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Research article

Prevalence and risk factors for refractive error in older adults in eight ethnicities in China: The China national health survey

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ABSTRACT

Purpose: This study aimed to investigate the prevalence of refractive error (RE) and risk factors for myopia among older adults in the Han and various minority ethnic groups across seven provinces in China.
Methods: This cross-sectional study forms a part of the ophthalmic dataset of the China National Health Survey (CNHS). Face-to-face interviews and ophthalmic examinations were conducted in seven provinces located in western and northern China. The age- and sex-adjusted prevalence of RE among Han and seven other ethnic groups aged 50–80 years were compared. A mixed-effects model was used to identify the risk factors associated with RE.
Results: A total of 12,902 participants, including 8800 Han and 4102 from ethnic minorities, were included in the study. The age- and sex-adjusted prevalence of myopia, high myopia, hyperopia, and astigmatism ranged from 15.3 % (Manchu) to 22.9 % (Han), 0.2 % (Yugur) to 2.8 % (Han), 21.6 % (Tibetan) to 48.9 % (Uyghur), and 38.7 % (Yi) to 57.5 % (Manchu) across different ethnicities, respectively. Compared to the Han population, the Mongolian (odds ratios (OR) 0.62, 95 % confidence interval (CI) 0.46–0.84, $p = 0.002$), Tibetan (OR 0.66, 95 % CI 0.52–0.85, $p = 0.001$), Uyghur (OR 0.63, 95 % CI 0.49–0.80, $p < 0.001$), Yi (OR 0.65, 95 % CI 0.46–0.92, $p = 0.014$), and Yugur (OR 0.65, 95 % CI 0.50–0.85, $p = 0.001$) ethnicities were less likely to have myopia. There was no significant difference in the prevalence of myopia between the Manchu, Korean, and Han ethnic groups. Factors associated with a lower prevalence of myopia included rural residence ($p < 0.001$), a body mass index (BMI) > 18.5 kg/m^2 (all $p < 0.001$), residence in higher latitude areas ($p = 0.020$), and a history of smoking ($p = 0.002$ in the past smoking group, $p = 0.031$ in the current smoking group). The Mongolian ($p = 0.006$) and Yugur ($p = 0.007$)

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populations, participants living in rural areas ($p = 0.012$), and those with a BMI >24 kg/m^2 ($p = 0.038$ in the $>24.0 \leq 27.0$ kg/m^2 group or $p = 0.041$ in the >27.0 kg/m^2 group) were less likely to have high myopia. Factors associated with a higher prevalence of hyperopia included older age (all $p < 0.001$), rural residence ($p = 0.039$), higher latitude areas ($p = 0.031$), smoking history ($p = 0.040$), and Mongolian ($p = 0.001$), Uyghur ($p < 0.001$), Yi ($p < 0.001$), and Yugur ($p = 0.002$) ethnicities. Conversely, the Manchu population ($p = 0.004$) and individuals with higher education levels than illiteracy ($p = 0.024$ or $p < 0.001$) were less likely to have hyperopia.

Conclusions: Myopia affected more than one-fifth of the older adults in the Han population in this survey. Significant differences in the prevalence of RE were observed between minority ethnicities and Han individuals, except for the Manchu and Korean groups.

1. Introduction

Complications of high myopia have become a significant cause of low vision in adults [1–3]. The early onset of myopia and its increasing prevalence among schoolchildren are exacerbating this global issue [4–6]. Previous research has shown that the prevalence of myopia is highest in East Asia [2,7]. In mainland China, several epidemiological studies have reported the prevalence of refractive errors (RE), particularly myopia, in the adult Han population of economically developed regions, ranging from 25 % to 36 % [8–10]. Despite China's ethnic diversity, research on myopia prevalence in the western regions and among ethnic minorities is limited.

The China National Health Survey (CNHS) was conducted to establish reference intervals for physiological constants among different ethnic groups across various regions. This survey represents the first comprehensive multiethnic population study to gather data from multiple regions in China [11]. RE data were collected in the western and northern ethnic minority areas across seven provinces. In previous CNHS RE studies conducted in Yunnan, Qinghai, and Gansu provinces, the prevalence of myopia and high myopia in the ethnic minority population was significantly lower than that in the Han population, whereas the prevalence of hyperopia was significantly higher [12,13]. Furthermore, compared to the Manchu population, Han participants had a higher risk of myopia and hyperopia but a lower risk of high myopia [14].

The differences in myopia prevalence among ethnic groups are complex, involving genetic factors and the living environment. Previous multiethnic studies in other countries have explored the differences in myopia prevalence between Chinese (Han) and other ethnicities. Adult Chinese Americans exhibit a higher burden of myopia, high myopia, and astigmatism [15]. In Singapore, Chinese adults have a higher prevalence of myopia, high myopia, and astigmatism compared to non-Chinese adults [16,17]. In the UK, Chinese ethnicity is associated with a 90 % increased risk of myopia compared to Caucasian ethnicity [18]. Similarly, a higher prevalence of myopia in the Han population compared to ethnic minorities has been observed in Xinjiang and Yunnan Provinces [12,19–21]. However, information on the prevalence of RE in minority ethnic groups in China remains limited. Does the Han ethnic group have a higher prevalence of myopia than all other minority groups? This study provides an opportunity to explore the prevalence of RE between Han and various ethnic groups in western and northern China. The seven provinces included in this study cover diverse geographical locations and living environments, offering further insights into the genetic and environmental impacts on myopia.

2. Materials and methods

2.1. Study population

Our study is a part of the CNHS, an ongoing cross-sectional evaluation of national health status in China. This survey uses a multistage cluster sampling method and is conducted by the Chinese Academy of Medical Sciences (CAMS) and the School of Basic Medicine at Peking Union Medical College [11]. Eleven provinces and autonomous regions were selected based on geographic location and the distribution of ethnic groups. The predominant ethnic minorities in each province were chosen as the study population. RE data were collected from seven provinces or regions: Heilongjiang Province, Xinjiang Uyghur Autonomous Region, Inner Mongolia, Qinghai Province, Gansu Province, Hebei Province, and Yunnan Province in mainland China. The survey, conducted from 2013 to 2017, included seven provincial capitals (Shijiazhuang, Harbin, Huhehaote, Xining, Wulumuqi, Kunming, and Lanzhou), five medium-sized cities, ten counties, and thirteen rural townships. Residents in the selected areas were all invited to participate. The provinces were selected based on their economic status and the size and distribution of their ethnic minority populations. Participants from diverse socioeconomic levels, living environments, and ethnicities were all recruited.

This study was approved by the institutional review board of the Institute of Basic Medical Sciences at the CAMS. The approval number is 028–2013.

2.2. Inclusion and exclusion criteria

Older adults aged 50–80 years were included in this survey because cycloplegia was not used in the refraction measurements. Another inclusion criterion was being a local resident for at least one year. Pregnant women, active-duty soldiers, individuals who were physically unable to complete a full physical examination, and those with severe mental disorders were excluded. Additionally, individuals with any eye diseases or a history of eye surgery or eye injuries were also excluded.

2.3. Measurements

A face-to-face questionnaire interview was conducted with all participants by experienced interviewers at the study center. The questionnaire collected information on demographics, lifestyle, and systemic diseases, including birthplace, current address, ethnicity, educational level, occupation, smoking status, alcohol consumption, activity level, and medical history. Anthropometric measurements of height and weight were taken during the physical examination. Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters (kg/m^2). Based on previous large-scale epidemiological studies on RE [13,18,22], BMI was categorized into four groups: $\leq$18.5, >18.5–$\leq$24.0, >24.0–$\leq$27.0, and $\geq$27.0 kg/m^2. Educational level was divided into five categories: illiteracy, primary school, middle school, high school, and university or higher. Occupation was categorized as outdoor or indoor, with physical labor further classified as light, medium, or heavy. Exercise status was categorized into the following frequencies: 5–7 days a week (at least 20 min per day), 3–4 days a week, 1–2 days a week, less than 3 days a month, and no exercise. Physical labor and exercise activities were grouped together to determine the overall activity level. A heavy activity level was defined as exercising $\geq$5 days a week or engaging in heavy physical labor. Smoking and alcohol consumption statuses were classified as never, past, or current smoker/drinker.

2.4. Assessment of RE

Noncycloplegic autorefraction and corneal curvature radius measurements were conducted by an experienced ophthalmologist using an autorefractor (ARK-510A, Nidek Co., Ltd., Tokyo, Japan). An anterior segment examination was performed with a handheld slit lamp (KJ5S2, Suzhou Kangjie Medical Co., Ltd., Jiangsu, China). The spherical equivalent (SE) was used to evaluate the RE data and was calculated as the sphere value plus half the cylinder value. According to previous large-scale epidemiological studies [13,16], emmetropia, myopia, and high myopia were defined as $-0.5 \leq SE \leq 0.5$ diopters (D), $SE < -0.5$ D, and $SE < -6.0$ D, respectively. Hyperopia was defined as $SE > +0.5$ D. Anisometropia was defined as a refractive cylinder >0.5 D or < -0.5 D, and astigmatism was defined as a difference in SE greater than 2.5 D between the two eyes.

2.5. Statistical analyses

Owing to the homogeneity of the binocular refractive data, we reported only the results for the right eye for conciseness [23,24]. The age- and sex-specific prevalence of myopia, high myopia, anisometropia, astigmatism, and hyperopia was calculated for all data and ethnic groups and within the Han population for each province. For all demographic, lifestyle-related, geographic, and physical examination data, the chi-squared test and Kruskal–Wallis rank-sum test were used to compare the categorical and continuous variables among the different provinces. Risk factors for anisometropia, astigmatism, myopia, high myopia, and hyperopia were analyzed using logistic regression models. The Loess algorithm was used to visualize the relationships among ethnicities, provinces, and RE prevalence, whereas a linear model was employed to illustrate the effect of latitude. Insignificant factors in these models were excluded from the subsequent analyses. Given the highly unbalanced distribution of participants across different ethnicities, mixed-effect models were utilized in the multivariant analysis. Provinces were treated as a random effect and other variables as fixed effects in this model, reflecting their presence in multiple provinces. This mixed model focuses on the association between ethnicities and the prevalence of RE. A p-value of <0.05 (two-tailed) was considered statistically significant. Age and sex were standardized by the direct method using the 6th National Census (2010) data of the Chinese population as the standard population. All data analyses were conducted using R version 4.2.2.

3. Results

3.1. Population characteristics

This study initially included 13,963 participants, but 986 were excluded owing to incomplete data. Seventy-five participants were excluded because they did not belong to the main ethnic groups being studied. Ultimately, 12,902 individuals, comprising 5337 men and 7565 women aged 50–80 years were included in the survey. The average proportion of the Han population was 68.2 %, with regional variations ranging from 58.1 % in Qinghai to 82.9 % in Heilongjiang. The mean proportion of urban residents was 59.1 %, with the lowest at 41.2 % in Hebei and the highest at 90.5 % in Inner Mongolia. Illiteracy was present in 15.6 % of the participants, ranging from 7.1 % in Heilongjiang to 33.6 % in Qinghai. Participants with a middle school education comprised 24.5 %, varying from 16.4 % in Gansu to 33.6 % in Heilongjiang, whereas those with a university degree or higher accounted for 13.3 %, from 7.8 % in Yunnan to 22.6 % in Inner Mongolia. The proportion of participants with a light activity level was 37.5 %, with the lowest at 31.3 % in Gansu and the highest at 44.0 % in Qinghai. Indoor workers made up 52.9 % of the participants, ranging from 40.5 % in Hebei to 75.9 % in Inner Mongolia. The proportions of never-smokers and never-drinkers were 67.1 % and 54.8 %, respectively, with the former ranging from 63.8 % in Inner Mongolia to 76.4 % in Yunnan and the latter from 45.5 % in Gansu to 68.8 % in Yunnan. The prevalence of hypertension and diabetes was 34.4 % and 9.8 %, respectively, with hypertension ranging from 26.1 % in Xinjiang to 49.4 % in Hebei and diabetes from 6.5 % in Yunnan to 13.5 % in Hebei. Detailed population characteristics are provided in the supplementary material.

Table 1
The prevalence of REs in the eight ethnicities and seven provinces.

	Anisometropia		Astigmatism		High myopia		Myopia		Hyperopia		Emmetropia	
	Crude prevalence /%	Adjusted prevalence[a]/% [95 % CI]	Crude prevalence /%	Adjusted prevalence[a]/% [95 % CI]	Crude prevalence /%	Adjusted prevalence[a]/% [95 % CI]	Crude prevalence /%	Adjusted prevalence[a]/% [95 % CI]	Crude prevalence /%	Adjusted prevalence[a]/% [95 % CI]	Crude prevalence /%	Adjusted prevalence[a]/% [95 % CI]
Race												
Mongolian	4.6	6.5 [3.5, 11.2]	44.3	53.1 [44.6, 63.2]	1.0	0.9 [0.2, 3.4]	18.6	19 [14.1, 25.3]	37.7	41.7 [34.4, 50.4]	43.8	39.4 [33.1, 47]
Tibetan	2.8	3.1 [1.6, 6.5]	38.4	46 [38.5, 55.0]	1.9	1.8 [0.7, 5]	22.2	22.4 [17.6, 28.6]	18.6	21.6 [16.8, 28]	59.2	56 [48.6, 64.8]
Uyghur	4.1	5.3 [3.5, 7.9]	42.7	47.3 [41.9, 53.5]	1.5	1.8 [0.8, 3.6]	13.8	17 [13.6, 21.1]	48.0	48.9 [43.6, 54.8]	38.2	34.2 [30, 39]
Yi	3.6	4.3 [1.9, 8.8]	34.3	38.7 [30.9, 48.2]	1.1	0.7 [0.2, 3.5]	13.9	15.4 [10.6, 22]	41.8	42.4 [34.6, 51.8]	44.3	42.3 [34.8, 51.3]
Korean	3.0	3.6 [1.5, 8.2]	58.1	54.9 [45.8, 66]	1.3	2.2 [0.5, 6.8]	16.9	21.4 [15.3, 29.8]	53.2	48.5 [40.2, 58.8]	29.9	30.1 [23.5, 38.7]
Manchu	2.8	2.8 [1.6, 4.9]	52.1	57.5 [51.4, 64.3]	1.9	1.3 [0.8, 2.7]	18.4	15.3 [12.7, 18.6]	36.0	43 [37.6, 49.3]	45.6	41.7 [37, 47]
Yugur	2.5	2.2 [1.2, 6.1]	39.4	44.7 [36.6, 54.9]	0.2	0.2 [0.0, 4.2]	14.1	15.8 [11.1, 22.8]	34.6	38.4 [31, 48]	51.3	45.8 [38.7, 54.9]
Han	4.0	4.5 [4.0, 5.1]	50.2	55 [53.1, 57]	2.9	2.8 [2.4, 3.3]	22.9	22.9 [21.8, 24.2]	32.8	36.4 [34.8, 38]	44.4	40.7 [39.3, 42.2]
Province												
Hebei	2.8	3.8 [2.6, 5.5]	52.5	57.7 [53.1, 62.7]	1.0	1.2 [0.6, 2.3]	16.8	17.2 [14.8, 19.9]	44.1	45.9 [41.9, 50.3]	39.2	37 [33.6, 40.7]
Heilongjiang	4.4	4.4 [3.1, 6.3]	52.7	57.5 [52.4, 63.1]	2.7	2.1 [1.4, 3.3]	16.5	16.8 [14.2, 20]	41.4	42.7 [38.5, 47.3]	42.2	40.5 [36.8, 44.7]
Inner Mongolia	5.2	6.1 [4.4, 8.4]	47.8	52.1 [47, 57.8]	4.2	4.1 [2.8, 5.9]	26.6	26.2 [22.7, 30.2]	29.8	34.3 [30.1, 39]	43.6	39.5 [35.5, 44]
Qinghai	4.6	4.4 [2.9, 6.9]	44.8	51.9 [45.7, 59]	4.3	3.4 [2.2, 5.6]	36.3	33 [28.5, 38.3]	17.3	24.7 [20.2, 30.1]	46.4	42.4 [37.3, 48.3]
Xinjiang	4.9	5.2 [3.9, 6.8]	48.6	52.3 [48, 57.1]	3.2	3.4 [2.3, 4.7]	21.1	21.3 [18.6, 24.3]	37.0	38.6 [34.9, 42.6]	42.0	40.1 [36.5, 44.1]
Yunnan	3.8	3.7 [2.4, 5.9]	47.3	51.4 [45.5, 58.1]	3.0	2.7 [1.5, 4.8]	24.3	24.3 [20.5, 28.8]	26.1	26.5 [22.4, 31.3]	49.6	49.3 [43.8, 55.5]
Gansu	3.4	3.3 [2.4, 4.7]	52.2	55.7 [51.2, 60.7]	3.2	2.9 [2.1, 4.2]	25.2	25.4 [22.5, 28.6]	26.0	32.3 [28.8, 36.3]	48.8	42.3 [38.9, 46.1]
Total	3.8	4.4 [4, 4.9]	48.4	53.5 [51.9, 55.1]	2.4	2.4 [2.1, 2.7]	21.0	21.4 [20.4, 22.4]	34.3	37.8 [36.5, 39.1]	44.8	40.8 [39.6, 42.1]

[a] Standardized prevalence was the sex- and age-standardized prevalence by direct method using the 6th national census (2010) data of Chinese population as the standard population. Emmetropia, myopia, and high myopia were defined as $-0.5 \leq SE \leq 0.5$ D, $SE < -0.5$ D and $SE < -6.0$ D, respectively. Hyperopia was defined as $SE > +0.5$D. Anisometropia was defined as a refractive cylinder >0.5 D or < -0.5 D, and astigmatism was defined as a difference in SE between two eyes greater than 2.5 D. CI: Confidence interval.

3.2. Prevalence of RE in seven provinces

The sex- and age-adjusted prevalence of RE across eight ethnicities and seven provinces is detailed in Table 1 and Fig. 1. The adjusted prevalence of anisometropia, astigmatism, myopia, high myopia, hyperopia, and emmetropia was 4.4 % (95 % CI 4.0–4.9 %), 53.5 % (95 % CI 51.9–55.1 %), 21.4 % (95 % CI 20.4–22.4 %), 2.4 % (95 % CI 2.1–2.7 %), 37.8 % (95 % CI 36.5–39.1 %), and 40.8 % (95 % CI 39.6–42.1 %), respectively. The prevalence of myopia and high myopia varied widely, from 15.3 % (95 % CI 12.7–18.6 %) in the Manchu population to 22.9 % (95 % CI 21.8–24.2 %) in the Han population, and from 16.8 % (95 % CI 14.2–20.0 %) in Heilongjiang to 33.0 % (95 % CI 28.5–38.3 %) in Qinghai Province. The rates for high myopia ranged from 0.2 % (95 % CI 0.0–4.2 %) in the Yugur population to 2.8 % (95 % CI 2.4–3.3 %) in the Han population and from 1.2 % (95 % CI 0.6–2.3 %) in Hebei Province to 4.1 % (95 % CI 2.8–5.9 %) in Inner Mongolia Province. The prevalence of hyperopia ranged from 21.6 % (95 % CI 16.8–28.0 %) in the Tibetan population to 48.9 % (95 % CI 43.6–54.8 %) in the Uyghur population and from 24.7 % (95 % CI 20.2–30.1 %) in Qinghai Province to 45.9 % (95 % CI 41.9–50.3 %) in Hebei Province.

3.3. Risk factors for RE

3.3.1. Myopia and high myopia

Ethnicity and significant factors identified in the bivariate analysis were analyzed using a mixed-effects model, with provinces as a parallel variable. The risk factors for myopia in the total population are presented in Fig. 2(a). Compared to the 50–54 years subgroup, the prevalence of myopia was lower in the 55–59 years group (OR 0.83, 95 % CI 0.74–0.93, $p = 0.002$) and the 60–64 years group (OR 0.72, 95 % CI 0.63–0.82, $p < 0.001$) but higher in the ≥70 years group (OR 1.34, 95 % CI 1.14–1.57, $p < 0.001$). Compared to the Han population, the Mongolian (OR 0.62, 95 % CI 0.46–0.84, $p = 0.002$), Tibetan (OR 0.66, 95 % CI 0.52–0.85, $p = 0.001$), Uyghur (OR 0.63, 95 % CI 0.49–0.80, $p < 0.001$), Yi (OR 0.65, 95 % CI 0.46–0.92, $p = 0.014$), and Yugur (OR 0.65, 95 % CI 0.50–0.85, $p = 0.001$) ethnicities had a lower myopia prevalence. Individuals living in rural areas had a lower myopia prevalence (OR 0.73, 95 % CI 0.65–0.82, $p < 0.001$). Compared to those with illiteracy, individuals with a high school (OR 1.58, 95 % CI 1.33–1.87, $p < 0.001$) and university or higher (OR 2.82, 95 % CI 2.34–3.40, $p < 0.001$) education level had a higher myopia prevalence. Participants with a BMI >18.5 kg/m^2 were less likely to have myopia (all $p < 0.001$). Patients with diabetes were more likely to have myopia (OR 1.34, 95 % CI 1.16–1.55, $p < 0.001$). Smokers (past smoker: OR 0.80, 95 % CI 0.70–0.93, $p = 0.002$; current smoker: OR 0.88, 95 % CI 0.79–0.99, $p = 0.031$) and participants living in higher latitude areas (OR 0.72, 95 % CI 0.55–0.95, $p = 0.020$) were less likely to have myopia. Activity level and working environment had no significant association with myopia.

The risk factors for high myopia are presented in Fig. 2(b). Compared to males, female participants had a higher probability of high myopia (OR 2.07, 95 % CI 1.39–3.07 $p < 0.001$). Compared to the Han population, the Mongolian (OR 0.24, 95 % CI 0.08–0.66, $p = 0.006$) and Yugur (OR 0.07, 95 % CI 0.01–0.48, $p = 0.007$) ethnicities had a lower prevalence of high myopia. Participants living in rural areas had a lower prevalence of high myopia (OR 0.66, 95 % CI 0.47–0.91, $p = 0.012$). Individuals with a higher BMI (OR 0.52, 95 % CI 0.28–0.97, $p = 0.038$ in the >24–≤27 kg/m^2 group and OR 0.52, 95 % CI 0.27–0.97, $p = 0.041$ in the > 27 kg/m^2 group) were less likely to have high myopia. Participants with a university or higher education level had a higher probability of high myopia (OR 1.79, 95 % CI 1.12–2.86, $p = 0.016$). Age, smoking history, and working environment had no significant association with high myopia in this seven-province survey.

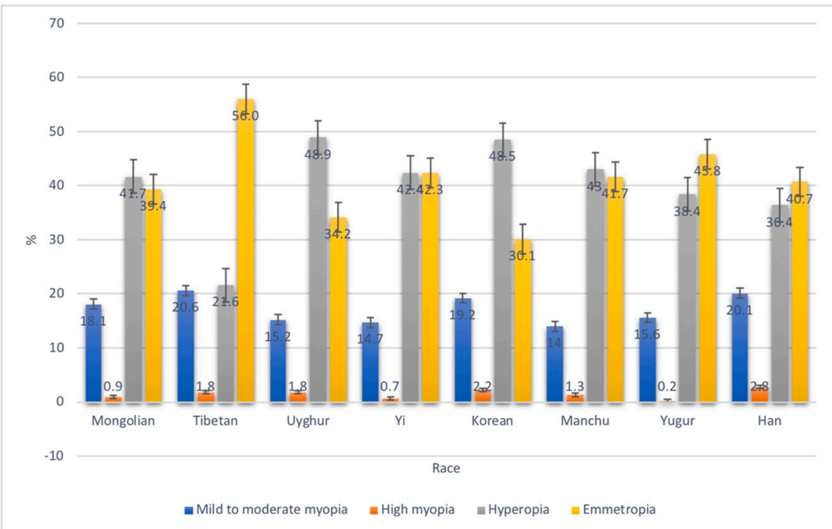


Fig. 1. Prevalence of myopia, high myopia, hyperopia, and emmetropia among eight ethnicities and seven provinces.
Age- and sex-adjusted prevalence of mild to moderate myopia, high myopia, hyperopia, and emmetropia in the eight ethnicities is shown in the column chart. Note: the myopia prevalence in this chart is equivalent to the sum of the prevalence of mild to moderate myopia and high myopia.

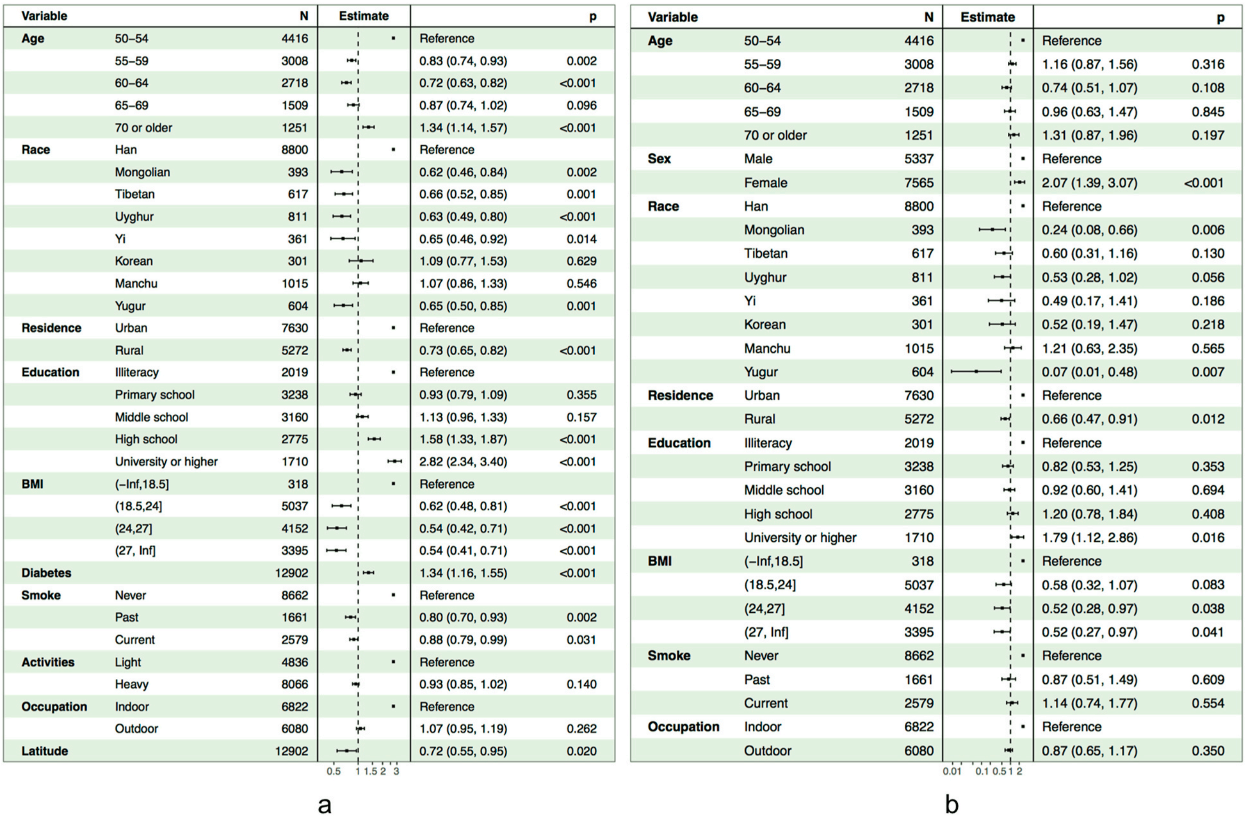


Fig. 2. Risk factors for myopia and high myopia in older adults in eight ethnicities in China.
The result of mixed-effects model analysis of ethnicity and significant factors for myopia (a) and high myopia (b), using provinces as a parallel variable. Reference is presented by OR (95 % CI). A p-value <0.05 (two-tailed) was considered statistically significant. BMI: body mass index.

3.3.2. Hyperopia

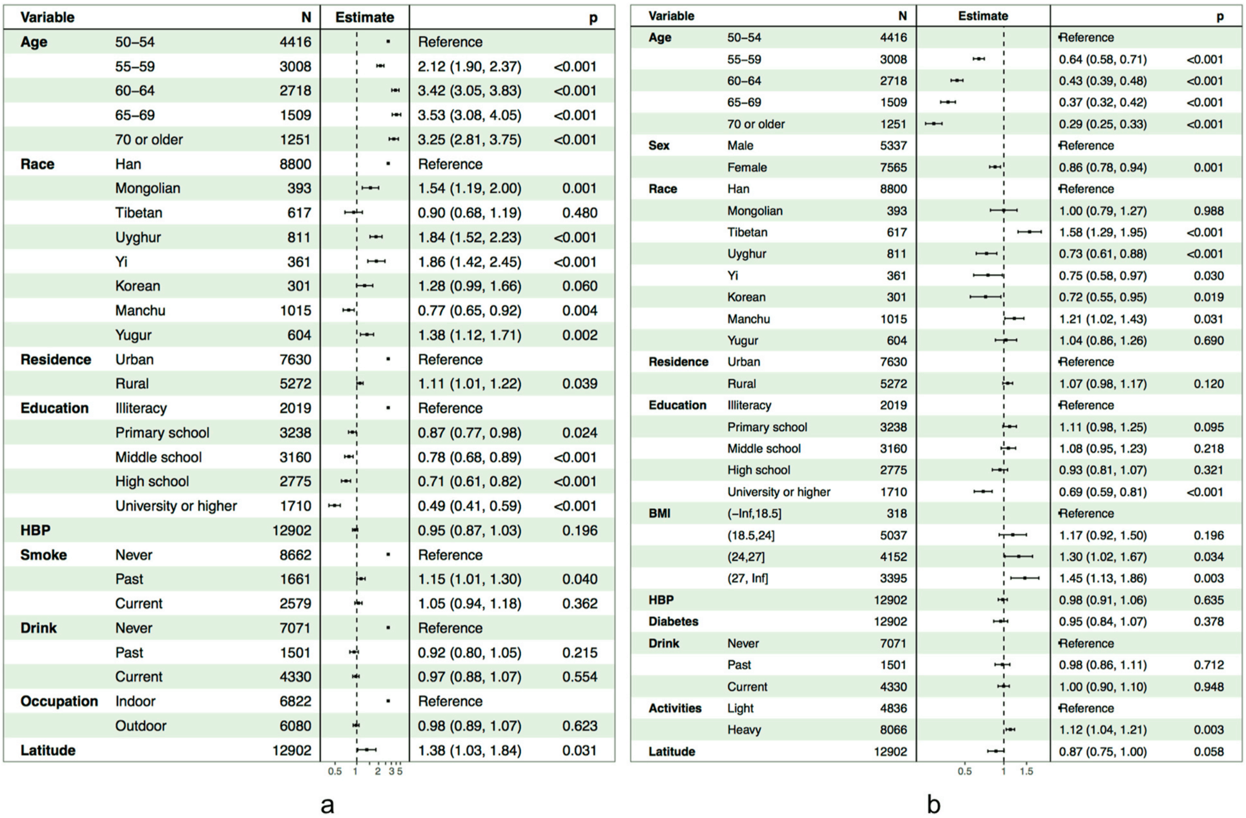
The risk factors for hyperopia are presented in Fig. 3(a). In this model, the prevalence of hyperopia increased with age compared to the youngest age group (50–54 years), with significant increases observed in the 55–59, 60–64, 65–69, and ≥70 years age groups (all $p < 0.001$). Compared to the Han population, the Mongolian (OR 1.54, 95 % CI 1.19–2.00, $p = 0.001$), Uyghur (OR 1.84, 95 % CI 1.52–2.23, $p < 0.001$), Yi (OR 1.86, 95 % CI 1.42–2.45, $p < 0.001$), and Yugur (OR 1.38, 95 % CI 1.12–1.71, $p = 0.002$) populations had a higher prevalence of hyperopia; the Manchu ethnicity (OR 0.77, 95 % CI 0.65–0.92, $p = 0.004$) had a lower prevalence. Compared to illiterate individuals, participants with a primary school education (OR 0.87, 95 % CI 0.77–0.98, $p = 0.024$) and those with higher education levels (all $p < 0.001$) were less likely to have hyperopia. Past smokers (OR 1.15, 95 % CI 1.01–1.30, $p = 0.040$) and residents of higher latitude areas (OR 1.38, 95 % CI 1.03–1.84, $p = 0.031$) were more likely to have hyperopia. However, hypertension and alcohol consumption showed no significant association with hyperopia in this model.

3.3.3. Emmetropia

The risk factors for emmetropia are presented in Fig. 3(b). In the mixed-effects model, compared to the youngest age group, older individuals (≥55 years) were less likely to have emmetropia (all $p < 0.001$), and females were less likely to have emmetropia (OR 0.86, 95 % CI 0.78–0.94, $p = 0.001$) compared to males. Compared to the Han population, Tibetan (OR 1.58, 95 % CI 1.29–1.95, $p < 0.001$) and Manchu (OR 1.21, 95 % CI 1.02–1.43, $p = 0.031$) populations were more likely to have emmetropia, whereas Uyghur (OR 0.73, 95 % CI 0.61–0.88, $p < 0.001$), Yi (OR 0.75, 95 % CI 0.58–0.97, $p = 0.030$), and Korean (OR 0.72, 95 % CI 0.55–0.95, $p = 0.019$) populations were less likely to have emmetropia. Participants with a university or higher education level were less likely to have emmetropia (OR 0.69, 95 % CI 0.59–0.81, $p < 0.001$). Individuals with a higher BMI (OR 1.30, 95 % CI 1.02–1.67, $p = 0.034$ in the >24–≤ 27 kg/m^2 group and OR 1.45, 95 % CI 1.13–1.86, $p = 0.003$ in the > 27 kg/m^2 group) and a higher activity level (OR 1.12, 95 % CI 1.04–1.21, $p = 0.003$) had a higher prevalence of emmetropia. In the mixed-effects model, neither a history of hypertension and diabetes nor latitude metrics showed significant associations with emmetropia.

3.3.4. Astigmatism

The risk factors for astigmatism are presented in Fig. 4(a). Compared to the youngest age group, older individuals (≥55 years) (all $p < 0.001$) and female participants (OR 1.22, 95 % CI 1.08–1.38, $p = 0.001$) were more likely to have astigmatism. Compared to the Han



Variable		N	p (OR, 95 % CI)	p
Age	50–54	4416	Reference	
	55–59	3008	2.12 (1.90, 2.37)	<0.001
	60–64	2718	3.42 (3.05, 3.83)	<0.001
	65–69	1509	3.53 (3.08, 4.05)	<0.001
	70 or older	1251	3.25 (2.81, 3.75)	<0.001
Race	Han	8800	Reference	
	Mongolian	393	1.54 (1.19, 2.00)	0.001
	Tibetan	617	0.90 (0.68, 1.19)	0.480
	Uyghur	811	1.84 (1.52, 2.23)	<0.001
	Yi	361	1.86 (1.42, 2.45)	<0.001
	Korean	301	1.28 (0.99, 1.66)	0.060
	Manchu	1015	0.77 (0.65, 0.92)	0.004
	Yugur	604	1.38 (1.12, 1.71)	0.002
Residence	Urban	7630	Reference	
	Rural	5272	1.11 (1.01, 1.22)	0.039
Education	Illiteracy	2019	Reference	
	Primary school	3238	0.87 (0.77, 0.98)	0.024
	Middle school	3160	0.78 (0.68, 0.89)	<0.001
	High school	2775	0.71 (0.61, 0.82)	<0.001
	University or higher	1710	0.49 (0.41, 0.59)	<0.001
HBP		12902	0.95 (0.87, 1.03)	0.196
Smoke	Never	8662	Reference	
	Past	1661	1.15 (1.01, 1.30)	0.040
	Current	2579	1.05 (0.94, 1.18)	0.362
Drink	Never	7071	Reference	
	Past	1501	0.92 (0.80, 1.05)	0.215
	Current	4330	0.97 (0.88, 1.07)	0.554
Occupation	Indoor	6822	Reference	
	Outdoor	6080	0.98 (0.89, 1.07)	0.623
Latitude		12902	1.38 (1.03, 1.84)	0.031

a

Variable		N	p (OR, 95 % CI)	p
Age	50–54	4416	Reference	
	55–59	3008	0.64 (0.58, 0.71)	<0.001
	60–64	2718	0.43 (0.39, 0.48)	<0.001
	65–69	1509	0.37 (0.32, 0.42)	<0.001
	70 or older	1251	0.29 (0.25, 0.33)	<0.001
Sex	Male	5337	Reference	
	Female	7565	0.86 (0.78, 0.94)	0.001
Race	Han	8800	Reference	
	Mongolian	393	1.00 (0.79, 1.27)	0.988
	Tibetan	617	1.58 (1.29, 1.95)	<0.001
	Uyghur	811	0.73 (0.61, 0.88)	<0.001
	Yi	361	0.75 (0.58, 0.97)	0.030
	Korean	301	0.72 (0.55, 0.95)	0.019
	Manchu	1015	1.21 (1.02, 1.43)	0.031
	Yugur	604	1.04 (0.86, 1.26)	0.690
Residence	Urban	7630	Reference	
	Rural	5272	1.07 (0.98, 1.17)	0.120
Education	Illiteracy	2019	Reference	
	Primary school	3238	1.11 (0.98, 1.25)	0.095
	Middle school	3160	1.08 (0.95, 1.23)	0.218
	High school	2775	0.93 (0.81, 1.07)	0.321
	University or higher	1710	0.69 (0.59, 0.81)	<0.001
BMI	(−Inf,18.5]	318	Reference	
	(18.5,24]	5037	1.17 (0.92, 1.50)	0.196
	(24,27]	4152	1.30 (1.02, 1.67)	0.034
	(27, Inf]	3395	1.45 (1.13, 1.86)	0.003
HBP		12902	0.98 (0.91, 1.06)	0.635
Diabetes		12902	0.95 (0.84, 1.07)	0.378
Drink	Never	7071	Reference	
	Past	1501	0.98 (0.86, 1.11)	0.712
	Current	4330	1.00 (0.90, 1.10)	0.948
Activities	Light	4836	Reference	
	Heavy	8066	1.12 (1.04, 1.21)	0.003
Latitude		12902	0.87 (0.75, 1.00)	0.058

b

Fig. 3. Risk factors for hyperopia and emmetropia in older adults in eight ethnicities in China.
The result of mixed-effects model analysis of ethnicity and significant factors for hyperopia (a) and emmetropia (b), using provinces as a parallel variable. Reference is presented by OR (95 % CI). A p-value<0.05 (two-tailed) was considered statistically significant. HBP: high blood pressure; BMI: body mass index; HBP: high blood pressure.

population, Tibetan (OR 0.74, 95 % CI 0.60–0.92, $p = 0.006$), Uyghur (OR 0.77, 95 % CI 0.63–0.92, $p = 0.005$), Yi (OR 0.55, 95 % CI 0.42–0.71, $p < 0.001$), and Yugur (OR 0.61, 95 % CI 0.50–0.75, $p < 0.001$) ethnicities had a lower prevalence of astigmatism. Patients with diabetes (OR 1.29, 95 % CI 1.14–1.46, $p < 0.001$) and outdoor workers (OR 1.11, 95 % CI 1.02–1.21, $p = 0.011$) were more likely to have astigmatism. Current drinkers (OR 0.88, 95 % CI 0.80–0.98, $p = 0.016$) and participants with a higher BMI (> 18.5 kg/m^2, all $p \leq 0.030$) were less likely to have astigmatism. A history of hypertension, smoking history, activity level, and latitude showed no significant association with astigmatism in this multivariable regression model.

3.3.5. Anisometropia

The risk factors for anisometropia are presented in Fig. 4(b). In the mixed-effects model, compared to the youngest age group, older individuals (≥55 years) were more likely to have anisometropia ($p < 0.001$ or $p = 0.004$), and females had a higher likelihood of developing anisometropia (OR 1.32, 95 % CI 1.08–1.61, $p = 0.006$). Ethnicity was not significantly associated with anisometropia. Compared to urban residents, those living in rural areas were less likely to have anisometropia (OR 0.78, 95 % CI 0.62–0.97, $p = 0.027$). Participants with a BMI >27 kg/m^2 were less likely to have anisometropia (OR 0.58, 95 % CI 0.35–0.96, $p = 0.034$). Education level was not significantly associated with anisometropia in the multivariable regression model.

4. Discussion

To our knowledge, this is the first study to explore the distribution of RE in older adults from various ethnicities in China. Individuals of Mongolian, Tibetan, Uyghur, Yi, and Yugur ethnicities exhibited a lower frequency of myopia, with Mongolian and Yugur groups also showing a lower frequency of high myopia compared to Han individuals. The adjusted myopia prevalence among the Han and minority groups differs by a maximum of 7.5 % and the high myopia prevalence differs by up to 2.6 % in this survey. However, there were no significant differences in myopia prevalence between Korean and Manchu ethnicities compared to the Han population. Additionally, the Manchu population was less likely to have hyperopia than the Han population. The Manchu and Korean populations reside in northeast China. The Manchu settled in Hebei Province during the Qing Dynasty, and a societal and behavioral fusion with the Han population has occurred for hundreds of years. Koreans primarily engage in aquaculture and agriculture. The living environments of these two groups are similar to those of the Han population. A study of current genetic patterns in East Asians revealed different gene

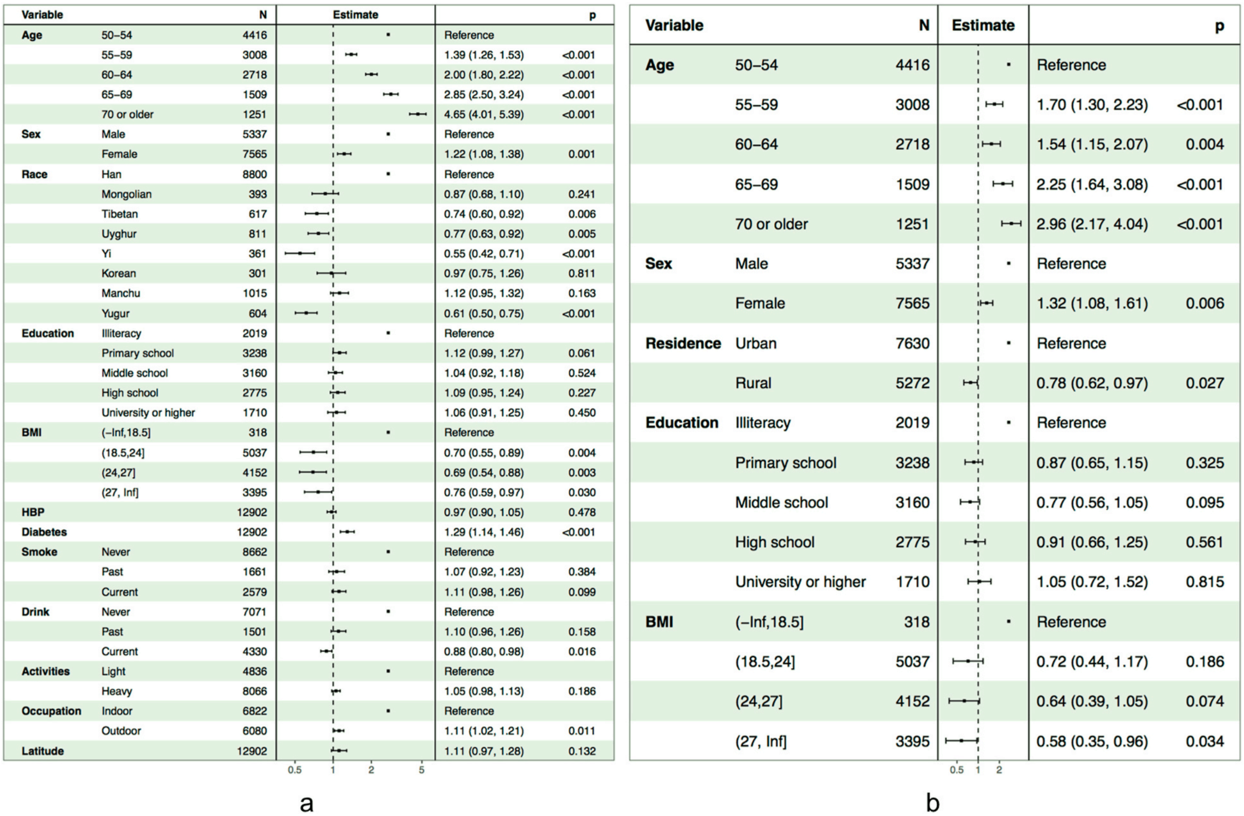


Fig. 4. Risk factors for astigmatism and anisometropia in older adults in eight ethnicities in China.
The result of mixed-effects model analysis of ethnicity and significant factors for astigmatism (a) and anisometropia (b), using provinces as a parallel variable. Reference is presented by OR (95 % CI). A p-value<0.05 (two-tailed) was considered statistically significant. BMI: body mass index; HBP: high blood pressure.

compositions across ethnicities, with more gene fusion and cultural exchange in the Han population in central and northeast China [25]. The absence of a significant difference in myopia prevalence among Manchu, Korean, and Han ethnicities provides new evidence for the integration of culture and genes in northeast China. Conversely, Mongolian, Tibetan, Uyghur, and Yugur populations inhabit West China, where grasslands are predominant, and these ethnicities maintain a nomadic lifestyle. This environment allows for more outdoor activities and less near-work activities during childhood, factors that have been shown to protect against myopia [1,26,27]. Genetically, the Mongolian, Uyghur, and Yugur populations exhibit an admixture of genes from European ancestors [28,29]. This study indicates that the variation in myopia prevalence between the Han and local ethnic minorities in different regions of China is marked, with significant differences particularly in the western regions of China.

A high prevalence of myopia and high myopia among younger adults in the Han population has been observed worldwide [18,30,31]. However, the differences in myopia prevalence among older adults (≥50 years) across various countries are not as marked [32]. In the present study, the total prevalence of myopia was 22.9 % among older Han adults, comparable to that reported by the Europe Eye Epidemiology (E^3) Consortium study (27.5 % among those aged 55–59 years) [33] and the Gutenberg Health Study (29.3 % among those aged 55–64 years) [34] and even lower than that in some epidemiological studies in the US (ranging from 30.7 % among those aged 46–60 years to 36.1 % among those aged 50–59 years) [15,35]. The relatively low myopia prevalence in the Han population in the present study can be attributed to the large multiethnic population-based sampling strategy used in the less developed northwest regions in China, where the prevalence of myopia is not as high as that in more developed areas, indicating an environmental association with myopia prevalence.

The risk factors for myopia in this study were also analyzed. Individuals in the 55–64-year age groups were less likely to have myopia, and an increase in myopia prevalence was observed at age 70 due to primary nuclear cataract formation. A rural residence, which typically provides more outdoor activity time, and higher education levels, which imply more near-work activities, were also noted. A higher myopia prevalence among older adults with diabetes was observed, possibly due to lens expansion caused by high blood glucose levels [36] or lens opacity. However, studies on the association between diabetes and myopia remain controversial. Some studies have reported a higher myopia prevalence in patients with diabetes [37,38], whereas others have found no significant difference [39,40]. These discrepancies could stem from varying levels of blood glucose control among the study participants. We also found that individuals in higher latitude areas, where there is less sunshine during the day, especially during winter, were less likely to have myopia. A study in southeast Norway (60 ° latitude north) revealed an extremely low myopia prevalence (13 % among

16–19-year-old Norwegian Caucasians), which contrasts the trends in Asia and cannot be explained by differences in sunshine duration but may be attributed to different education patterns and cultural practices. Norwegian preschool and school children spend 3–5 h outdoors per day at school [41], and additional outdoor time after school is a part of their culture [42]. This study merely shows the distribution of myopia across different latitudes in China. In our study, ever-smokers were less likely to have myopia, although the role of the retinal nicotinic cholinergic receptor in myopia formation is unknown [43]. The association between smoking and myopia is controversial in previous studies [9,13,44,45]; however, smokers may spend more time outdoors, which may also correlate with lower levels of education or socioeconomic status [46,47]. The complexity of smoking behavior should be considered when interpreting these results. Participants with a higher BMI were less likely to have myopia in our study. A large-scale study in Israeli adolescents found that BMI has a U-shaped relationship with the prevalence of myopia [48]. However, a previous study conducted in Korea reported that a lower BMI increases the risk of myopia [49]. The differing conclusions may be attributed to other factors such as ethnicity and the age range of the study population.

The rapid increase in vision impairment due to high myopia has become a social and economic burden worldwide, particularly in East Asia [50]. Recent studies indicate that the prevalence of high myopia among university students in East Asia ranges from 16 % to 28 % [51,52]. Preventing the progression of moderate myopia to high myopia has become a significant research focus [1]. In this study, the risk factors for high myopia differed from those for myopia. Apart from ethnicity and BMI, only sex, high education level, and rural residence were associated with high myopia. A university or higher education level as a risk factor for high myopia suggests that academic stress and extended study time could contribute to the development of high myopia. Living in rural areas often provides more opportunities for outdoor activity. Increased outdoor activity and reduced near-work may also help protect against the progression from myopia to high myopia. Therefore, preventing the early onset of myopia and slowing its progression are critical to reducing the incidence of high myopia in younger populations.

In the mixed-effects model, the risk factors for hyperopia also showed ethnic differences. The Mongolian, Yi, Uyghur, and Yugur populations were more likely to have hyperopia, whereas the Manchu population was less likely to have hyperopia compared to the Han population. A study on ethnic differences in hyperopia in the US observed a lower prevalence of hyperopia among Chinese individuals [15]; a lower frequency of hyperopia was associated with a higher frequency of myopia. The significant risk factors for hyperopia were the opposite of those for myopia [15,53].

The strengths of our study include a large multiethnic population-based sampling strategy and a detailed questionnaire. However, this study also had some limitations. Owing to its cross-sectional design, causal relationships regarding risk factors for myopia could not be established. Cycloplegia was not included in the refraction measurements, which may have caused slight distortions in RE estimates due to myopic shifts. Additionally, ocular axial length and other biometric data were not measured in our study, and myopia caused by primary cataracts was not excluded. This resulted in the inability of this study to conduct statistical analysis on the biometric values associated with axial myopia.

5. Conclusion

This is the first study to explore the distribution of RE in older adults of eight different ethnicities in areas with large ethnic minorities in China. Myopia affected more than one-fifth of the older adult individuals of Han ethnicity in this survey. The prevalence of myopia in the western and northern regions of China is lower than that in the developed areas. The significant differences in the prevalence of myopia between Han and ethnic minorities are particularly pronounced in the western regions of China.

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Ethics approval and consent to participate

All methods were carried out in accordance with relevant guidelines and regulations in the present study. And this study was approved by the institutional review board of the Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences. Project number: 028–2013. All participants provided informed, written consent and all data were anonymized prior to analysis.

Strobe statement

A checklist of items that should be included in reports of observational studies is presented in supplemental material.

Data availability statement

The data that support the findings of this study are available from the correspondence author.

CRediT authorship contribution statement

Xuqian Wang: Writing – review & editing, Writing – original draft, Methodology. **Rui luo:** Formal analysis. **Guangliang Shan:**

Project administration, Funding acquisition. **Huijing He:** Methodology, Data curation. **Ting Chen:** Data curation. **Xuejiao Wang:** Data curation. **Linyang Gan:** Data curation. **Yuhan Wang:** Data curation. **Yuyu Chou:** Data curation. **Jiantao Cui:** Data curation. **Pan Li:** Project administration, Methodology, Funding acquisition. **Yong Zhong:** Writing – review & editing, Conceptualization. **Jin Ma:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

RE	Refractive error
CNHS	The China National Health Survey
BMI	Body mass index
SE	Spherical equivalent
OR	odds ratios
CI	confidence interval

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36354.

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