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# Factors Underlying Different Myopia Prevalence between Middle- and Low-income Provinces in China

Currently available data on myopia and spectacle wear are drawn largely from China's richer and middle-income areas, and little is known about refractive error and spectacle wear in the lowest income provinces. Studies from China and elsewhere suggest that large differences in myopia prevalence may exist between areas of different socioeconomic status within countries, but reasons for these differences are not well understood. The current report details the prevalence and predictors of myopia measured using the identical protocols and equipment in 2 adjoining provinces of western China, middle-income Shaanxi and low-income Gansu. Study methods including institutional review board approvals and consent have been described elsewhere.[1]

The study was carried out in Yulin prefecture, Shaanxi, and Tianshui prefecture, Gansu Province, which are nearby areas. Shaanxi's gross domestic product per capita is $US6108 and was ranked 14th among China's 31 administrative regions in 2012, while Gansu is the second-poorest province in the country (per capita gross domestic product of $US3100).[2] Yulin is a relatively wealthy region in a middle-income province and Tianshui constitutes a poor region of one of China's lowest-income provinces.

A complete list of primary schools was obtained, and 1 school from each township in the 2 prefectures was selected at random (Yulin, Shaanxi n = 132; Tianshui, Gansu n = 120). Within each school, 1 class was randomly chosen in each of the 4th and 5th grades.

The following data were collected in September 2012: children's age, sex, boarding at school, parental schooling and migration for work, family wealth, classroom blackboard use, and visual acuity. Children with uncorrected visual acuity of ≤6/12 in either eye underwent cycloplegic refraction. A study-specific mathematics test was administered as an index of academic achievement. In May and June 2013, we collected data on parental spectacle wear, children's time spent outdoors and in near/middle distance work using validated instruments.[3]

Clinically significant myopia was defined as uncorrected visual acuity of ≤6/12 in either eye and a spherical equivalent of ≤−0.5 diopter in both eyes. Characteristics were compared between children in the 2 prefectures, accounting for sampling weight and school clustering. Relative risk (RR) estimation using general linear modeling with Poisson regression and robust error variance was used to determine the association between potential risk factors and myopia for the 2 provinces separately and for the total study population. Subjects with missing myopia data (n = 306 [1.5%]) were excluded.

Among 9489 children in Shaanxi (mean age, 10.4±1.03 years; 53.1% boys), the prevalence of clinically significant myopia (22.9%; 95% CI, 21.2%−24.7%) was nearly twice that of 10 137 children (mean age, 10.7±1.24 years; 49.1% boys) in Gansu (12.7%; 95% CI, 11.3%−14.1%; RR for Shaanxi vs Gansu 1.81 [95% CI, 1.58−2.07; $P < 0.001$]).

Parents out-migrating for work were less common in the Shaanxi cohort (8.10%) than in the Gansu cohort (16.8%; $P < 0.001$), and families were less likely to be in the lowest wealth tertile for the total sample in Shaanxi (17.2% vs 38.7%; $P < 0.001$). One-half of our Shaanxi cohort (49%) versus 3.6% in Gansu lived in low population density areas ($P < 0.001$). Mathematics scores were higher in Shaanxi ($P = 0.03$), and the blackboard was used less in Shaanxi than in Gansu (26.7% of classes spending the majority of class time directed at the blackboard in Shaanxi vs 45.5% in Gansu; $P < 0.001$; Table 1, available at www.aaojournal.org). Differences in outdoor activity and near and middle distance work were minimal between Shaanxi and Gansu, and between children with and without myopia (Table 2, available at www.aaojournal.org).

Older age (RR, 1.07; 95% CI, 1.02−1.13), parental glasses wear (RR, 1.57; 95% CI, 1.39−1.77), and higher math score (RR, 1.20 [95% CI, 1.13−1.28] per increase of 1 standard deviation in score) were associated with increased risk for myopia in both provinces separately and in the total study population (above RRs are for the total study population). Male sex (RR, 0.81; 95% CI, 0.73−0.91) was associated with lower risk and near work (RR, 1.02 [95% CI, 1.00−1.03] per hour/week increase), with greater risk in the total study population and in Shaanxi alone, but not in Gansu alone. Blackboard use and family wealth were not associated with myopia risk in the multivariate model and no clear linear pattern was found for population density across quartiles (Table 3). Residence in Shaanxi was associated with a 69% increased risk of myopia (RR, 1.69; 95% CI, 1.39; 2.06) after adjusting for other risk factors. The likelihood ratio test ($P < 0.001$) and pseudo $R^2$ (<20%) both suggest that the current model fits the data well, and that the conclusion is valid that real, as-yet-unexplained differences exist between myopia prevalence in Shaanxi and Gansu.

Even after adjusting for differences in factors associated with myopia, such as near work,[4] school achievement,[4] and outdoor activity,[3] we could not explain much of the large variation in prevalence of clinically significant myopia between middle-income Shaanxi and low-income Gansu. The current study is among the first to compare known myopia risk factors between nearby areas with large differences in myopia rates. It is possible that the low near work demand in the current cohort (8 hours in both Gansu and Shaanxi vs 23−30 hours in Singapore and Australia[3]) might explain the lack of large effects of near work and outdoor activity.

Greater blackboard use was protective against myopia in univariate analyses (data not shown), perhaps owing to lower near work demands: weekly near work was lower with highest (6.7 hours) versus lowest (7.6 hours; $P < 0.05$) blackboard use. Greater blackboard use was also associated with less wealth here (data not shown), because schools in low-income areas could not afford textbooks, which may confound the association with myopia. More research is needed on myopia risk and classroom use of near and distance teaching tools.

Our definition of myopia included visual acuity, which limits comparisons with other studies, although not internal comparison between Shaanxi and Gansu. Primary school attendance rates are >95% in the area[5]; thus, this school-based sample is likely representative of the population. It is unlikely that genetic factors

Table 3. Multiple Regression Model of Risk Factors for Myopia in Shaanxi and Gansu*

| Characteristics | Shaanxi | | | Gansu | | | All | | |
|---|---|---|---|---|---|---|---|---|---|
| | *RR* | *95% CI* | *P* | *RR* | *95% CI* | *P* | *RR* | *95% CI* | *P* |
| Age | **1.09** | **1.02, 1.17** | **0.02** | 1.07 | 0.99, 1.16 | 0.10 | **1.07** | **1.02, 1.13** | **0.008** |
| Male sex | **0.73** | **0.64, 0.82** | **<0.001** | 0.99 | 0.81, 1.20 | 0.90 | **0.81** | **0.73, 0.91** | **<0.001** |
| One or both parents with high school or greater education | 0.91 | 0.76, 1.09 | 0.30 | **1.28** | **1.01, 1.63** | **0.04** | 1.04 | 0.90, 1.21 | 0.57 |
| Both parents out-migrated for work | 0.99 | 0.75, 1.30 | 0.92 | 0.97 | 0.75, 1.26 | 0.82 | 0.97 | 0.80, 1.17 | 0.75 |
| Family wealth | | | | | | | | | |
| Lowest tertile | | Reference | | | Reference | | | Reference | |
| Middle tertile | 1.01 | 0.82, 1.23 | 0.95 | 1.07 | 0.85, 1.33 | 0.56 | 1.03 | 0.89, 1.20 | 0.69 |
| Highest tertile | 1.13 | 0.94, 1.36 | 0.18 | 0.94 | 0.72, 1.23 | 0.65 | 1.08 | 0.92, 1.25 | 0.35 |
| Parents wearing glasses | **1.61** | **1.39, 1.86** | **<0.001** | **1.51** | **1.22, 1.87** | **<0.001** | **1.57** | **1.39, 1.77** | **<0.001** |
| Population density (persons/km$^2$) | | | | | | | | | |
| $\leq$83 | | Reference | | | Reference | | | Reference | |
| 83–166 | **0.76** | **0.65, 0.88** | **0.001** | 1.06 | 0.64, 1.74 | 0.83 | **0.76** | **0.66, 0.88** | **<0.001** |
| 166–319 | 0.80 | 0.63, 1.01 | 0.06 | 1.13 | 0.72, 1.75 | 0.59 | **0.80** | **0.66, 0.98** | **0.03** |
| >319 | 0.53 | 0.27, 1.02 | 0.06 | 1.31 | 0.85, 2.03 | 0.21 | 0.94 | 0.74, 1.19 | 0.59 |
| Total time spent in near-work (h/wk) | **1.02** | **1.00, 1.04** | **0.02** | 1.01 | 0.98, 1.04 | 0.57 | **1.02** | **1.00, 1.03** | **0.04** |
| Baseline math scores | **1.19** | **1.10, 1.28** | **<0.001** | **1.22** | **1.09, 1.37** | **0.001** | **1.20** | **1.13, 1.28** | **<0.001** |
| Proportion of class-time using blackboard | | | | | | | | | |
| More than half | | Reference | | | Reference | | | Reference | |
| Half | 0.95 | 0.79, 1.14 | 0.58 | **1.39** | **1.12, 1.71** | **0.002** | 1.13 | 0.98, 1.29 | 0.09 |
| Less than half | 1.01 | 0.86, 1.19 | 0.88 | 1.36 | 0.97, 1.89 | 0.07 | 1.14 | 0.98, 1.33 | 0.08 |
| Shaanxi vs Gansu residency | | — | | | — | | **1.69** | **1.39, 2.06** | **<0.001** |

Values in boldface are significant at the $P < 0.05$ level.
*Relative risk (RR) and 95% CI for multiple regression including all potential risk factors (1st column) taking into account sampling weight and clustering within schools.

explain refractive differences between these populations, which unlike some parts of western China, are both >90% Han. Nutrition-related differences in body height have also not been associated with refractive errors in previous studies in China.

Although unexamined or unknown economic factors might have better explained differences in myopia between these regions, it remains unclear how economic differences affect myopia, if not through known behavioral risk factors. Understanding reasons for low myopia prevalence in low-income areas might eventually lead to myopia prevention strategies.

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## The Early Treatment in Diabetic Retinopathy Study Chart Compared with the Tumbling-E and Landolt-C

Visual acuity (VA) is a measure of the visual system's ability to resolve fine detail and is expressed using the logarithm of the minimal angle of resolution (logMAR), which depends on the angular size of critical detail in optotypes. Charts originally developed for the Early Treatment in Diabetic Retinopathy Study (ETDRS) and subsequently refined have become the gold standard in ophthalmology research and are based on the design principles of Bailey and Lovie; they have logarithmic scales, 5 optotypes per line, and geometric progression in letter size and spacing.[1,2] The letter size on each line is 1.2589, or 0.1 log units, times bigger than those on the next line and optotypes are the 10 Sloan letters (C, D, H, K, N, O, R, S, V, and Z).

Because not all patients are familiar with the Roman alphabet, from which Sloan letters originate, other optotypes are used in charts modelled on the ETDRS layout. The Landolt-C and Tumbling-E are such optotypes consisting of a single shape (C or E) presented in 1 of 4 orientations: upright or up-side-down and facing left or right. The Landolt-C is internationally regarded as the reference optotype and the Tumbling-E is commonly used in clinical practice.[3] Interestingly, of ETDRS optotypes, C has been shown to be the most difficult to resolve, whereas E is not utilized.[2] This study aimed to compare VA measured by Tumbling-E and Landolt-C charts with the gold standard ETDRS charts, thus helping to standardize clinical data across populations not using the Roman alphabet, such as many of those native to eastern Europe, the Middle East, Indian subcontinent, and Asia, as well as people using Latin languages who may be illiterate, particularly in the developing world.

Patients presenting at a community ophthalmology practice were invited to participate; 112 patients with an average age of 63 years (range 18-87) were recruited. The analysis included 221 eyes, almost one-half (48.9%) were healthy and various pathologic conditions affected remaining eyes (Table 1, available at www.aaojournal.org). Three low-vision eyes were excluded because no ETDRS optotypes could be determined at 1 meter. Patients were refracted according to the Age-related Eye Disease Study (AREDS) Manual of Procedures.[4] Vision was tested using ETDRS, Landolt-C, and Tumbling-E charts, with separate versions of each for right and left eyes (Precision Vision, La Salle, IL; CAT Nos: 2122, 2123, 2210, 2210A, 2305, and 2305A). Charts were mounted in a retro-illuminated cabinet with luminance of 85 cd/m$^2$ (Precision Vision; CAT No: 2425). The order of chart presentation was randomized and instructions to patients and VA scoring were in accordance with the AREDS manual, with minor modifications allowing for the Landolt-C and Tumbling-E charts. Institutional ethics committee approval was granted by Trinity College Dublin Research Ethics Committee.

Descriptive statistics, with computation of mean, standard deviation, and 95% confidence interval (CI) and the Shapiro–Wilk test for normality of distributions were applied. A specific procedure for generalized linear mixed models (GLIMMIX) for data with skewed distribution, correlations, or nonconstant variability was used. The procedure was applied with repeated effect for comparison between methods to obtain solutions with compound symmetry of covariance structures for all eyes with adjustment for possible correlation between the right and left eyes of an individual. Least-square means with 95% CIs were obtained and, if necessary, post hoc Tukey–Kramer adjustment for multiple comparisons of $P$ values was calculated. Additional subgroup analysis was undertaken on eyes with poor VA ($\geq$0.5 logMAR ETDRS). Differences between charts were graphically presented using Bland–Altman and frequency–distribution plots. Statistical significance was set at $P < 0.05$. Analyses were performed using statistical software packages IBM SPSS Statistics Ver.22 (IBM, Armonk, NY), Stata Ver.12.1 (StataCorp, College Station, TX), and SAS Ver.9.3 (SAS Inc, Cary, NC).

Using the GLIMMIX approach, the estimated mean VA measured with the ETDRS chart was 0.15 logMAR (95% CI, 0.11–0.20), the Tumbling-E chart was 0.17 logMAR (95% CI, 0.13–0.21) and the Landolt-C chart was 0.25 logMAR (95% CI, 0.21–0.30). The adjusted 0.02 logMAR difference between ETDRS and Tumbling-E charts was not significant ($P = 0.116$). However, the adjusted 0.10 logMAR difference between ETDRS and Landolt-C charts was significant ($P < 0.0001$). This shows that, although the average difference in VA measured with the Tumbling-E and ETDRS charts is negligible, there is a 1-line difference between the Landolt-C and ETDRS charts that may be clinically important. Bland–Altman plots, constructed with data from all 221 eyes, further demonstrate greater discrepancy between Landolt-C and ETDRS than that between Tumbling-E and ETDRS charts (Fig 1). Furthermore, the frequency of identical VA measurements was greater when comparing ETDRS to Tumbling-E charts than in the ETDRS versus Landolt-C comparison (Fig 2, available at www.aaojournal.org). Thus, the Tumbling-E chart provides VA measurements more closely matching the ETDRS chart. For low-vision eyes (ETDRS $\geq$ 0.5 logMAR), the mean difference between ETDRS and Tumbling-E charts was −0.07 (median, −0.04; interquartile range, −0.10 to 0.00) and between the ETDRS and Landolt-C was 0.13 logMAR (median, 0.10; interquartile range, 0.05–0.17). Possibly owing to the limited sample size ($n = 21$), the differences were not significant but do suggest that low-vision patients may score better with Tumbling-E than ETDRS charts; they may find the Landolt-C even more difficult to read.

Our findings are supported by a comparison performed amongst the Landolt-C, Tumbling-E, and the University of Crete letter charts, showing that the Tumbling-E was more comparable with the letter chart.[5] The University of Crete chart is based on the ETDRS chart but uses different letters common to the Roman, Greek, and Cyrillic alphabets, so that it is readable in Greece and other parts of Eastern Europe. Our study is the first to compare the Landolt-C and Tumbling-E charts with the gold standard ETDRS chart. Limitations of our study are that test–retest variability was not measured and relatively few subjects with poor VA were included.