BMJ Open

Interaction between parental myopia and children lifestyle on the incidence of myopia among children aged 6–18 years: a cross-sectional study in Tianjin, China

Tongtong Li ,[1,2] Jing Yang,[3] Jing Yan ,[1,2] Xuyang Yao,[4] Bei Du ,[4] Qi Wu,[1,2] Xiangda Meng,[2,3] Yuanyuan Liu,[2,3] Yuezhu Lu,[5] Qihua Wang,[3,6] Qiang Yang,[7] Chea-su Kee,[8] Clement C Tham,[9] Ruihua Wei,[4] Guowei Huang ,[1,2] Hua Yan [2,3,10]

To cite: Li T, Yang J, Yan J, *et al*. Interaction between parental myopia and children lifestyle on the incidence of myopia among children aged 6–18 years: a cross-sectional study in Tianjin, China. *BMJ Open* 2024;**14**:e080929. doi:10.1136/bmjopen-2023-080929

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2023-080929).

TL, JY and JY contributed equally.

Received 14 October 2023
Accepted 04 January 2024

Check for updates

For numbered affiliations see end of article.

Correspondence to
Dr Hua Yan; zyyyanhua@tmu.edu.cn, Dr Guowei Huang; huangguowei@tmu.edu.cn and Dr Ruihua Wei; weirhua2009@126.com

ABSTRACT

Objectives This study aimed to explore the influence of the interaction between parental myopia and lifestyle on myopia among school-age children.

Design Cross-sectional study.

Setting This study used data from the Tianjin Child and Adolescent Research of Eye between August and October 2022.

Participants A total of 49 035 participants between 6 and 18 years of age were eligible for this study.

Primary and secondary outcome measures The primary outcome was the interaction between eye-healthy lifestyle and parental myopia on myopia. Parental myopia and eye-healthy lifestyle were ascertained by a Child and Adolescent Behavior Questionnaire. The lifestyle risk score (LRS) of eye health was calculated based on beta-coefficient in the backward regression model. The interaction between LRS and parental myopia was analysed by multivariate logistic regression. The predictive value of different predicted models was estimated using receiver operating characteristic curves. Multiple linear regression was used to evaluate the associations of lifestyle risk factors and parental myopia with spherical equivalent refraction, which were defined as the secondary outcomes.

Results A total of 31 839 participants aged 6–18 years were included, and the myopia prevalence was 55.46%. Eye-healthy lifestyle and parental myopia were significantly associated with myopia, as was interaction. The predictive value for LRS & parental myopia was 0.714 (95% CI: 0.709 to 0.720), which was higher than LRS (0.693, 95% CI: 0.687 to 0.699) and parental myopia (0.710, 95% CI: 0.704 to 0.716) separately.

Conclusions High-risk lifestyles of myopia and parental myopia were significantly associated with a higher risk of myopia, and the combination had the strongest effect. For children, lifestyle adjustment should be prioritised in preventing myopia, especially for those with parental myopia.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ A strength of this study was a large dataset, with city-wide-scale investigation.
⇒ The extensive evaluation of lifestyle risk factors, whether treated as a single factor or combined factor by lifestyle risk score.
⇒ The effects on myopia were explored comprehensively through analysing the interaction of eye-healthy lifestyle and genetic factors, and the influence of paternal myopia and maternal myopia on myopia was distinguished, separately.
⇒ Information bias was inevitable due to self-reporting lifestyle risk factors.
⇒ Non-cycloplegia refraction was tested during ocular examinations, which could result in an overestimation of myopia prevalence.

INTRODUCTION

Myopia is a common eye disorder that develops during childhood and early adulthood. It occurs when excessive elongation of the eye causes images of distant objects to focus in front of the retina and contributes to unclear distance vision.[1] Myopia has emerged as a significant public health concern, and its prevalence is still rapidly increasing. It is estimated that myopia is likely to affect approximately 50% of the worldwide population by 2050.[2] High myopia is particularly concerning because it is linked to significantly higher rates of visual impairment and blindness via retinal complications such as myopic macular degeneration.[3–5] In 2015, the global potential productivity loss was estimated at US$244 billion due to uncorrected myopia and US$6 billion due to myopic macular degeneration.[6] Meanwhile, the cost of correcting myopia and treating its complications could impose a significant financial burden on individuals and society. Therefore, knowledge of the factors affecting myopia is crucial.

Genetic and environmental factors play a central role in the onset and progression of myopia. The heritability of myopia has been investigated through familial and genome-wide association studies. Twin studies show the highest estimates of heritability of refractive error varying from 50% to 96%, followed by that of familial aggregation studies.[7–10] Children with two parents with myopia are five to seven times more likely to be myopic than those with one or no parent with myopia.[9 10] However, the independent impacts of the environmental factors cannot be sufficiently controlled in this research. When taking into account environmental variance, a majority of heritability remains unsettled. The growing body of evidence indicates that environmental factors are associated with myopia. Established evidence supports that outdoor activity protects against myopia development in both animal models and human studies.[11–13] Additional factors affecting myopia include near work time, reading posture, sleep time, green space and eating habits.[14–19] The role of extrinsic factors in the progression of myopia cannot be understated.

The rapid increase in the prevalence of myopia is likely explained by a complex interaction between lifestyle and heritability. Heritability may be acquired by assessing parental myopia status. However, research on the interaction between parental myopia and lifestyle in children has been limited. It is unclear whether individuals might be genetically liable to develop myopia if exposed to certain lifestyles of myopia. Thus, research exploring the differential effect of lifestyle on heritability remains a worthy goal. This study aimed to examine whether eye-healthy lifestyle can influence parental myopia's effect on children aged 6–18 years developing myopia and to provide new information regarding this critical public health issue for prevention.

METHODS

Study population

This cross-sectional study used the Tianjin Child and Adolescent Research of Eye (TCARE) data. The TCARE is a city-wide, school-based and large-scale ocular examination and survey conducted annually. This study was performed on children and adolescents in primary and secondary schools in Tianjin, China, from August to October in 2022. A stratified, multistage, cluster sampling design is used to select participants in the survey. First, the probability proportional to size sampling method was used to randomly select three districts in each rural, urban and suburban area, totalling to nine districts. Second, 20 primary schools, 10 junior high schools and 6 senior high schools were randomly selected from each district, respectively. Third, 2nd, 4th, 6th, 8th and 11th grade were randomly selected from each school. A total of 49 035 participants between 6 and 18 years of age completed the questionnaire; of them, 32 229 participants underwent ophthalmological examinations. 16 806 students failed to receive an ophthalmological examination because they completed distance education at home during the COVID-19 pandemic. Among 32 229 participants, 94 children with missing data for parental myopia, 161 children with missing data or abnormal data for homework time, and 135 children with missing data or abnormal data for outdoor exercise time were excluded. Finally, 31 839 participants were analysed. A flow diagram of participants can be found in figure 1.

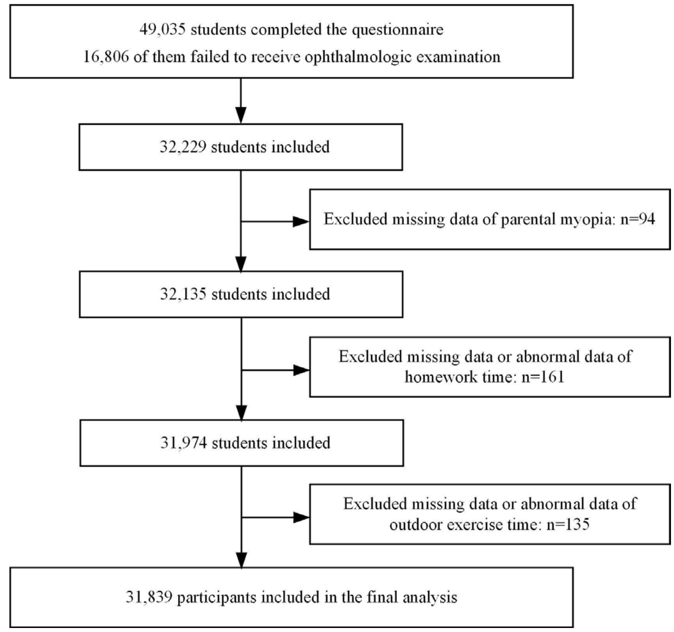

Figure 1 Flow diagram of participants in this study.

Ocular examinations

Visual acuity was measured as uncorrected visual acuity (UCVA) using a standard logarithmic visual acuity E chart at a distance of 5 m. Corrected and uncorrected visual acuity was measured separately for those with spectacles. Refraction was measured without cycloplegia with the Tianle RM-9600 autorefractor (Shanghai, China). Non-cycloplegic refraction was performed three times in each eye on each participant, with the average value being used. Each individual was re-examined if there were more than 0.50 dioptres (D) differences between any two of the three outcomes. Ocular examinations were performed by certified ophthalmic practitioners who had received standardised training. All the data were uploaded to an internet access database instantaneously.

Spherical equivalent refraction (SER) was calculated as the spherical dioptres plus half of the cylindrical dioptres (sphere+1.5 cylinder). Myopia was defined as an SER of ≤ -0.50 D and a UCVA <5.0 in either eye according to the appropriate technical guidelines for preventing and controlling myopia in children and adolescents by the National Health Commission of the People's Republic of China.[20]

Measurement of covariates

Demographic characteristics, behaviour and lifestyle and parental myopia status were collected through a Child and Adolescent Behavior Questionnaire filled in by the parents. Demographic characteristics included age, sex, region, weight, height, etc. Behaviour and lifestyle included constant near work, reading distance (<33 cm or ≥33 cm), poor reading posture, sleep deprivation, homework time (<2 hours/day or ≥2 hours/day), outdoor exercise time (<2 hours/day or ≥2 hours/day), frequency of green space per month (<2 times or ≥2 times), intake of salt (<4 g/day or ≥4 g/day) and intake of carbonated drinks or milk tea (≤1 time per month or >1 time per month). For constant near work, the question 'Will you take a long look or close your eyes to rest after 30 min of near work?' was asked. Poor reading posture was defined as reading while walking or in a moving car. Sleep deprivation was assessed based on specific criteria for primary (<10 hours), middle (<9 hours) and high school students (<8 hours).[21] For parental myopia, paternal myopia and maternal myopia were registered by a questionnaire separately.

Lifestyle risk score of eye health

Lifestyle risk score (LRS) of eye health was calculated based on each lifestyle factor's beta-coefficient (β) in the multivariate regression model, adjusting age, sex, region and parental myopia. Backward logistic regression analysis was performed until the final model only included significant lifestyle risk factors (p<0.05). Each lifestyle risk factor was assigned 0 or 1. Each binary lifestyle variable was multiplied by the β, summed, divided by the sum of the β and multiplied by the number of risk factors.

Classification of parental myopia

Parental myopia was categorised into four groups: '0' (no parents with myopia), '1' (paternal myopia), '2' (maternal myopia) and '3' (both parents with myopia).

Statistical analyses

Normally distributed continuous variables were presented as mean±SD, while skew continuous variables were described by medians and quartiles (P_{25}, P_{75}), and categorical variables were shown as frequencies and percentages. The t-test or χ^2 test was used to examine the differences in essential characteristics between individuals with and without myopia. Multivariate logistic regression was used to analyse the associations of lifestyle risk factors and parental myopia with myopia, controlling for age, sex and region. The interactions between LRS and parental myopia were also analysed. Parental myopia ('0', '1', '2' and '3') and lifestyle risk tertiles (low, medium and high) were converted into 12 dummy variables. These were then used in the multivariate logistic regression models to obtain β, ORs and covariance. Three indicators for interaction evaluation were determined by β and covariance: relative excess risk due to interaction (RERI), attributable proportion due to interaction (AP) and synergy index (S). The bootstrap resampling method was used for calculating the corresponding 95% CIs. The sensitivity and specificity of different predicted models were calculated, and the overall effectiveness was analysed by receiver operating characteristic (ROC) curves. Multiple linear regression was used to evaluate the associations between lifestyle risk factors and parental myopia with SER. The SER of the right eye was used to analyse, as Pearson's correlation coefficient for the right and left eye spherical equivalent was strong (r=0.861, p<0.01). A two-sided p value of <0.05 was considered statistically significant. Statistical analyses were applied using SPSS software V.24.0 and R software V.4.2.3. Figures were created using R software V.4.2.3 and Origin software V.2021.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

This study included 31 839 participants aged 6–18 years old, and the overall prevalence of myopia was 55.46%. The mean age was 10.98±2.77 years. Among the participants, 16 643 (52.27%) were boys and 15 196 (47.73%) were girls. The characteristics of participants with and without myopia were shown in table 1.

A backward regression model indicated that reading distance, poor reading posture, sleep deprivation, homework time, outdoor exercise time, frequency of green space, salt intake, and carbonated drinks or milk tea were significantly associated with myopia (p<0.05). For parental myopia, paternal myopia (OR=1.451, 95% CI: 1.346 to 1.564), maternal myopia (OR=1.525, 95% CI: 1.426 to 1.631) and both parents with myopia (OR=2.101, 95% CI: 1.973 to 2.237) were associated with a higher risk of myopia, compared with no parents with myopia (table 2).

For interactions between LRS and parental myopia, the 95% CI of RERI and AP did not contain 0 (RERI=0.836, 95% CI: 0.518 to 1.295; AP=0.380, 95% CI: 0.288 to 0.464), and the 95% CI of S did not contain 1 (S=3.288, 95% CI: 2.597 to 4.556), indicating that the additive interaction was significant for myopia. Figure 2 suggests that the risk of myopia among individuals with two parents with myopia and the highest tertiles for lifestyle risk was increased ($OR_{combined}$=2.979, 95% CI: 2.681 to 3.311), and was higher than the multiplication of the risks among participants who had only one of these factors ($OR_{combined}$ for both parents with myopia=1.989, 95% CI: 1.806 to 2.190; $OR_{combined}$ for high LRS=1.259, 95% CI: 1.142 to 1.388) (figure 1 and online supplemental table 1). The predictive value (calculated as the area under the ROC curve) for LRS & parental myopia was 0.714 (95% CI: 0.709 to 0.720), which was higher than LRS (0.693, 95% CI: 0.687 to 0.699) and parental myopia (0.710, 95% CI: 0.704 to 0.716) separately (figure 3). After the post-hoc

Table 1 Characteristics of participants with and without myopia

Characteristics	Total (n=31 839)	Myopia No (n=14 181)	Myopia Yes (n=17 658)	P value*
Age (years)	10.98±2.77	9.66±2.30	12.04±2.65	<0.001
Sex				<0.001
Male	16 643 (52.27)	7774 (46.71)	8869 (53.29)	
Female	15 196 (47.73)	6407 (42.16)	8789 (57.84)	
Region				<0.001
Six central districts	18 809 (59.08)	8609 (45.77)	10 200 (54.23)	
Four districts adjacent to the centre	5641 (17.72)	2609 (46.25)	3032 (53.75)	
Suburb	2893 (9.09)	1161 (40.13)	1732 (59.87)	
Binhai New Area	4496 (14.12)	1802 (40.08)	2694 (59.92)	
SER of right eye, D	−0.88 (−2.50, 0.00)	0.00 (−0.38, 0.38)	−2.25 (−3.75, −1.13)	<0.001
SER of left eye, D	−0.75 (−2.38, 0.00)	0.00 (−0.38, 0.38)	−2.00 (−3.50, −0.88)	<0.001
UCVA of right eye	4.75±0.35	5.01±0.16	4.54±0.31	<0.001
UCVA of left eye	4.76±0.34	5.01±0.16	4.57±0.31	<0.001
Constant near work	21 269 (66.80)	4425 (41.86)	6145 (58.14)	<0.001
Reading distance (<33 cm)	25 240 (79.27)	2621 (39.72)	3978 (60.28)	<0.001
Poor reading posture	26 874 (84.41)	1678 (33.80)	3287 (66.20)	<0.001
Sleep deprivation	14 580 (45.79)	7503 (45.80)	9756 (54.20)	<0.001
Homework (≥2 hours/day)	8816 (27.69)	2832 (32.12)	5984 (67.88)	<0.001
Outdoor exercise (<2 hours/day)	25 706 (80.74)	11 077 (43.09)	14 629 (56.91)	<0.001
Green space (<2 times per month)	17 226 (54.10)	7050 (40.93)	10 176 (59.07)	<0.001
Intake of salt (≥4 g/day)	26 869 (84.39)	11 738 (43.69)	15 131 (56.31)	<0.001
Intake of carbonated drinks or milk tea (>1 time per month)	8414 (26.43)	3274 (38.91)	5140 (61.09)	<0.001
Paternal myopia	13 434 (42.19)	5432 (40.43)	8002 (59.57)	<0.001
Maternal myopia	15 357 (48.23)	6278 (40.88)	9079 (59.12)	<0.001

All data are presented as n (%) for categorical variables or mean±SD, median (P_{25}, P_{75}) for continuous variables.
*P value based on t-test or χ^2 test, as appropriate.
D, dioptre; SER, spherical equivalent refraction; UCVA, uncorrected visual acuity.

tests, the results of the pairwise comparison showed that all p values were less than 0.001.

The multiple linear regression analysis results showed the associations of lifestyle risk factors and parental myopia with SER, after adjusting for age, sex and region. Constant near work and poor reading posture failed to reach statistical significance (β=0.042, 95% CI: −0.004 to 0.088; β=−0.050, 95% CI: −0.108 to 0.007). Paternal myopia (β=−0.433, 95% CI: −0.495 to −0.371), maternal myopia (β=−0.429, 95% CI: −0.485 to −0.374) and both parents with myopia (β=−0.763, 95% CI: −0.814 to −0.712) were associated with worse SER, compared with no parents with myopia (table 3).

DISCUSSION

In this cross-sectional study of 31 839 Chinese children and adolescents aged 6–18 years, we found a myopia prevalence of 55.46%. There were additive interactions between parental myopia and LRS of eye health, indicating that individuals with a high LRS in combination with worse parental myopia status had a greater risk of myopia than those with only one of these factors. The effect of interaction on myopia increased step by step within higher levels of parental myopia in combination with higher levels of LRS. The predictive value for LRS & parental myopia was 0.714, significantly higher than LRS and parental myopia separately.

This study investigated the effect of parental myopia and eye-healthy lifestyle on myopia outcome as single exposures. Our study suggested that children with parents with myopia increased myopia risk consistent with established research. A study on children aged 12–13 years in Northern Ireland concluded that children with one or both parents with myopia were 2.91 and 7.79 times more

Table 2 Logistic regression analysis of the correlation of parental myopia and lifestyle risk factors with myopia

	Full regression model*			Backward regression model*		
	β	OR (95% CI)	P value	β	OR (95% CI)	P value
Lifestyle risk factors†						
Constant near work	0.024	1.025 (0.969 to 1.083)	0.388	–	–	–
Reading distance (<33 cm)	0.171	1.186 (1.112 to 1.264)	<0.001	0.162	1.176 (1.106 to 1.249)	<0.001
Poor reading posture	0.092	1.096 (1.020 to 1.178)	0.012	0.089	1.093 (1.018 to 1.174)	0.015
Sleep deprivation	0.114	1.121 (1.067 to 1.176)	<0.001	0.113	1.120 (1.066 to 1.175)	<0.001
Homework (≥2 hours/day)	0.152	1.164 (1.097 to 1.236)	<0.001	0.151	1.162 (1.095 to 1.234)	<0.001
Outdoor exercise (<2 hours/day)	0.075	1.078 (1.014 to 1.145)	0.016	0.073	1.075 (1.012 to 1.143)	0.019
Green space (<2 times per month)	0.133	1.143 (1.088 to 1.200)	<0.001	0.131	1.140 (1.086 to 1.198)	<0.001
Intake of salt (≥4 g/day)	0.081	1.084 (1.015 to 1.158)	0.016	0.080	1.083 (1.014 to 1.157)	0.017
Intake of carbonated drinks or milk tea (>1 time per month)	0.113	1.120 (1.059 to 1.185)	<0.001	0.112	1.119 (1.057 to 1.184)	<0.001
Parental myopia‡						
Paternal myopia	0.373	1.452 (1.347 to 1.566)	<0.001	0.372	1.451 (1.346 to 1.564)	<0.001
Maternal myopia	0.423	1.527 (1.428 to 1.633)	<0.001	0.422	1.525 (1.426 to 1.631)	<0.001
Both	0.744	2.104 (1.975 to 2.241)	<0.001	0.742	2.101 (1.973 to 2.237)	<0.001

*Full and backward regression model adjusted for age, sex, region and parental myopia.
†OR based on healthy lifestyle factors as a reference.
‡OR based on no parents with myopia as a reference.
β, beta-coefficient.

likely to develop myopia than those with no parent with myopia, respectively.[22] Our study not only investigated the effects of parental myopia, but also analysed the effects of paternal and maternal myopia on children's myopia. Our survey showed that the probability of having myopia for children with maternal myopia increased by 7.4% compared with those with paternal myopia. The study of Bian *et al* also showed that maternal myopia increased the risk of myopia than paternal myopia.[23] This also reminds us to pay attention to children whose parents have myopia and underscore maternal myopia. Generally speaking, mothers spend more time with their children than fathers do. Mothers with myopia are more likely to have higher educational levels and pay more attention to their children's study, so that their children spend more time on studying. Thus, genetic factors and the lifestyle of mothers with myopia jointly increase the risk of myopia in children.

With respect to lifestyle factors, we found significant associations for reading distance, poor reading posture, sleep deprivation, homework time, outdoor exposure, frequency of green space, and intake of salt and carbonated drinks or milk tea with myopia. These factors remained significant after adjustment for age, sex, region and parental myopia, suggesting that they are independent risk factors. This is in line with previous findings.[24–27] Yang *et al* examined the effect of varied reading distances on the accommodation of children and observed accommodative lag for near distance. With decreased reading distances, accommodative lag increases, which may induce hyperopic retinal defocus and may aggravate myopia progression.[28] The mechanism for myopia due

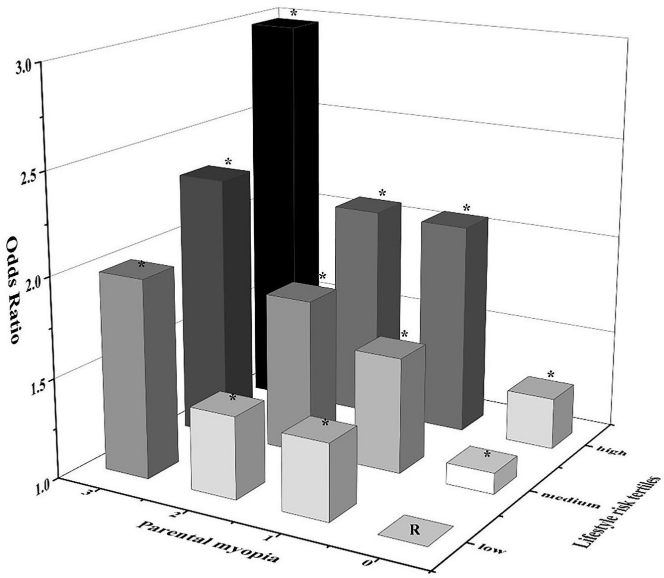

Figure 2 OR for myopia per parental myopia and lifestyle risk of myopia tertiles. The depth of the colour represents the size effect. *P<0.05. R, reference.

to excessive near work is similar.[29] Bright outdoor light might prevent myopia via stimulating the release of dopamine from the retina, because dopamine has been proven to inhibit axial elongation.[30] In an animal model using chicks, sunlight may have a protective effect against the development of myopia.[31] This may be the possible reason for outdoor exposure and green space as protective factors for myopia. Myopia is caused by sleep deprivation because the circadian rhythm of children is disrupted, which may affect the growth of the eyeball.[32] Previous study supports that long-term high-glucose intake leads to chronic elevation of plasma glucose, insulin and serum triacylglycerol levels and then promotes the transmission of various metabolic pathways, which can affect myopia

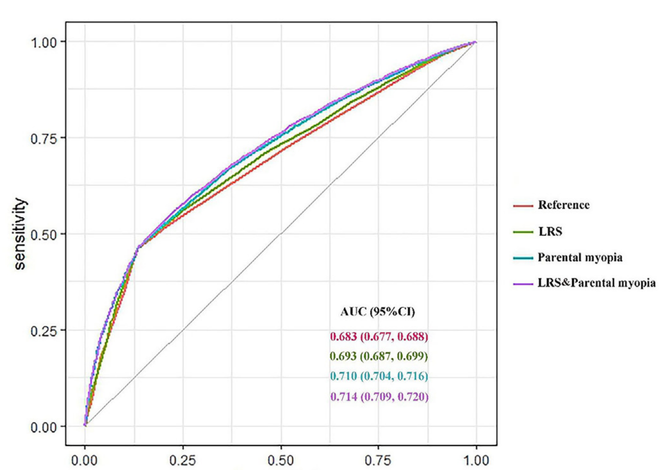

Figure 3 ROC plots. Reference model included age, sex and region; LRS, parental myopia and LRS and parental myopia model adjusted for age, sex and region. AUC, area under the curve; LRS, lifestyle risk score; ROC, receiver operating characteristic.

progression.[33] In China, students with high academic performance are selected for higher-level classes under an examination-driven educational system.[34] Chinese students are pressurised to study; therefore, they tend to spend large amounts of time on homework leading to reduced outdoor and green space exposure, or even less sleep time, causing the risk of myopia to be further increased. Our study highlights the importance of lifestyle adjustment to reduce the risk of developing myopia. Given that eye habits are multifactorial, our study used an LRS of eye health to assess the overall effect of behavioural habits on myopia, which is more comprehensive than previous studies, evaluating the effect of a single factor on myopia and the interaction of factors may be overlooked.

This study concluded that there was an additive interaction between parental myopia and eye-healthy lifestyle. Some scholars have proposed that exploring biological interaction using the additive model is more scientific.[35] In our analysis results, familial risk is influenced by lifestyle exposure, and vice versa. Children with high lifestyle risk had a higher risk of myopia than those with low lifestyle risk if they were exposed to the same familial risk. Of all the combinations, children with two parents with myopia in combination with high lifestyle risk had the greatest risk of myopia. This would imply that we should pay more attention to students whose parents have myopia to actively correct poor lifestyles to reduce the possibility of developing myopia.

As molecular genetics and related detection technologies advance, a large number of genes related to myopia have been identified. Currently, genetic testing for children is not feasible in a clinical environment, nor at general population screening. Hence, the assessment of genetic risk score is unlikely to become a routine procedure. The study of Enthoven *et al* revealed that the predictive value for parental myopia (0.67) was as good as the genetic risk score (0.67).[36] Our study showed that the predictive value for LRS & parental myopia was up to 0.714. It is significantly easier to detect children at risk of myopia before its onset by ascertainment of parental myopia and LRS of eye health. Given that changing habits is relatively difficult, identifying high-risk individuals with myopia may specifically help children at risk to adhere to lifestyle advice.

The strengths of this study included a large dataset, city-wide-scale investigation and the extensive evaluation of lifestyle risk factors, whether treated as a single factor or combined factor by LRS. The effects on myopia were explored comprehensively through analysing the interaction of genetic factors and eye-healthy lifestyle. For genetic factors, the influence of paternal myopia and maternal myopia on myopia was distinguished separately. This study also had several limitations. First, the correlation was found in the cross-sectional study, but not causation. Second, UCVA and non-cycloplegia refraction were tested during ocular examinations due to the large number and considering the feasibility of the survey. This could result in an overestimation of myopia prevalence.[37]

Table 3 Multiple linear regression analysis of the correlation of parental myopia and lifestyle risk factors with SER

	β (95% CI)	P value
Lifestyle risk factors		
Constant near work	0.042 (−0.004 to 0.088)	0.076
Reading distance (<33 cm)	−0.083 (−0.136 to 0.030)	0.002
Poor reading posture	−0.050 (−0.108 to 0.007)	0.086
Sleep deprivation	−0.057 (−0.097 to 0.016)	0.006
Homework (≥2 hours/day)	−0.222 (−0.270 to 0.174)	<0.001
Outdoor exercise (<2 hours/day)	−0.055 (−0.106 to 0.003)	0.037
Green space (<2 times per month)	−0.141 (−0.182 to 0.100)	<0.001
Intake of salt (≥4 g/day)	−0.106 (−0.161 to 0.051)	<0.001
Intake of carbonated drinks or milk tea (>1 time per month)	−0.067 (−0.113 to 0.021)	0.005
Parental myopia		
Paternal myopia	−0.433 (−0.495 to 0.371)	<0.001
Maternal myopia	−0.429 (−0.485 to 0.374)	<0.001
Both parents with myopia	−0.763 (−0.814 to 0.712)	<0.001

The results of full and backward regression analysis are exactly the same.
Full and backward regression model adjusted for age, sex and region.
SER, spherical equivalent refraction; β, beta-coefficient.

Third, the exclusion of eligible children from final analyses (children without refractive error data or complete lifestyle factors data) may have inevitably introduced selection bias. Fourth, recall bias was inevitable due to self-reporting lifestyle risk factors. Besides, in self-report questionnaires, study participants have a tendency to answer questions in such a way as to present themselves in socially acceptable terms, or in an attempt to gain the approval of others, which could introduce social desirability bias. Future studies incorporating more accurate evaluations of lifestyle risk factors and cycloplegic refraction should be considered in a small sample size. Finally, the study was conducted in Tianjin, China, which may limit the generalisability of the findings to other populations with different lifestyles and genetic backgrounds.

CONCLUSIONS

In conclusion, high-risk lifestyles of myopia and parental myopia were significantly associated with a higher risk of myopia in school-age children, and these both had additive interactions. Our findings highlight the need for teachers and parents to promote eye-healthy lifestyle interventions, and children with parental myopia should be targeted during myopia prevention efforts.

Author affiliations
[1]School of Public Health, Tianjin Medical University, Tianjin, China
[2]Tianjin Key Laboratory of Ocular Trauma, Tianjin, China
[3]Department of Ophthalmology, Tianjin Medical University General Hospital, Laboratory of Molecular Ophthalmology, Tianjin Medical University, Tianjin, China
[4]Tianjin Key Laboratory of Retinal Functions and Diseases, Tianjin Branch of National Clinical Research Center for Ocular Disease, Eye Institute and School of Optometry, Tianjin Medical University Eye Hospital, Tianjin, China
[5]Department of Ophthalmology, Peking Union Medical College Hospital, Peking Union Medical College, Chinese Academy of Medical Sciences, Beijing, China
[6]Beijing Tsinghua Changgung Hospital, School of Clinical Medicine, Tsinghua University, Beijing, China
[7]Shenyang Xingqi Pharmaceutical Co., Ltd, Shenyang, China
[8]School of Optometry, Centre for Myopia Research, Research Centre for SHARP Vision, The Hong Kong Polytechnic University, Hong Kong, China
[9]Department of Ophthalmology & Visual Sciences, The Chinese University of Hong Kong, Hong KonSARg, China
[10]School of Medicine, Nankai University, Tianjin, China

Acknowledgements We appreciate all of participants who enrolled in this study.

Contributors Concept and design—HY, GH and RW. Acquisition, analysis or interpretation of data—TL, JYang, JYan, XY, BD, QWu, XM, YLiu, YLu, QWang and QY. Drafting of the manuscript—TL, JYang and JYan. Critical revision of the manuscript for important intellectual content—HY, GH, RW, QY, C-sK and CCT. Statistical analysis—TL, JYang, JYan, BD and QWu. Obtained funding—HY. Administrative, technical or material support—HY, GH and RW. Supervision—HY, GH and RW. Guarantor: HY.

Funding This work was supported by the National Key Research and Development Program of China (grant number 2021YFC2401404) and National Natural Science Foundation of China (grant numbers 82020108007 and 81830026).

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study involves human participants. The study protocol was approved by the Medical Ethics Committee of Tianjin Medical University Eye Hospital, China (no. 2020KY-39) and the Ethical Committee of Tianjin Medical University General Hospital (no. IRB2022-YX-087-01) and conducted according to the Declaration of Helsinki. Informed consent to participate was taken from parents/legal guardians of minor participants. The form of informed consent is oral without signature. The Medical Ethics Committee of Tianjin Medical University Eye Hospital exempted informed consent signature. In addition, a professional institution is responsible for data management and data security.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

ORCID iDs
Tongtong Li http://orcid.org/0000-0002-7958-2562
Jing Yan http://orcid.org/0000-0003-0203-8451
Bei Du http://orcid.org/0000-0002-0947-1541
Guowei Huang http://orcid.org/0000-0002-0346-6303
Hua Yan http://orcid.org/0000-0002-7650-3320

REFERENCES

1 Baird PN, Saw S-M, Lanca C, *et al*. Myopia. *Nat Rev Dis Primers* 2020;6:99.
2 Holden BA, Fricke TR, Wilson DA, *et al*. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology* 2016;123:1036–42.
3 Morgan IG, Ohno-Matsui K, Saw SM. Myopia. *Lancet* 2012;379:1739–48.
4 Wong TY, Ferreira A, Hughes R, *et al*. Epidemiology and disease burden of pathologic myopia and myopic choroidal neovascularization: an evidence-based systematic review. *Am J Ophthalmol* 2014;157:9–25.
5 Lin S-C, Singh K, Chao DL, *et al*. Refractive error and the risk of age-related macular degeneration in the South Korean population. *Asia Pac J Ophthalmol* 2016;5:115–21.
6 Naidoo KS, Fricke TR, Frick KD, *et al*. Potential lost productivity resulting from the global burden of myopia: systematic review, meta-analysis, and modeling. *Ophthalmology* 2019;126:338–46.
7 Lyhne N, Sjølie AK, Kyvik KO, *et al*. The importance of genes and environment for ocular refraction and its Determiners: a population based study among 20-45 year old twins. *Br J Ophthalmol* 2001;85:1470–6.
8 Hammond CJ, Snieder H, Gilbert CE, *et al*. Genes and environment in refractive error: the twin eye study. *Invest Ophthalmol Vis Sci* 2001;42:1232–6.
9 Naiglin L, Clayton J, Gazagne C, *et al*. Familial high myopia: evidence of an Autosomal dominant mode of inheritance and genetic heterogeneity. *Ann Genet* 1999;42:140–6.
10 Pacella R, McLellan J, Grice K, *et al*. Role of genetic factors in the etiology of juvenile-onset myopia based on a longitudinal study of refractive error. *Optom Vis Sci* 1999;76:381–6.
11 Alvarez-Peregrina C, Sánchez-Tena MÁ, Martinez-Perez C, *et al*. The relationship between screen and outdoor time with rates of myopia in Spanish children. *Front Public Health* 2020;8:560378.
12 He M, Xiang F, Zeng Y, *et al*. Effect of time spent outdoors at school on the development of myopia among children in China: A randomized clinical trial. *JAMA* 2015;314:1142–8.
13 Wang Y, Ding H, Stell WK, *et al*. Exposure to sunlight reduces the risk of myopia in Rhesus monkeys. *PLoS ONE* 2015;10:e0127863.
14 Philipp D, Vogel M, Brandt M, *et al*. The relationship between myopia and near work, time outdoors and socioeconomic status in children and adolescents. *BMC Public Health* 2022;22:2058.
15 Jiang D, Shi B, Gao H, *et al*. Associations between reading and writing postures and myopia among school students in Ningbo, China. *Front Public Health* 2022;10:713377.
16 Liu XN, Naduvilath TJ, Sankaridurg PR. Myopia and sleep in children - a systematic review. *Sleep* 2023;46:zsad162.
17 Zhang C, Wang C, Guo X, *et al*. Effects of greenness on myopia risk and school-level myopia prevalence among high school-aged adolescents: cross-sectional study. *JMIR Public Health Surveill* 2023;9:e42694.
18 Xu Y, Gan Q, Zhang Q, *et al*. Association of beverages intake with myopia among 11-14-year-old Chinese children in 2019-2021. *Wei Sheng Yan Jiu* 2022;51:707–19.
19 Li Q, Fang W, Hu F, *et al*. A high-salt diet aggravates retinal ischaemia/reperfusion injury. *Experimental Eye Research* 2019;188:107784.
20 National Health Commission. Appropriate technical guidelines for the preventing and controlling of myopia in children and adolescents. 2019. Available: http://www.nhc.gov.cn/jkj/ s5898bm/201910/c475e0bd2de444379402f157523f03fe.shtml
21 Ministry of Education the People's Republic of China. Implementation Program for Comprehensive Prevention and Control of myopia in Children and Adolescents [EB/OL], . 2018Available: http://www.moe.gov.cn/srcsite/A17/moe_943/s3285/201808/t20180830_346672.html
22 O'Donoghue L, Kapetanankis VV, McClelland JF, *et al*. Risk factors for childhood myopia: findings from the NICER study. *Invest Ophthalmol Vis Sci* 2015;56:1524–30.
23 Bian HX, Bian MT, Guo M, *et al*. Investigation on the current situation of myopia among pupils in Baotou and analysis of related factors. *Int J Ophthalmol* 2021:1834–8.
24 Shi H, Fu J, Liu X, *et al*. Influence of the interaction between parental myopia and poor eye habits when reading and writing and poor reading posture on prevalence of myopia in school students in Urumqi, China. *BMC Ophthalmol* 2021;21:299.
25 You X, Wang L, Tan H, *et al*. Near work related behaviors associated with myopic shifts among primary school students in the Jiading District of Shanghai: a school-based one-year cohort study. *PLoS One* 2016;11:e0154671.
26 Liu SX, Xi W, Cui TK, *et al*. The association between lifestyle and myopia among primary school students. *Health Educ and Health Promot* 2021;16:598–601.
27 Zhang X. Environmental factors and myopia: prospects for prevention. *Chin J Sch Health* 2018;39:6–8.
28 Yang X, Gong XM, Lan WZ, *et al*. Effects of different reading distances on the accommodation of children with myopia. *Chin J Pract Ophthalmol* 2006;24:138–41.
29 Li S-M, Li S-Y, Kang M-T, *et al*. Near work related parameters and myopia in Chinese children: the Anyang childhood eye study. *PLoS One* 2015;10:e0134514.
30 Iuvone PM, Tigges M, Stone RA, *et al*. Effects of apomorphine, a dopamine receptor agonist, on ocular refraction and axial elongation in a Primate model of myopia. *Invest Ophthalmol Vis Sci* 1991;32:1674–7.
31 Ashby R, Ohlendorf A, Schaeffel F. The effect of ambient Illuminance on the development of deprivation myopia in chicks. *Invest Ophthalmol Vis Sci* 2009;50:5348–54.
32 Jee D, Morgan IG, Kim EC. Inverse relationship between sleep duration and myopia. *Acta Ophthalmol* 2016;94:e204–10.
33 Yu T, Song JK, Bi HS, *et al*. Study on high glucose diet and myopia related signal pathway. *Recent Adv Ophthalmol* 2020;40:789–92.
34 Yang Y, Li R, Ting D, *et al*. The associations of high academic performance with childhood Ametropia prevalence and myopia development in China. *Ann Transl Med* 2021;9:745:745.:.
35 Rothman KJ, Greenland S. *Modern epidemiology*3rd edition. Philadelphia: Lippincott Williams & Wilkins, 2008.
36 Enthoven CA, Tideman JWL, Polling JR, *et al*. Interaction between lifestyle and genetic susceptibility in myopia: the generation R study. *Eur J Epidemiol* 2019;34:777–84.
37 Li T, Zhou X, Zhu J, *et al*. Effect of Cycloplegia on the measurement of refractive error in Chinese children. *Clin Exp Optom* 2019;102:160–5.