's age, sex, and home

Table 2. Accuracy of Refractive Error in the Better Seeing Eye, Comparing Local Refractionists and University Optometrists, Stratified by Rural Refractionists' ($n = 21$) Characteristics

Characteristic, *n*	Median, D	Proportion of Prescriptions Differing by <1.0 D*	Proportion of Prescriptions Differing by ≥ 1.0 D*	Proportion of Prescriptions Differing by ≥ 2.0 D*	Proportion of Prescriptions Differing by ≥ 3.0 D*
Age, y					
≤30, *n* = 10	−0.40	81.0	19.0	8.4	4.2
>30, *n* = 11	−0.40	82.2	17.8	10.7	4.3
Sex					
Male, *n* = 15	−0.40	81.6	18.4	9.9	4.0
Female, *n* = 6	−0.40	81.5	18.5	8.6	4.7
Home province					
Gansu, *n* = 10	−0.40	80.5	19.5	8.0	3.6
Shaanxi , *n* = 11	−0.40	82.2	17.8	10.5	4.6
Education					
Middle school, *n* = 5	−0.40	86.7	13.3	6.5	2.2
High school, *n* = 10	−0.40	82.7	17.3	7.8	4.1
College, *n* = 6	−0.40	77.8	22.2	12.9†	5.4
Certification					
Junior, *n* = 4	−0.40	82.5	17.5	8.1	4.0
Middle, *n* = 10	−0.40	83.6	16.4	9.4	4.9
Senior, *n* = 7	−0.40	79.2	20.8	10.5	3.7
Working experience					
≤10 years, *n* = 13	−0.40	80.4	19.6	10.1	5.1
>10 years, *n* = 8	−0.40	83.7	16.3	8.4	2.7
Graduated from professional school					
Yes, *n* = 6	0.0	83.8	16.2	7.7	3.7
No, *n* = 15	−0.40	80.6	19.3	10.3	4.5
Glasses sold each month					
≤200, *n* = 12	−0.40	80.0	20.0	11.3	4.7
>200, *n* = 9	−0.40	84.2	15.8	6.6†	3.4

The values represent estimated differences across the entire population-based cohort of children, based on our random sample, if all had been examined by the rural refractionists and university optometrists. A negative value for the difference between rural refractionists and university optometrists indicates that the refractive power from the university optometrist was more minus (myopic).

* Proportions are compared to the χ^2 test, and refer to absolute value of the refractive power.

† $P < 0.05$.

province were unassociated with inaccuracy of refraction (Table 3).

In logistic regression models of the risk of having ≥1.0 D of error (absolute value) compared to university optometrists (Table 4), only having a university education was significantly associated among refractionist characteristics (OR = 1.9; 95% confidence interval [CI], 1.2–3.2; $P = 0.01$ in the simple regression analysis). However, among children, having hyperopia (OR = 4.2; 95% CI, 2.4–7.3; $P < 0.001$), astigmatism (OR = 3.8; 95% CI, 2.5–5.6; $P < 0.001$), and VA uncorrectable to >6/12 (OR = 4.7; 95% CI, 3.1–7.3; $P < 0.001$) all were associated independently with refractive inaccuracy in the multiple regression model (Table 4).

Comparing the power by autorefraction and that by subjective refraction from the rural refractionist, the automated value was more myopic among the majority of children in whom VA could be improved with refraction (Fig. 3).

Among 201 children whose vision was uncorrectable in at least one eye by the rural refractionists, vision could be improved in one or both eyes by the university optometrist in 110/201 (54%; Gansu, 40/87 = 46%; Shaanxi, 70/114 = 61%). Assuming the same rate among all 783 children with VA ≤ 6/12 that could not be improved by the rural refractionists, vision could have been improved with more expert refraction in an additional 425 children in the entire study sample (161 in Gansu, 264 in Shaanxi), or 9.1% of all children undergoing refraction (9.0% in Gansu and 9.1% in Shaanxi).

Discussion

While powers for the large majority of children as measured by the rural refractionists were accurate, particularly for those children with simple myopia, a number of factors were associated with relatively poor accuracy, particularly astigmatism, hyperopia, and children whose vision could not be improved to ≥6/12.

The visual consequences of poor refractive accuracy among rural refractionists were significant: more than one in six children (783/4669 = 17%) with poor vision undergoing refraction in the larger, population-based study in which the current project was nested could not be corrected by rural refractionists to >6/12 in one or both eyes. In more than half

TABLE 3. Accuracy of Refractive Error in the Better Seeing Eye, Comparing Local Refractionists and University Optometrists, Stratified by Children's Characteristics

Characteristic, *n*	Median, D	Proportion of Prescriptions Differing by <1.0 D*	Proportion of Prescriptions Differing by ≥1.0 D*	Proportion of Prescriptions Differing by ≥2.0 D*	Proportion of Prescriptions Differing by ≥3.0 D*
Total, *n* = 3696	−0.40	81.6	18.4	9.5	4.2
Age, y					
≤9, *n* = 771	−0.40	85.1	14.9	4.7	3.7
10, *n* = 1340	−0.40	80.6	19.4	12.6	4.4
11, *n* = 1047	−0.40	79.7	20.3	10.4	4.7
≥12, *n* = 538	−0.40	82.6	17.4	7.2	3.7
Sex					
Male, *n* = 1711	−0.40	80.5	19.5	8.4	4.3
Female, *n* = 1985	−0.40	82.5	17.5	10.5	4.2
Home province					
Gansu, *n* = 1427	−0.40	80.5	19.5	8.0	3.6
Shaanxi, *n* = 2269	−0.40	82.2	17.8	10.5	4.6
Spherical equivalent					
≤−0.5 D, *n* = 3096	−0.40	86.3	13.7	8.1	2.9
−0.5 to +0.5 D, *n* = 374	−0.40	64.4	35.6	7.8	4.6
≥+0.5 D, *n* = 226	−1.12	44.6	55.4†	32.1†	21.9†
Astigmatism					
< 0.5 D, *n* = 2946	−0.40	87.2	12.8	5.7	2.5
≥0.5 D, *n* = 750	−0.78	59.5	40.5†	24.6†	11.1‡
Clinical status per local refractionist					
VA correctable in both eyes to > 6/12, *n* = 2913	−0.40	88.9	11.1	6.1	2.0
Visual acuity not correctable with refraction in at least 1 eye, *n* = 783	−0.79	54.1	45.9†	22.4†	12.4†

The values represent estimated differences across the entire population-based cohort of children, based on our random sample, if all had been examined by the rural refractionists and university optometrists. A negative value for the difference between rural refractionists and university optometrists indicates that the refractive power from the university optometrist was more minus (myopic).

* Proportions are compared to the χ^2 test and refer to the absolute value of the refractive power.

† $P < 0.001$.

‡ $P < 0.01$.

(54%) of such cases in our quality control sample, the university optometrists could improve vision to >6/12 in one or both eyes. Among all children undergoing refraction in this rural setting in western China, we estimated that nearly one in 10 (9.1%) had poor vision due to inaccurate refraction, which could have been improved with more expert care.

Examination of data from the autorefractors used by the rural refractionists (Fig. 3) offers a potential explanation for at least part of the inaccuracy problem. Rural refractionists consistently had subjective refractive power that was less myopic than produced by the autorefractor used, or than was prescribed by the university optometrists. We hypothesized that rural refractionists, who generally are not permitted to administer cycloplegic agents in China due to their lack of medical licensure, have developed the habit of prescribing a less myopic power than indicated by an autorefractor to correct for instrument accommodation in children without cycloplegia. This practice not only is unnecessary in a setting where cycloplegia is used, but, in fact, leads to inaccurate power and less-than-optimal visual results as seen here.

Our results have clear implications for training of rural refractionists. These practitioners have very little formal education, with fewer than one in three (28.6%) having attended university or having received any formal professional training. It is clear that refractionists in this setting require further formal training in how to interpret and use the results of an automated refractor, which remains the most widely-used tool for refraction of children in rural China. A more accurate understanding of correcting for accommodation, managing hyperopia, and improving the vision of children with astigmatism are areas that must be addressed in a formal curriculum for rural refractionists. Finally, it is clear that in those cases where autorefraction did not improve vision optimally, refractionists were overly-dependent on the device, and unable to use subjective refraction to improve vision.

Few other studies have investigated the prevalence and causes of inaccurate refraction, particularly among rural practitioners. Zhang et al.[6] found that 48.8% of glasses owned by a cohort of some 600 older (mean age 15.0 years) children in rural China were inaccurate by ≥1.0 D, and that nearly a third (30.3%) of these children had presenting VA ≤ 6/12. Many of these spectacles were inaccurate due to being out of date rather than due to poor refractive practices, making it difficult to comment on specific areas requiring improvement in training. Robaei et al.[19] report that over a third (38.3%) of 12-year-old children wearing glasses in Australia had no significant refractive error in either eye, though again, changes in refractive power since the time of original assessment could not be ruled out as a cause, and specific recommendations to improve results could not be made readily.

Strengths of the current study include the population-based nature of the underlying investigation from which subjects

TABLE 4. Generalized Linear Mixed Model of Potential Predictors of Local Refractionists Producing an Inaccurate Prescription (Absolute Power of the Difference in Refractive Power Compared to University Optometrists $\geq$ 1.0 D)

	Simple Model			Multiple Model		
Characteristic	OR	P Value	95% CI	OR	P Value	95% CI
Children's characteristics						
Age, y	1.2	0.26	0.9–1.5	1.0	0.64	0.9–1.2
Male sex	1.0	0.84	0.7–1.5	0.8	0.37	0.6–1.2
Home province Gansu	0.9	0.73	0.7–1.4	0.9	0.69	0.6–1.4
Visual acuity not correctable with refraction according to rural refractionist	7.8*	<0.001*	5.5–11.3*	4.7*	<0.001*	3.1–7.3*
Spherical equivalent,† reference is ≤−0.5 D						
−0.5 to +0.5 D	3.0*	<0.001*	1.9–5.0*	1.5	0.18	0.8–2.6
≥+0.5 D	12.4*	<0.001*	7.6–20.2*	4.2*	<0.001*	2.4–7.3*
Astigmatism ≥ 0.5 D	4.8*	<0.001*	3.4–6.9*	3.8*	<0.001*	2.5–5.6*
Rural refractionists' characteristics						
Age, y	1.0	0.83	0.98–1.03	1.0	0.61	0.98–1.04
Male sex	0.8	0.32	0.6–1.2	0.8	0.50	0.5–1.4
Education, vs. middle school						
High school	1.4	0.21	0.8–2.2	1.4	0.32	0.7–2.6
University	1.9*	0.01*	1.2–3.2*	1.7	0.14	0.8–3.6
Certification, vs. junior						
Middle + senior	1.1	0.66	0.7–1.8	1.0	0.92	0.5–2.0
Working experience						
>10 y	0.9	0.47	0.6–1.3	0.9	0.71	0.6–1.5
Graduated from professional school	0.9	0.75	0.6–1.4	0.8	0.41	0.5–1.4
Glasses sold each mo > 200	0.8	0.17	0.5–1.1	0.9	0.62	0.5–1.5

Both eyes of 502 children are included, and the model adjusts for the correlation between them.
* $P < 0.05$.
† As prescribed by the university optometrist.

were drawn, the selection of a relevant population in whom uncorrected refractive error is prevalent, and availability of quality control refractions by trained specialists. Weaknesses include the fact that insufficient rural refractionists were available to draw many meaningful inferences about practitioner-level factors associated with poor performance, and the fact that application of these conclusions to regions outside of the study area must be made only with care. Further, we did not mask the university optometrists to the results of the rural refractionists, or carry out testing or analyses to determine the accuracy of the university optometrists. Though the focus of this study was on accuracy among rural refractionists and not university practitioners, we cannot exclude the possibility that the latter may have conducted inaccurate examinations as well, nor that differences between rural refractionists and university practitioners might have been greater if masking had been used.

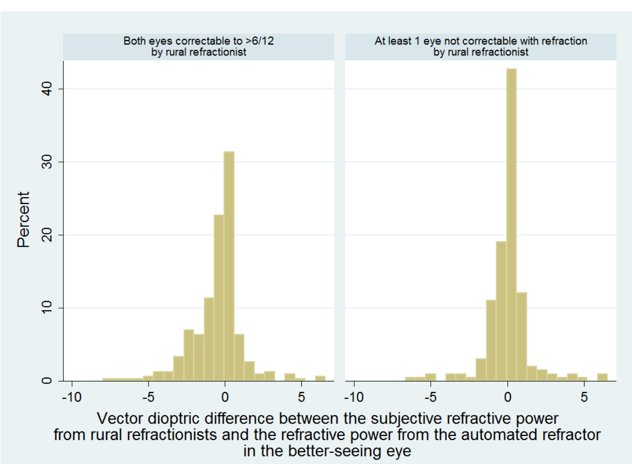


FIGURE 3. Vector diopteric difference between the subjective refractive power from rural the refractionists and from the autorefractor, in the better-seeing eye of 503 rural children. A negative value means that the power from the autorefractor was more myopic (minus).

Despite its limitations, this study provided previously-unavailable evidence that incompletely-corrected vision due to inaccurate refraction is likely to be a significant problem in western China, while also suggesting specific topic areas in which additional training could improve current practice. The number of children potentially affected in China is very large, with the World Health Organization reporting that nearly half of vision impairment among children in the world occurs there.[20] Further, few if any data are available on the quality of refraction in other areas of limited resources, and similar problems may well exist elsewhere. Studies of refractive outcomes in other such settings are indicated, as are randomized trials of the impact of targeted training programs for refractionists on quality.

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