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Correlation analysis of myopia and dietary factors among primary and secondary school students in Shenyang, China

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Currently, the global prevalence of myopia is high and on the rise, seriously affecting the health of students. Studies have suggested that dietary factors may be associated with the occurrence and development of myopia, but the results are inconsistent. This survey aims to analyze the correlation between dietary factors and myopia while controlling for more confounding factors. A multi-stage stratified cluster sampling method was performed to select 10,619 primary and secondary school students in Shenyang for visual examination, and questionnaires were administered to 6974 of them. Logistic regression was performed with myopia as the dependent variable and the variables with $p < 0.1$ in the univariate analysis as independent variables. Sensitivity analysis was conducted using propensity score matching. The results showed that the overall prevalence of myopia among primary and secondary school students in Shenyang was 59.1%, with mild myopia predominating. Students who ate fresh fruits two or more times a day had a 0.69 times lower risk of myopia compared to those who did not eat fruits (95% CI 0.50–0.97). However, subgroup analysis demonstrated that this protective effect was only significant for male students, with an OR of 0.59 (95% CI 0.38–0.91). Moreover, female students who consumed sugary beverages once or more a day had a 1.8 times higher risk of myopia compared to those who did not consume sugary beverages (95% CI 1.03–3.15). Vegetable consumption, intake of fried foods, and breakfast habits were not significantly associated with myopia. In summary, excessive consumption of sugary beverages could increase the risk of myopia, especially in female students, whereas fruit intake contributed to reducing the risk of myopia, particularly in male students.

Keywords Myopia, Students, Prevalence, Risk factors, Dietary factors

Myopia is a common visual impairment, and its incidence is increasing with global economic and social development. According to the survey results of the National Health Commission of China, as of 2020, the overall myopia rate among Chinese youth was 52.7%, with 14.3% of 6-year-olds, 35.6% of primary school students, 71.1% of middle school students, and 80.5% of high school students suffering from myopia[1]. The prevalence of myopia was found to be 73% among Korean children aged 12–18[2]. In Europe, the prevalence of myopia in Spanish children aged 5–7 was 20.1% in 2020[3], while in the French population aged 10–19, the prevalence reached 42.7%[4]. It is estimated that by 2050, the global population of persons with myopia will reach 4.758 billion, accounting for 49.8% of the total population[5]. Myopia not only affects students' lives and studies, but may also cause a variety of eye diseases, such as retinal detachment, macular degeneration and glaucoma, which can lead to blindness in severe cases[6,7]. Myopia is becoming a common disease that seriously affects students' health.

In addition to genetic factors, myopia is closely related to environmental factors. Several studies suggested that dietary factors may be related to the occurrence and development of myopia. Research by Bone et al.[8] and Beatty et al.[9] indicated that a reasonable diet structure had an effect on improving vision. However, the study by Li et al.[10] did not find any association between nutrients or food groups and myopia among children in Singapore.

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Berticat et al.[11] revealed that the intake of refined carbohydrates may be related to childhood myopia with an increased risk of myopia in girls, while the study by Chua et al.[12] demonstrated that there was no association between carbohydrate intake and spherical equivalent (SE), axial length (AL), or myopia. The studies conducted by Berticat et al.[11] and Xu et al.[13] also found that there are gender differences in the influence of dietary factors on myopia. It can be observed that there is inconsistency in the influence of dietary factors on myopia, which may be related to incomplete control of confounding factors, or differences in sample size of the investigated populations. For example, the study by Xu et al.[13] only controlled for several confounding variables such as sex, age, screen time, sleep time, and moderate-to-vigorous physical activity time, without controlling for important factors related to myopia such as family genetic history and students' learning situation, and the study by Chua et al.[12] had a sample size of only 317 individuals.

Given the high and increasing incidence of myopia, as well as the potential role and uncertainty of diet in preventing myopia, it is important to further investigate the relationship between diet and myopia. The present study investigated the relationship between dietary factors and myopia based on a relatively large sample size and controlling for more confounding factors, and propensity score matching was used to validate the stability of the results, which may contribute to clarifying the relationship between dietary factors and myopia.

Materials and methods

Investigation subjects

The survey was conducted in April–May 2020 and November–December 2021, respectively, using a multi-stage stratified cluster sampling method. One district or county was randomly selected from each of the five urban districts (Heping, Shenhe, Huanggu, Dadong, and Tiexi) and eight suburban districts or counties (Sujiatun, Hunnan, Shenbei, Yuhong, Liaozhong, Xinmin, Kangping, and Faku) in Shenyang. Two primary schools, two junior high schools, two high schools, and one vocational school were selected in each survey site. In each grade of the selected schools, 2–3 classes were selected for the survey. The survey was approved by the Ethics Committee of Shenyang Center for Disease Control and Prevention (sycdc-2020–001), and written informed consent was obtained from the legal guardians of the participants.

Investigation methods

Vision examination

The visual acuity of students' left and right eyes was measured using standard logarithmic visual acuity charts and an automatic computerized optometry method under non-cycloplegic conditions. The results of the examination were recorded on-site by the testing doctors in the Liaoning Province Student Common Disease and Health Influence Factors Monitoring Information System.

Questionnaire survey

Students were organized to complete a questionnaire survey on the WeChat public website, but no questionnaire survey was arranged for primary school students in grades one to three considering the lack of reading comprehension skills. The survey mainly included several aspects, such as parents' myopia status, eye usage environment, eye usage habits, screen usage, outdoor activities and sleep, and dietary status. The survey questionnaire results were directly uploaded to the Liaoning Province Student Common Disease and Health Influence Factors Monitoring Information System.

Diagnosis criteria and related definitions

The visual acuity chart used in the study is from GB/T 11533-2011 Standard for logarithmic visual acuity charts[14], which is a 5-point scale. Here, L is a logarithmic record indicating visual acuity, defined as 5 points minus the logarithm of the angle of view, and is expressed by the formula: $L = 5\text{-}lg\alpha$. The visual acuity values obtained were converted to international standard visual acuity values, i.e., the logarithm of the minimum angle of resolution (LogMAR) (Supplementary Table 1). The diagnosis criteria for myopia were defined as unaided-eye visual acuity < 1.0 logMAR and non-cycloplegic computerized optometry equivalent spherical degree < − 0.50D. Those who were diagnosed with myopia in one eye or confirmed to wear orthokeratology lenses would be counted in the myopia population. The diagnosis criteria for low myopia, moderate myopia and high myopia were defined as monocular visual acuity < 1.0 logMAR and − 3.0D ≤ spherical equivalent < − 0.5D, monocular visual acuity < 1.0 logMAR and − 6.0D ≤ spherical equivalent < − 3.0D, and monocular visual acuity < 1.0 logMAR and spherical equivalent < − 6.0D, respectively.

Sugary drinks refer to any form of sugary beverages, mainly including soda, cola, iced tea, orange juice, Nutri-Express, etc. Fried foods mainly consisted of fried bread sticks, fried cakes, French fries, fried chicken wings, etc. Fresh fruits did not include canned fruits, and vegetables were counted whether they were raw or cooked.

Quality control

The testers participating in the survey were unified in their testing methods and equipment. The testing team was composed of one testing team leader, at least one ophthalmologist holding a national practicing certificate in optometry, and several professionals or school health professionals holding qualifications in optometry-related technology or nursing certificates. All testing personnel received uniform training, proficiently mastered the testing methods, and were only allowed to take up their post after passing the assessment.

During the survey, 5% of the randomly selected retest subjects were tested for naked-eye visual acuity, corrected visual acuity, spherical and cylindrical refractive error for both eyes. The retest subjects for visual acuity testing did not include those wearing orthokeratology lenses. A measurement error exceeding ± 1 line for naked and corrected visual acuity, or ± 0.50D for spherical equivalent, was considered a testing error. If the error rate

exceeded 5%, the testing team leader should promptly convene a meeting to investigate the reasons and improvement measures, and conduct retesting, rechecking, and correction for indicators that exceeded the allowable error range. If the error rate exceeded 10%, all the test data for that day were invalid, and a retest was required.

Data analysis

A database was established using EpiData 3.1 for parallel double entry, and statistical analysis was performed using R 4.2.2 software. Measurement data were described using mean ± standard deviation or median (quartile), and counted data were described using the number of cases (percentage). The dietary factors (sugary drinks, fried foods, fruits, vegetables, and breakfast consumption) and other factors influencing myopia were analyzed using the chi-square test for single-factor analysis. Factors with $p < 0.1$ in the single-factor analysis were taken as independent variables, while myopia was the dependent variable. Non-conditional multiple factor logistic regression was performed, and subgroup analysis was conducted based on sex. The significance level was set at $\alpha = 0.05$.

To validate the stability of the results, a propensity score matching (PSM) method was utilized to control for other confounding factors, excluding dietary factors. The nearest neighbor matching method was adopted, with a caliper value set to 0.05. The dietary factor was then taken as the independent variable, and myopia as the dependent variable. Non-conditional multiple factor logistic regression was employed to examine the correlation between diet and myopia, and subgroup analysis was conducted based on sex.

Results

Basic characteristics of the survey participants

As shown in Table 1, a total of 10,619 participants were included in this survey with a median age of 12 years old, of which 51.5% were male, slightly higher than female (48.5%). The majority of participants were of Han ethnicity, accounting for 81.2%, while the percentage of urban students was 53.1%, slightly higher than suburban students. In terms of educational stage, primary school students accounted for the highest proportion, reaching 51.5%, while middle school students accounted for 25.0%, and the rest were high school students. There were significant differences in the demographic characteristics between the myopia group and the non-myopia group.

The prevalence of myopia among students in Shenyang

As can be seen from Fig. 1, the prevalence of myopia among students in Shenyang was 59.1% overall, with a higher rate among females than males (61.6% vs. 56.7%). The prevalence of myopia was also higher in urban areas compared to suburban areas (61.0% vs. 56.9%), and the Han population had a higher myopia prevalence than the Non-Han group (59.5% vs. 57.1%). The prevalence of myopia increased rapidly with increasing school segments, from 42.4% in primary school to 81.0% in high school. More detailed data can be found in Supplementary Table 2.

As shown in Fig. 2, mild myopia was the most common type, but the prevalence of moderate and high myopia gradually increased with age, with the same trend for males and females. However, due to the relatively small number of students aged 18 years and above, in particular the fact that there were only 5 males and 4 females aged 19 years and 2 males and 2 females aged 20 years, the prevalence of myopia in the population aged 18 years and above might not accurately reflect the situation (Supplementary Table 3).

Characteristic	Overall N = 10,619 (100%)[a]	Myopia N = 6273 (59%)[a]	Non-myopia N = 4346 (41%)[a]	*p*-value[b]
Age (years)	12.0 (9.0, 15.0)	13.0 (11.0, 15.0)	9.0 (7.0, 12.0)	< 0.001
Sex				< 0.001
Male	5473 (51.5%)	3102 (49.5%)	2371 (54.6%)	
Female	5146 (48.5%)	3171 (50.5%)	1975 (45.4%)	
Ethnicity				0.042
Han	8621 (81.2%)	5133 (81.8%)	3488 (80.3%)	
Non-Han	1998 (18.8%)	1140 (18.2%)	858 (19.7%)	
Region				< 0.001
Urban	5635 (53.1%)	3439 (54.8%)	2196 (50.5%)	
Rural	4984 (46.9%)	2834 (45.2%)	2150 (49.5%)	
Educational stage				< 0.001
Primary school	5468 (51.5%)	2316 (36.9%)	3152 (72.5%)	
Middle school	2653 (25.0%)	1933 (30.8%)	720 (16.6%)	
High school	2498 (23.5%)	2024 (32.3%)	474 (10.9%)	

Table 1. Basic characteristics of survey participants. [a]Median (IQR); n (%). [b]Wilcoxon rank sum test; Pearson's Chi-squared test.

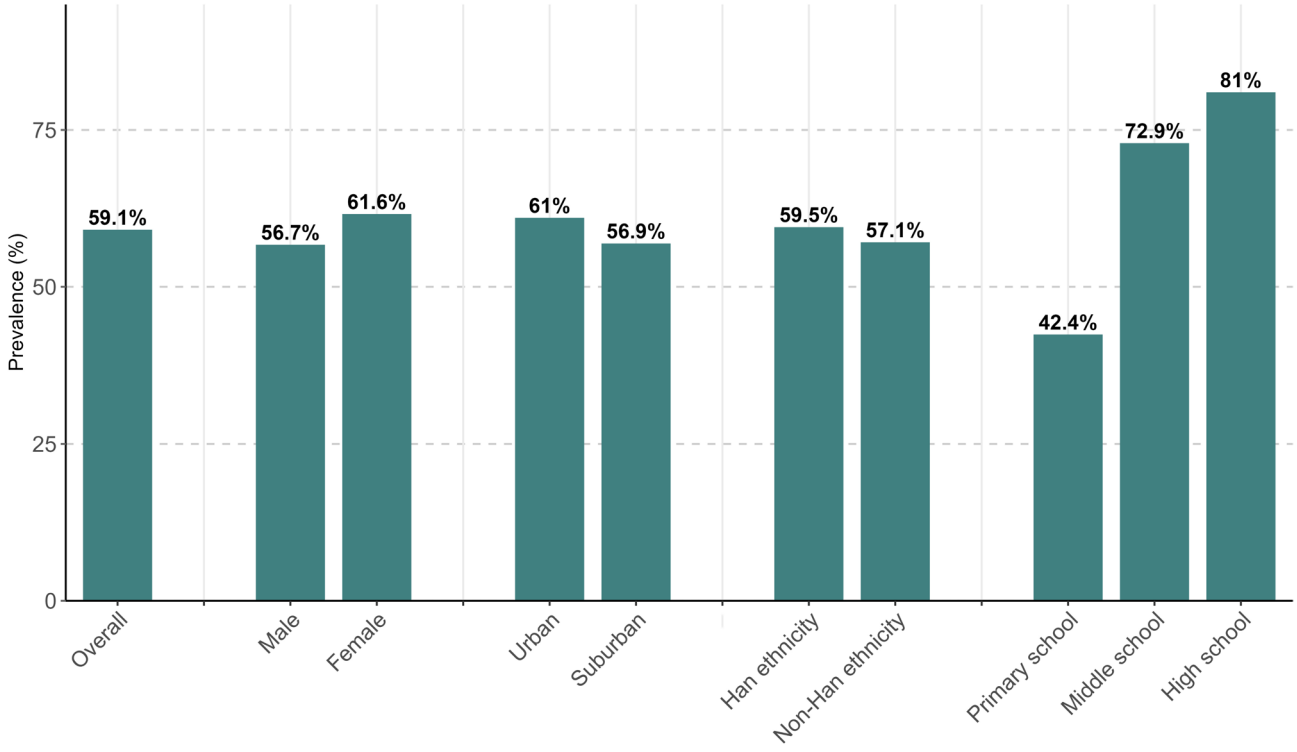


Fig. 1. The prevalence of myopia among students in Shenyang.

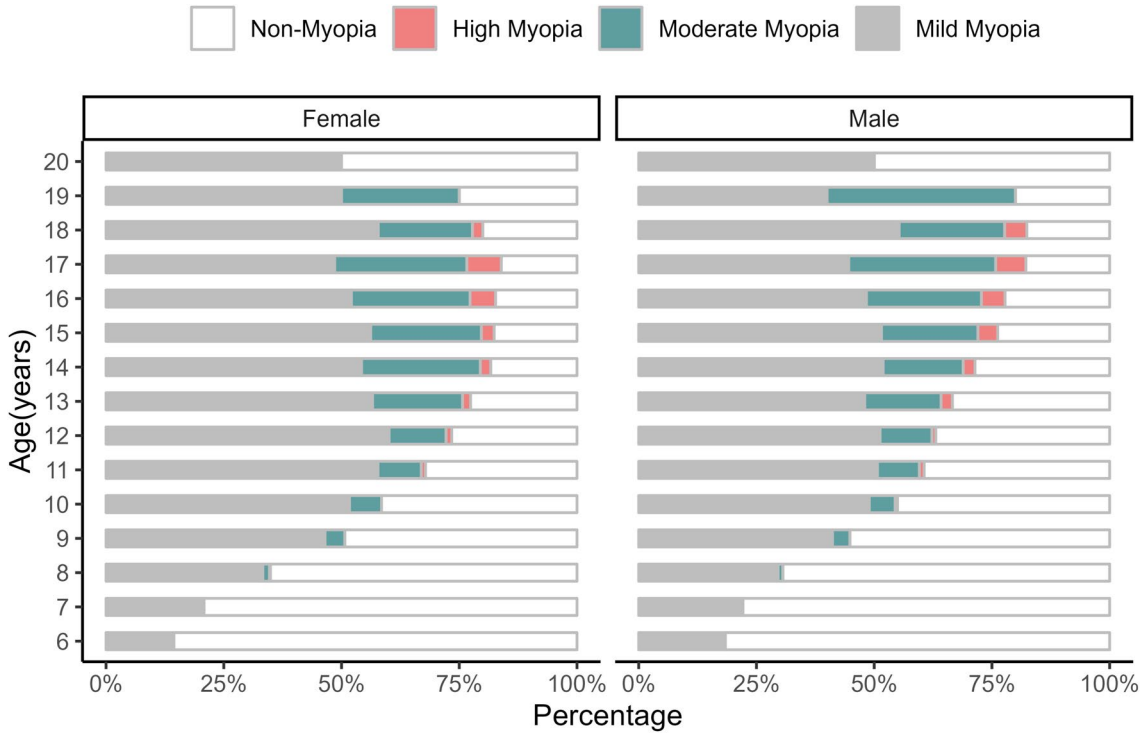


Fig. 2. Prevalence of myopia in different age groups by sex.

Correlation analysis between dietary factors and myopia

Correlation between dietary factors and myopia

The students who participated in the questionnaire were in grade 4 and above, with a total of 6974 students, including 2037 with normal vision and 4937 with myopia. As shown in Table 2 and Supplementary Fig. 1, in univariate analysis, consuming sugary drinks was a risk factor for myopia, while consuming fresh fruits at least twice a day was a protective factor against myopia. The consumption of fried food, fresh vegetables, and whether

Variables	Levels	Non-myopia (N = 2037)	Myopia (N = 4937)	OR (univariable)	OR (multivariable)
Sugary drinks	Never	659 (32.4%)	1428 (28.9%)		
	Less than once a day	1321 (64.9%)	3321 (67.3%)	1.16 (1.04–1.30, $p = 0.009$)	1.05 (0.92–1.18, $p = 0.481$)
	Once a day or more	57 (2.8%)	188 (3.8%)	1.52 (1.12–2.08, $p = 0.008$)	1.27 (0.92–1.77, $p = 0.150$)
Fried foods	Never	463 (22.7%)	1072 (21.7%)		
	Less than once a day	1528 (75%)	3734 (75.6%)	1.06 (0.93–1.20, $p = 0.394$)	
	Once a day or more	46 (2.3%)	131 (2.7%)	1.23 (0.86–1.75, $p = 0.251$)	
Fresh fruits	Never	58 (2.8%)	166 (3.4%)		
	Less than once a day	438 (21.5%)	1177 (23.8%)	0.94 (0.68–1.29, $p = 0.698$)	0.83 (0.59–1.17, $p = 0.286$)
	Once a day	1065 (52.3%)	2682 (54.3%)	0.88 (0.65–1.20, $p = 0.414$)	0.87 (0.63–1.20, $p = 0.394$)
	Twice a day or more	476 (23.4%)	912 (18.5%)	0.67 (0.49–0.92, $p = 0.014$)	**0.69 (0.50–0.97, $p = 0.034$)**
Vegetables	Never	64 (3.1%)	141 (2.9%)		
	Less than once a day	284 (13.9%)	610 (12.4%)	0.97 (0.70–1.35, $p = 0.879$)	
	Once a day	756 (37.1%)	1865 (37.8%)	1.12 (0.82–1.52, $p = 0.471$)	
	Twice a day or more	933 (45.8%)	2321 (47%)	1.13 (0.83–1.53, $p = 0.435$)	
Whether to eat breakfast	Every day	1714 (84.1%)	4123 (83.5%)		
	Sometimes	293 (14.4%)	740 (15%)	1.05 (0.91–1.22, $p = 0.515$)	
	Never	30 (1.5%)	74 (1.5%)	1.03 (0.67–1.57, $p = 0.908$)	
Sex	Male	1171 (57.5%)	2429 (49.2%)		
	Female	866 (42.5%)	2508 (50.8%)	1.40 (1.26–1.55, $p < 0.001$)	**1.40 (1.26–1.57, $p < 0.001$)**
Educational stage	Primary 4–6th grade	1018 (50%)	1445 (29.3%)		
	Middle school	609 (29.9%)	1677 (34%)	1.94 (1.72–2.19, $p < 0.001$)	**2.23 (1.94–2.57, $p < 0.001$)**
	High school	410 (20.1%)	1815 (36.8%)	3.12 (2.73–3.57, $p < 0.001$)	**3.45 (2.89–4.13, $p < 0.001$)**
Region	Urban	1119 (54.9%)	2884 (58.4%)		
	Rural	918 (45.1%)	2053 (41.6%)	0.87 (0.78–0.96, $p = 0.007$)	**1.38 (1.22–1.56, $p < 0.001$)**
Ethnicity	Han	967 (47.5%)	2362 (47.8%)		
	Non-Han	1070 (52.5%)	2575 (52.2%)	0.99 (0.89–1.09, $p = 0.778$)	
Family genetic history	Neither parent is myopic	1344 (66%)	2588 (52.4%)		
	Father is myopic	217 (10.7%)	713 (14.4%)	1.71 (1.45–2.01, $p < 0.001$)	**1.96 (1.65–2.34, $p < 0.001$)**
	Mother is myopic	290 (14.2%)	975 (19.7%)	1.75 (1.51–2.02, $p < 0.001$)	**2.11 (1.80–2.47, $p < 0.001$)**
	Both parents are myopic	186 (9.1%)	661 (13.4%)	1.85 (1.55–2.20, $p < 0.001$)	**2.66 (2.19–3.24, $p < 0.001$)**
Frequency of changing seat	Weekly	954 (46.8%)	2346 (47.5%)		
	Biweekly	316 (15.5%)	788 (16%)	1.01 (0.87–1.18, $p = 0.856$)	
	Once a month/no change	767 (37.7%)	1803 (36.5%)	0.96 (0.85–1.07, $p = 0.435$)	
Adjusting the height of the desk and chair according to the height	Never or non-adjustable	773 (37.9%)	2188 (44.3%)		
	Once a year	291 (14.3%)	617 (12.5%)	0.75 (0.64–0.88, $p < 0.001$)	0.89 (0.75–1.05, $p = 0.174$)
	Once a term	612 (30%)	1245 (25.2%)	0.72 (0.63–0.82, $p < 0.001$)	0.96 (0.84–1.11, $p = 0.618$)
	Once every 2 to 3 months	361 (17.7%)	887 (18%)	0.87 (0.75–1.01, $p = 0.060$)	1.07 (0.91–1.26, $p = 0.404$)
Frequency of daily eye exercises	Once	1316 (64.6%)	3138 (63.6%)		
	Twice and more	651 (32%)	1583(32.1%)	1.02 (0.91–1.14, $p = 0.731$)	**0.86 (0.76–0.98, $p = 0.019$)**
	No	70 (3.4%)	216 (4.4%)	1.29 (0.98–1.71, $p = 0.068$)	0.85 (0.63–1.14, $p = 0.278$)
Recess activity space	Inside the building	602 (29.6%)	1741 (35.3%)		
	Outdoor	1435 (70.4%)	3196 (64.7%)	0.77 (0.69–0.86, $p < 0.001$)	1.03 (0.91–1.17, $p = 0.635$)
Average daily time spent doing homework or reading and writing after school	< 1 h	132 (6.5%)	207 (4.2%)		
	1–2 h	610 (29.9%)	1391 (28.2%)	1.45 (1.15–1.85, $p = 0.002$)	**1.41 (1.09–1.81, $p = 0.008$)**
	2–3 h	804 (39.5%)	1966 (39.8%)	1.56 (1.23–1.97, $p < 0.001$)	**1.48 (1.15–1.89, $p = 0.002$)**
	≥ 3 h	327 (16.1%)	904 (18.3%)	1.76 (1.37–2.27, $p < 0.001$)	**1.57 (1.20–2.05, $p = 0.001$)**
	No	164 (8.1%)	469 (9.5%)	1.82 (1.38–2.42, $p < 0.001$)	**1.50 (1.11–2.03, $p = 0.008$)**
Reading and writing with your chest more than one fist away from the table	No	963 (47.3%)	2370 (48%)		
	Yes	1074 (52.7%)	2567 (52%)	0.97 (0.88–1.08, $p = 0.579$)	
Reading and writing with eyes more than one foot away from the book	No	873 (42.9%)	2258 (45.7%)		
	Yes	1164 (57.1%)	2679 (54.3%)	0.89 (0.80–0.99, $p = 0.028$)	0.95 (0.85–1.07, $p = 0.423$)
Reading and writing with fingers one inch from the tip of the pen	No	797 (39.1%)	1888 (38.2%)		
	Yes	1240 (60.9%)	3049 (61.8%)	1.04 (0.93–1.15, $p = 0.490$)	
Hours of mobile electronic devices use	No	1140 (56%)	2881 (58.4%)		
	< 0.5 h	609 (29.9%)	1410 (28.6%)	0.92 (0.81–1.03, $p = 0.143$)	
	≥ 0.5 h	288 (14.1%)	646 (13.1%)	0.89 (0.76–1.04, $p = 0.131$)	

Continued

Variables	Levels	Non-myopia (N = 2037)	Myopia (N = 4937)	OR (univariable)	OR (multivariable)
Reading a book or electronic screen in direct sunlight	No/Occasionally	1966 (96.5%)	4758 (96.4%)		
	Often	55 (2.7%)	125 (2.5%)	0.94 (0.68–1.30, $p = 0.702$)	
	Always	16 (0.8%)	54 (1.1%)	1.39 (0.80–2.44, $p = 0.245$)	
Reading the electronic screen with the lights off after dark	No/Occasionally	1883 (92.4%)	4590 (93%)		
	Often	105 (5.2%)	239(4.8%)	0.93 (0.74–1.18, $p = 0.569$)	
	Always	49 (2.4%)	108 (2.2%)	0.90 (0.64–1.27, $p = 0.564$)	
Reading a book or electronic screen while lying down or lying on the back	No/Occasionally	1779 (87.3%)	4224 (85.6%)		
	Often	217 (10.7%)	606 (12.3%)	1.18 (1.00–1.39, $p = 0.053$)	1.00 (0.84–1.20, $p = 0.998$)
	Always	41 (2%)	107 (2.2%)	1.10 (0.76–1.58, $p = 0.611$)	0.91 (0.62–1.33, $p = 0.620$)
Reading a book or electronic screen while walking or riding in a car	No/Occasionally	1944 (95.4%)	4681 (94.8%)		
	Often	74 (3.6%)	214 (4.3%)	1.20 (0.92–1.57, $p = 0.183$)	
	Always	19 (0.9%)	42 (0.9%)	0.92 (0.53–1.58, $p = 0.758$)	
When using eyes at close range, how often to rest your eyes	< 15 min	536 (26.3%)	1116 (22.6%)		
	≤ 15 to < 30 min	604 (29.7%)	1577 (31.9%)	1.25 (1.09–1.44, $p = 0.002$)	**1.22 (1.06–1.42, $p = 0.007$)**
	≤ 30- < 60 min	318 (15.6%)	868 (17.6%)	1.31 (1.11–1.55, $p = 0.001$)	1.15 (0.96–1.37, $p = 0.128$)
	≥ 60 min	579 (28.4%)	1376 (27.9%)	1.14 (0.99–1.31, $p = 0.067$)	1.06 (0.92–1.24, $p = 0.417$)
Daytime outdoor activity hours	< 1 h	577 (28.3%)	1599 (32.4%)		
	1–2 h	823 (40.4%)	1915 (38.8%)	0.84 (0.74–0.95, $p = 0.006$)	0.92 (0.80–1.06, $p = 0.236$)
	≥ 2 h	637 (31.3%)	1423 (28.8%)	0.81 (0.71–0.92, $p = 0.002$)	0.96 (0.82–1.11, $p = 0.540$)
Average daily sleep duration	< 8 h	627 (30.8%)	2415 (48.9%)		
	≥ 8 h	1410 (69.2%)	2522 (51.1%)	0.46 (0.42–0.52, $p < 0.001$)	**0.75 (0.66–0.86, $p < 0.001$)**

Table 2. Univariate and multivariate logistic regression analysis of myopia-related factors. Significance values are in bold.

to have breakfast was not associated with myopia. In multivariate analysis, after adjusting for confounding factors that showed significance in univariate analysis, such as sex, school segment, region, family genetic history, adjusting the height of the desk and chair according to the height, frequency of daily eye exercises, recess activity space, average daily time spent doing homework or reading and writing after school, reading and writing with eyes more than one foot away from the book, reading a book or electronic screen while lying down or lying on the back, eye rest frequency while using eyes at close range, daytime outdoor activity hours, and average daily sleep duration, no significant association was found between consuming sugary drinks and myopia, while consuming fresh fruits at least twice per day remained a protective factor against myopia. Students who ate fresh fruits twice or more per day had a 0.69 times lower risk of myopia than those who did not eat fruits (95% CI = 0.50–0.97, $p = 0.034$).

Subgroup analysis of the correlation between dietary factors and myopia by sex

As shown in Fig. 3, in univariate analysis, eating more fruits was found to be a protective factor against myopia in males, whereas no significant correlation was observed in females. Moreover, consuming more sugary drinks was identified as a risk factor for myopia in females (Fig. 3B), while no significant correlation was found in males (Fig. 3A). After adjusting for confounding factors that were significant in the univariate analysis (Supplementary Tables 4 and 5), the above correlations persisted. Males who ate fruits twice or more daily had a 0.59 times lower risk of myopia compared to those who did not eat fruits (Fig. 3A, 95% CI = 0.38–0.91, $p = 0.017$), whereas females who consumed sugary drinks once or more daily had a 1.80 times higher risk of myopia compared to those who did not consume sugary drinks (Fig. 3B, 95% CI = 1.03–3.15, $p = 0.037$).

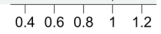
Sensitivity analysis

A total of 1994 myopic students and 1994 non-myopic students were selected by 1:1 propensity score matching. After matching, no significant differences were observed between the two groups except for dietary factors (Supplementary Table 6). Furthermore, multivariate logistic regression was performed with myopia as the dependent variable and all dietary factors as independent variables. It can be seen from Fig. 4 that the students who consumed sugary drinks once or more daily had a 1.47 times higher risk of myopia compared to those who did not consume sugary drinks (95% CI = 1.01–2.14, $p = 0.044$), indicating consuming sugary drinks was a risk factor for myopia. Moreover, the students who ate fruits twice or more daily had a 0.59 times lower risk of myopia compared to those who did not eat fruits (95% CI = 0.38–0.90, $p = 0.016$), suggesting eating more fruits was a protective factor against myopia.

As shown in Fig. 5, sex subgroup analysis after PSM revealed that males who ate fruits twice or more daily had a 0.51-fold lower risk of myopia compared to those who did not eat fruits (95% CI = 0.29–0.89, $p = 0.017$), while females who consumed sugary drinks less than once daily and once or more daily had a 1.43-fold (95% CI = 1.13–1.82, $p = 0.003$) and 1.86-fold (95% CI = 1.03–3.86, $p = 0.038$) higher risk of myopia compared to those who did not consume sugary drinks, respectively.

A

Variables	Levels	Non-myopia(N=1171)	Myopia(N=2429)	Univariable OR(95% CI,p value)	Multivariable OR(95% CI,p value)	Forest plot(Male)
Sugary drinks	Never	353 (30.1%)	712 (29.3%)	1.00(ref)		
	Less than once a day	778 (66.4%)	1623 (66.8%)	1.03 (0.89-1.21, p=.667)		
	Once a day or more	40 (3.4%)	94 (3.9%)	1.17 (0.79-1.72, p=.444)		
Fried foods	Never	286 (24.4%)	569 (23.4%)	1.00(ref)		
	Less than once a day	860 (73.4%)	1805 (74.3%)	1.05 (0.90-1.24, p=.522)		
	Once a day or more	25 (2.1%)	55 (2.3%)	1.11 (0.67-1.81, p=.690)		
Fresh fruits	Never	37 (3.2%)	103 (4.2%)	1.00(ref)	1.00(ref)	
	Less than once a day	271 (23.1%)	640 (26.3%)	0.85 (0.57-1.27, p=.422)	0.70 (0.46-1.07, p=.098)	
	Once a day	611 (52.2%)	1275 (52.5%)	0.75 (0.51-1.10, p=.145)	0.70 (0.46-1.05, p=.087)	
	Twice a day or more	**252 (21.5%)**	**411 (16.9%)**	**0.59 (0.39-0.88, p=.010)**	**0.59 (0.38-0.91, p=.017)**	
Vegetables	Never	37 (3.2%)	68 (2.8%)	1.00(ref)		
	Less than once a day	173 (14.8%)	317 (13.1%)	1.00 (0.64-1.55, p=.989)		
	Once a day	446 (38.1%)	908 (37.4%)	1.11 (0.73-1.68, p=.630)		
	Twice a day or more	515 (44.0%)	1136 (46.8%)	1.20 (0.79-1.82, p=.387)		
Whether to eat breakfast	Every day	984 (84.0%)	2051 (84.4%)	1.00(ref)		
	Sometimes	163 (13.9%)	344 (14.2%)	1.01 (0.83-1.24, p=.904)		
	Never	24 (2.0%)	34 (1.4%)	0.68 (0.40-1.15, p=.152)		



B

Variables	Levels	Non-myopia(N=866)	Myopia(N=2508)	Univariable OR(95% CI,p value)	Multivariable OR(95% CI,p value)	Forest plot(Female)
Sugary drinks	Never	306 (35.3%)	716 (28.5%)	1.00(ref)	1.00(ref)	
	Less than once a day	543 (62.7%)	1698 (67.7%)	1.34 (1.13-1.58, p<.001)	1.18 (0.99-1.41, p=.061)	
	Once a day or more	**17 (2.0%)**	**94 (3.7%)**	**2.36 (1.39-4.03, p=.002)**	**1.80 (1.03-3.15, p=.037)**	
Fried foods	Never	177 (20.4%)	503 (20.1%)	1.00(ref)		
	Less than once a day	668 (77.1%)	1929 (76.9%)	1.02 (0.84-1.23, p=.870)		
	Once a day or more	21 (2.4%)	76 (3.0%)	1.27 (0.76-2.13, p=.355)		
Fresh fruits	Never	21 (2.4%)	63 (2.5%)	1.00(ref)		
	Less than once a day	167 (19.3%)	537 (21.4%)	1.07 (0.64-1.81, p=.795)		
	Once a day	454 (52.4%)	1407 (56.1%)	1.03 (0.62-1.71, p=.900)		
	Twice a day or more	224 (25.9%)	501 (20.0%)	0.75 (0.44-1.25, p=.267)		
Vegetables	Never	27 (3.1%)	73 (2.9%)	1.00(ref)		
	Less than once a day	111 (12.8%)	293 (11.7%)	0.98 (0.60-1.60, p=.924)		
	Once a day	310 (35.8%)	957 (38.2%)	1.14 (0.72-1.81, p=.572)		
	Twice a day or more	418 (48.3%)	1185 (47.2%)	1.05 (0.67-1.65, p=.838)		
Whether to eat breakfast	Every day	730 (84.3%)	2072 (82.6%)	1.00(ref)		
	Sometimes	130 (15.0%)	396 (15.8%)	1.07 (0.87-1.33, p=.520)		
	Never	6 (0.7%)	40 (1.6%)	2.35 (0.99-5.56, p=.052)		

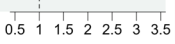


Fig. 3. Forest plot of logistic regression for sex subgroups. (**A**) Univariate and multivariate analysis of the correlation between dietary factors and myopia in males; (**B**) univariate and multivariate analysis of the correlation between dietary factors and myopia in females.

Variables	Levels	Non-myopia(N=1994)	Myopia(N=1994)	OR(95% CI,p value)	Forest
Sugary drinks	Never	630 (31.6%)	608 (30.5%)	1.00(ref)	
	Less than once a day	1300 (65.2%)	1310 (65.7%)	1.10 (0.94-1.29, p=.229)	
	Once a day or more	**64 (3.2%)**	**76 (3.8%)**	**1.47 (1.01-2.14, p=.044)**	
Fried foods	Never	461 (23.1%)	472 (23.7%)	1.00(ref)	
	Less than once a day	1492 (74.8%)	1491 (74.8%)	0.95 (0.80-1.12, p=.530)	
	Once a day or more	41 (2.1%)	31 (1.6%)	0.69 (0.42-1.15, p=.156)	
Fresh fruits	Never	57 (2.9%)	73 (3.7%)	1.00(ref)	
	Less than once a day	436 (21.9%)	402 (20.2%)	0.66 (0.43-1.01, p=.054)	
	Once a day	1037 (52%)	1103 (55.3%)	0.72 (0.47-1.09, p=.120)	
	Twice a day or more	**464 (23.3%)**	**416 (20.9%)**	**0.59 (0.38-0.90, p=.016)**	
Vegetables	Never	63 (3.2%)	58 (2.9%)	1.00(ref)	
	Less than once a day	278 (13.9%)	231 (11.6%)	1.07 (0.68-1.69, p=.756)	
	Once a day	741 (37.2%)	746 (37.4%)	1.28 (0.83-1.96, p=.262)	
	Twice a day or more	912 (45.7%)	959 (48.1%)	1.39 (0.91-2.14, p=.131)	
Whether to eat breakfast	Every day	1672 (83.9%)	1699 (85.2%)	1.00(ref)	
	Sometimes	292 (14.6%)	268 (13.4%)	0.92 (0.77-1.11, p=.377)	
	Never	30 (1.5%)	27 (1.4%)	0.88 (0.52-1.50, p=.647)	

Fig. 4. Forest plot of multivariate logistic regression between dietary factors and myopia after propensity score matching.

Discussion

Shenyang is the capital city of Liaoning Province, located in the northeast of China. It is one of the largest cities in northeastern China and a multi-ethnic city, and its survey results are representative. The results of this survey showed that the overall myopia rate among primary and secondary school students in Shenyang was 59.1%, which was higher than the overall myopia rate among Chinese children and adolescents in 2020 (52.7%) and higher

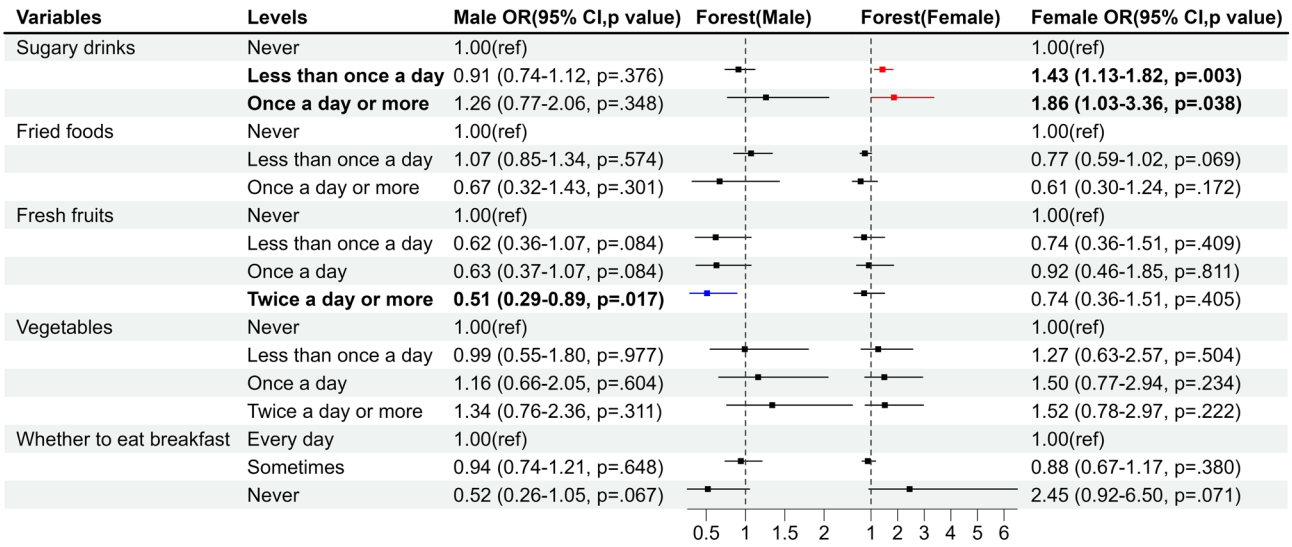


Fig. 5. Forest plot of sex subgroups for multivariate logistic regression analysis of the association between dietary factors and myopia after propensity score matching.

than the myopia prevalence in Liaoning Province in 2020 (53.9%)[15]. The myopia prevalence among high school students in Shenyang has reached 81.0%, which also reflects the severity of myopia among students in large cities in China due to the pressure of further education. In recent years, China has increased its efforts to prevent and control myopia among students, and has elevated the prevention and control of myopia in children and adolescents to a national strategy. However, more measures are still needed to reduce the myopia rate among students.

The hypothesis that diet may contribute to myopia was first proposed by Gardiner in 1965[16]. In recent years, there has been an increasing amount of research on the relationship between diet and myopia[10,17–19]. In particular, much attention has been paid to the effects of carbohydrate-rich foods on myopia. In France, Berticat et al.[11] explored the probability of myopia associated with the consumption of refined carbohydrates, which revealed a potential relationship between the intake of refined carbohydrates and myopia, with girls being more likely to be myopic. In China, a nationwide survey conducted by the Nutrition and Health Institute of the Chinese Center for Disease Control and Prevention demonstrated that from 2019 to 2021, the consumption of pastries, preserved fruits, candies, chocolates, ice cream, and other sweet snacks was quite common among children aged 11 to 14, and there was a certain positive correlation between the intake of sweets and the prevalence of myopia.[20] Moreover, Liu et al.[21] investigated the relationship between whole grain consumption and myopia in Chinese children and indicated that a high intake of whole grains (> 50%) was an independent protective factor against myopia. However, Li et al.[10] found no association between refined grains, sugary drinks, and myopia when investigating the relationship between dietary intake and myopia among 9-year-old children in Singapore. In this study, after adjusting for other confounding factors, the analysis of the entire sample revealed that while there was a tendency for consumption of sugary drinks to increase the risk of myopia, it was not statistically significant. However, it was found that consuming sugary drinks once or more per day had a significant impact on myopia in the sample analysis using propensity score matching. Notably, different results were obtained using different statistical methods, suggesting that the effect of sugary beverages on myopia may be relatively limited and susceptible to other factors. It is currently believed that the effect of carbohydrate-rich foods on myopia may be mediated through insulin, as studies have suggested that high levels of insulin can stimulate the production of growth factors that promote eye elongation, leading to progressive lengthening of the eye axis and the development of myopia[22–24]. Recently, Li et al.[25] investigated the relationship between six glycemic traits (leptin, body mass index, fasting blood glucose, fasting insulin, glycated hemoglobin (HbA1c), and proinsulin levels) and myopia by a two-sample Mendelian randomization analysis and the results indicated that low leptin levels and high HbA1c were associated with an increased risk of myopia. The above findings may suggest that the effect of carbohydrate-rich foods on myopia depends more on the severity of their effect on blood glucose levels.

Although the results of the two statistical methods showed differences in the effects of sugary beverages on myopia in the overall population, consistent results were obtained in the gender subgroup analyses. There was a gender difference in the effect of sugary drinks on myopia, with females being more sensitive. Berticat et al.[11] reported similar findings that the consumption of refined carbohydrates increased the risk of myopia in girls, while unexpectedly reducing the myopia rate in boys, which may be attributed to sex differences in metabolism or to the fact that boys are more physically active than girls. For example, Krishnan et al.[26] explored the relationship between insulin resistance, habitual physical activity, resting energy expenditure, and anthropometric variables in 107 boys and 101 girls aged 9 ± 0.25 years. The results demonstrated that compared with boys, girls had significantly higher resting heart rates, stronger insulin resistance, and less physical activity. Cnop et al.[27] investigated the relationship between adiponectin, body fat distribution, insulin sensitivity, and plasma lipoproteins, and found that women were more sensitive to insulin (SI: 6.8 ± 3.9 vs 5.9 ± 4.4, $p < 0.01$).

In this study, both the whole-sample and the propensity score matching analyses demonstrated that increased fruit intake could reduce the risk of myopia. Similar results were also obtained by London et al.[28], who compared

the food systems and visual acuity of isolated Amazonian Kawymeno Waorani hunter-gatherers and neighboring Kichwa subsistence agrarians by dietary surveys and visual acuity tests. The study revealed that hunter-gatherers maintained higher visual acuity throughout their lives due to their consumption of a greater variety of foods and more wild plants, including 76 types of wild fruits. Furthermore, eating more fruit reduces the risk of myopia, possibly attributed to the abundance of phytochemicals found in fruit. For example, Iida et al.[29] demonstrated the inhibitory effect of black-currant extract on myopia using a chick myopia model. A population-based cross-sectional study conducted in Xinjiang Uyghur Autonomous Region of China, showed an association between higher consumption of foods rich in anthocyanins and a lower prevalence of myopia[30]. It was found that anthocyanins prevented myopia by exerting a relaxing effect on the ciliary muscle[31]. Additionally, the role of carotenoids in the prevention and control of myopia has also been reported by scholars. A study from the European Eye Institute involving several European countries found that plasma lutein concentration was negatively correlated with myopia[32]. A multicenter randomized double-blind placebo-controlled clinical trial showed that dietary supplementation of crocetin may have an inhibitory effect on the progression of myopia in children[33]. Although the aforementioned studies theoretically support our findings, some studies did not find an association between increased consumption of fruits and vegetables and myopia. For example, Li et al.[10] assessed the relationship between dietary factors and myopia, spherical equivalent (SE), and axial length (AL) in 9-year-old children from the Growing Up in Singapore Towards Healthy Outcomes (GUSTO) birth cohort and found no association between the consumption of fruits and vegetables and myopia. Therefore, further research is still needed to confirm the role of fruits in the prevention and control of myopia.

Similar to sugary beverages, the effects of fruit on myopia exhibit sex differences, which may also be attributed to varying metabolisms resulting from different sexes. Vatanparast et al.[34] reported the impact of vegetable and fruit intake on bone mineral accumulation during growth in children and adolescents, and found that vegetable and fruit intake increased whole-body bone mineral accumulation in male students, but had no effect on female students. In addition, fruit contains a certain amount of sugar, and the hypersensitivity of girls to sugar metabolism may partially offset the protective effect of fruit against myopia.

Vegetables are also rich in the phytochemicals that have a protective effect against myopia mentioned above, but the results of this survey showed no association between increased vegetable consumption and myopia. The lack of association between vegetables and myopia may be related to the fact that vegetables are mainly consumed in cooked form in the Chinese diet. The cooking process can cause the loss of some nutrients in vegetables[35], the decomposition of some bioactive substances[36,37], and the addition of salt during cooking can increase the risk of retinal ischemia/reperfusion injury[38]. Mérida et al.[39] recently found an increased level of nitrite in patients with high myopia, and vegetables had a high content of nitrate, which can be metabolized into nitrite in the body, thereby increasing the risk of myopia. These factors may offset the beneficial effects of consuming vegetables on myopia to some extent, resulting in no protective effect of vegetables against myopia. However, the inference has not been confirmed, so further research is needed to ascertain whether eating more vegetables is beneficial in preventing and controlling myopia.

Fried foods are usually high in fat and calories, and diets high in fat and calories can lead to health problems such as obesity and high blood pressure. Obesity and high blood pressure, in turn, could increase intraocular pressure, raising the risk of myopia[40]. A nationwide study in Israel involving 1.3 million adolescents indicated a "J" shaped relationship between body mass index and myopia, with both low and high BMI associated with mild, moderate, and severe myopia[41]. The Korean National Health and Nutrition Examination Survey also revealed an association between obesity and high myopia in children and adolescents[42]. Our research found no correlation between consumption of fried foods and myopia in either males or females, which suggested that fried foods themselves may not directly affect the occurrence and development of myopia. Similarly, skipping breakfast may affect nutrient intake, but according to our results, the impact of skipping breakfast on nutrient intake did not appear to affect the development of myopia.

Although the impact of dietary factors on myopia is limited, they are easy to implement and control in myopia prevention. Therefore, it is of interest to explore the effects of dietary factors on myopia. While the dietary factors discussed in this study have been previously reported, the results of this study provide references for further elucidating the relationship between dietary factors and myopia. Meanwhile, we further processed the data using propensity score matching to ensure the reliability of the results, but there are still some limitations in the study.

First, it is important to note that noncycloplegic assessment of refractive errors in children overestimates myopia because noncycloplegic refraction is prone to significant errors primarily due to the active accommodative response[43]. In the present study, visual acuity assessment was performed without cycloplegia limited by the large number of participants, and it is possible that some subjects who were classified in the low myopia category were actually not myopic. Although factors such as site lighting, examination time, and environment were adjusted during measurements to minimize the effects of accommodative spasm, it was not feasible to completely rule out the potential for these factors to interfere with the results. As an internationally recognized gold standard for diagnosing myopia, cycloplegic optometry can accurately detect refractive error, but it is also associated with discomfort such as transient photophobia and blurred vision, and is time-consuming and not suitable for large-scale population screening[43,44]. A recent study has shown that the need for cycloplegic assessment and the refractive state of cycloplegia in school-age children can be predicted based on noncycloplegic ocular parameters in school-age children, according to big data collection and machine learning techniques[45]. In order to decrease the detection error and improve the accuracy of the examination results, when the subject is susceptible to subjective and objective factors, it is still recommended to perform cycloplegic refraction to determine myopia if necessary. In the future, there is still a need to further explore new fast, easy, and more accurate methods for myopia screening and prevention. Moreover, as a cross-sectional study, although our results indicate an association between sugary beverage and fruit intake and myopia, we cannot confirm a direct causal relationship. In addition, the current survey only investigated the frequency of food intake without exploring

the impact of food intake on myopia in terms of quantity. Therefore, further research is needed to verify these relationships and explore their mechanisms.

Conclusion

In summary, excessive consumption of sugary drinks may increase the risk of myopia, particularly in female students who are relatively sensitive to insulin. Consumption of large quantities of fruit may contribute to reducing the risk of myopia because of the high levels of active substances in fruit that can prevent myopia. However, the protective effect of fruits against myopia may be weakened in female students due to their own metabolic characteristics. These results need to be verified by further research.

Data availability

Data is contained within the article or supplementary material.

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References

1. Chen, S. Overall myopia rate of 527% among children and youth in China by 2020. *China Womens J.* https://doi.org/10.28067/n.cnki.ncfnb.2021.002094 (2021).
2. Rim, T. H. *et al.* Refractive errors in Koreans: The Korea National Health and Nutrition Examination Survey 2008–2012. *Korean J. Ophthalmol.* **30**, 214–224. https://doi.org/10.3341/kjo.2016.30.3.214 (2016).
3. Alvarez-Peregrina, C. *et al.* The prevalence of myopia in children in Spain: An updated study in 2020. *Int. J. Environ. Res. Public Health* https://doi.org/10.3390/ijerph182312375 (2021).
4. Matamoros, E. *et al.* Prevalence of myopia in France: A cross-sectional analysis. *Medicine (Baltimore)* **94**, e1976. https://doi.org/10.1097/md.0000000000001976 (2015).
5. Holden, B. A. *et al.* Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology* **123**, 1036–1042. https://doi.org/10.1016/j.ophtha.2016.01.006 (2016).
6. Saw, S. M., Gazzard, G., Shih-Yen, E. C. & Chua, W. H. Myopia and associated pathological complications. *Ophthal. Physiol. Opt.* **25**, 381–391. https://doi.org/10.1111/j.1475-1313.2005.00298.x (2005).
7. Liang, Y. B. *et al.* Prevalence and causes of low vision and blindness in a rural Chinese adult population: The Handan Eye Study. *Ophthalmology* **115**, 1965–1972. https://doi.org/10.1016/j.ophtha.2008.05.030 (2008).
8. Bone, R. A., Landrum, J. T., Fernandez, L. & Tarsis, S. L. Analysis of the macular pigment by HPLC: Retinal distribution and age study. *Investig. Ophthalmol. Vis. Sci.* **29**, 843–849 (1988).
9. Beatty, S., Koh, H., Phil, M., Henson, D. & Boulton, M. The role of oxidative stress in the pathogenesis of age-related macular degeneration. *Surv. Ophthalmol.* **45**, 115–134. https://doi.org/10.1016/s0039-6257(00)00140-5 (2000).
10. Li, M. *et al.* Dietary intake and associations with myopia in Singapore children. *Ophthal. Physiol. Opt.* **42**, 319–326. https://doi.org/10.1111/opo.12929 (2022).
11. Berticat, C. *et al.* Probability of myopia in children with high refined carbohydrates consumption in France. *BMC Ophthalmol.* **20**, 337. https://doi.org/10.1186/s12886-020-01602-x (2020).
12. Chua, S. Y. *et al.* Diet and risk of myopia in three-year-old Singapore children: the GUSTO cohort. *Clin. Exp. Optom.* **101**, 692–699. https://doi.org/10.1111/cxo.12677 (2018).
13. Xu, Y. *et al.* Relationship between beverage intake and myopia among 11- to 14-year-old children in China 2019–2021. *J. Hyg. Res.* **51**, 707–712. https://doi.org/10.19813/j.cnki.weishengyanjiu.2022.05.006 (2022).
14. Ministry of Health of the People's Republic of China.. GB/T 11533–2011 Standard for logarithmic visual acuity charts.
15. Gao, Q., Liu, Y. Q., Ye, Q. W., Sun, W. & Wu, M. Trends in the prevalence of myopia among students in Liaoning Province and its influencing factors in 2018–2020. *Chin. J. Dis. Control Prev.* **26**, 673–678. https://doi.org/10.16462/j.cnki.zhjbkz.2022.06.010 (2022).
16. Gardiner, P. A. The diet of growing myopes. *Trans. Ophthalmol. Soc. U. K.* **76**, 171–180 (1956).
17. Ng, F. J., Mackey, D. A., O'Sullivan, T. A., Oddy, W. H. & Yazar, S. Is dietary vitamin A associated with myopia from adolescence to young adulthood?. *Transl. Vis. Sci. Technol.* **9**, 29. https://doi.org/10.1167/tvst.9.6.29 (2020).
18. Pan, M. *et al.* Dietary ω-3 polyunsaturated fatty acids are protective for myopia. *Proc. Natl. Acad. Sci. U. S. A.* https://doi.org/10.1073/pnas.2104689118 (2021).
19. Mori, K. *et al.* Lipidomic analysis revealed n-3 polyunsaturated fatty acids suppressed choroidal thinning and myopia progression in mice. *Faseb J.* **36**, e22312. https://doi.org/10.1096/fj.202101947R (2022).
20. Ren, Z. *et al.* Relationship between sugary food intake and myopia in 11–14 years old Chinese children in 2019–2021. *J. Hyg. Res.* **51**, 713–719. https://doi.org/10.19813/j.cnki.weishengyanjiu.2022.05.007 (2022).
21. Liu, Z. *et al.* Association between whole-grain intake and myopia in Chinese children: A cross-sectional epidemiological study. *BMC Ophthalmol.* **23**, 1. https://doi.org/10.1186/s12886-022-02764-6 (2023).
22. Cordain, L., Eaton, S. B., Brand Miller, J., Lindeberg, S. & Jensen, C. An evolutionary analysis of the aetiology and pathogenesis of juvenile-onset myopia. *Acta Ophthalmol. Scand.* **80**, 125–135. https://doi.org/10.1034/j.1600-0420.2002.800203.x (2002).
23. Feldkaemper, M. P., Neacsu, I. & Schaeffel, F. Insulin acts as a powerful stimulator of axial myopia in chicks. *Investig. Ophthalmol. Vis. Sci.* **50**, 13–23. https://doi.org/10.1167/iovs.08-1702 (2009).
24. Zhu, X. & Wallman, J. Opposite effects of glucagon and insulin on compensation for spectacle lenses in chicks. *Investig. Ophthalmol. Vis. Sci.* **50**, 24–36. https://doi.org/10.1167/iovs.08-1708 (2009).
25. Li, F. F. *et al.* Causal relationships between glycemic traits and myopia. *Investig. Ophthalmol. Vis. Sci.* **64**, 7. https://doi.org/10.1167/iovs.64.3.7 (2023).
26. Krishnan, B. *et al.* Gender differences in the relationship between heart rate control and adiposity in young children: A cross-sectional study (EarlyBird 33). *Pediatr. Diabetes* **10**, 127–134. https://doi.org/10.1111/j.1399-5448.2008.00455.x (2009).
27. Cnop, M. *et al.* Relationship of adiponectin to body fat distribution, insulin sensitivity and plasma lipoproteins: Evidence for independent roles of age and sex. *Diabetologia* **46**, 459–469. https://doi.org/10.1007/s00125-003-1074-z (2003).
28. London, D. S. & Beezhold, B. A phytochemical-rich diet may explain the absence of age-related decline in visual acuity of Amazonian hunter-gatherers in Ecuador. *Nutr. Res.* **35**, 107–117. https://doi.org/10.1016/j.nutres.2014.12.007 (2015).
29. Iida, H. *et al.* Effect of black-currant extract on negative lens-induced ocular growth in chicks. *Ophthal. Res.* **44**, 242–250. https://doi.org/10.1159/000313559 (2010).
30. Shi, Y. *et al.* Ethnic disparities in risk factors for myopia among han and minority schoolchildren in Shawan, Xinjiang, China. *Optom. Vis. Sci.* **100**, 82–90. https://doi.org/10.1097/opx.0000000000001949 (2023).

31. Tsuda, T. Dietary anthocyanin-rich plants: Biochemical basis and recent progress in health benefits studies. *Mol. Nutr. Food Res.* **56**, 159–170. https://doi.org/10.1002/mnfr.201100526 (2012).
32. Williams, K. M. *et al.* Association between myopia, ultraviolet B radiation exposure, serum vitamin D concentrations, and genetic polymorphisms in vitamin D metabolic pathways in a multicountry European study. *JAMA Ophthalmol.* **135**, 47–53. https://doi.org/10.1001/jamaophthalmol.2016.4752 (2017).
33. Mori, K. *et al.* The effect of dietary supplementation of crocetin for myopia control in children: A randomized clinical trial. *J. Clin. Med.* https://doi.org/10.3390/jcm8081179 (2019).
34. Vatanparast, H., Baxter-Jones, A., Faulkner, R. A., Bailey, D. A. & Whiting, S. J. Positive effects of vegetable and fruit consumption and calcium intake on bone mineral accrual in boys during growth from childhood to adolescence: The University of Saskatchewan Pediatric Bone Mineral Accrual Study. *Am. J. Clin. Nutr.* **82**, 700–706. https://doi.org/10.1093/ajcn.82.3.700 (2005).
35. Chung, R. W. S., Leanderson, P., Gustafsson, N. & Jonasson, L. Liberation of lutein from spinach: Effects of heating time, microwave-reheating and liquefaction. *Food Chem.* **277**, 573–578. https://doi.org/10.1016/j.foodchem.2018.11.023 (2019).
36. Sun, J. *et al.* The effect of processing and cooking on glucoraphanin and sulforaphane in brassica vegetables. *Food Chem.* **360**, 130007. https://doi.org/10.1016/j.foodchem.2021.130007 (2021).
37. Yu, L. *et al.* Home food preparation techniques impacted the availability of natural antioxidants and bioactivities in kale and broccoli. *Food Funct.* **9**, 585–593. https://doi.org/10.1039/c7fo00948h (2018).
38. Li, Q. *et al.* A high-salt diet aggravates retinal ischaemia/reperfusion injury. *Exp. Eye Res.* **188**, 107784. https://doi.org/10.1016/j.exer.2019.107784 (2019).
39. Mérida, S. *et al.* Imbalance between oxidative stress and growth factors in human high myopia. *Front. Physiol.* **11**, 463. https://doi.org/10.3389/fphys.2020.00463 (2020).
40. Pileggi, C., Papadopoli, R., De Sarro, C., Nobile, C. G. A. & Pavia, M. Obesity, blood pressure, and intraocular pressure: A cross-sectional study in Italian children. *Obes. Facts* **14**, 169–177. https://doi.org/10.1159/000514096 (2021).
41. Peled, A. *et al.* Myopia and BMI: A nationwide study of 13 million adolescents. *Obesity (Silver Spring)* **30**, 1691–1698. https://doi.org/10.1002/oby.23482 (2022).
42. Lee, S., Lee, H. J., Lee, K. G. & Kim, J. Obesity and high myopia in children and adolescents: Korea National Health and Nutrition Examination Survey. *PLoS One* **17**, e0265317. https://doi.org/10.1371/journal.pone.0265317 (2022).
43. Sankaridurg, P. *et al.* Comparison of noncycloplegic and cycloplegic autorefraction in categorizing refractive error data in children. *Acta Ophthalmol.* **95**, e633–e640. https://doi.org/10.1111/aos.13569 (2017).
44. Morgan, I. G. *et al.* Cycloplegic refraction is the gold standard for epidemiological studies. *Acta Ophthalmol.* **93**, 581–585. https://doi.org/10.1111/aos.12642 (2015).
45. Du, B. *et al.* Prediction of spherical equivalent difference before and after cycloplegia in school-age children with machine learning algorithms. *Front. Public Health* **11**, 1096330 (2023).

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Author contributions

Conceptualization, D.Z., M.W., L.G. and L.Z.; methodology, D.Z., M.W., X.Y., J.S., Y.O. N.D., and G.G.; software, N.D., G.G. and L.G.; validation, X.Y., J.S. and Y.O. and L.Z.; data curation, D.Z., M.W., L.G. and L.Z; writing—original draft preparation, D.Z., L.G. and L.Z.; writing—review and editing, D.Z., M.W., L.G. and L.Z.; visualization, D.Z., L.G. and L.Z.; supervision, M.W., L.G. and L.Z.; project administration, D.Z., M.W., L.G. and L.Z. All authors have read and agreed to the published version of the manuscript.

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Competing interests

The authors declare no competing interests.

Ethical approval

Our study was conducted according to the tenets of the Declaration of Helsinki. The investigation was reviewed and approved by the Ethics Committee of the Shenyang Center for Disease Control and Prevention. Written informed consent was obtained from the legal guardians of all participants.

Additional information

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