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Shaping school for childhood myopia: the association between floor area ratio of school environment and myopia in China

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ABSTRACT

Aim To investigate the association of floor area ratio (FAR), an indicator of built environments, and myopia onset.

Methods This prospective cohort study recruited 136 753 children aged 6–10 years from 108 schools in Shenzhen, China at baseline (2016–2017). Refractive power was measured with non-cycloplegic autorefraction over a 2-year follow-up period. FAR was objectively evaluated using geographical information system technology. Mixed-effects logistic regression models were constructed to examine the association of FAR with a 2-year cumulative incidence of myopia among individuals without baseline myopia; multiple linear regression model, with a 2-year cumulative incidence rate of myopia at each school.

Results Of 101 624 non-myopic children (56.3% boys; mean (SE) age, 7.657±1.182 years) included in the study, 26 391 (26.0%) of them developed myopia after 2 years. In the individual-level analysis adjusting for demographic, socioeconomic and greenness factors, an IQR in FAR was associated with a decreased risk of 2-year myopia incidence (OR 0.898, 95% CI 0.866 to 0.932, p<0.001). Similar findings were observed in the analysis additionally adjusted for genetic and behavioural factors (OR 0.821, 95% CI 0.766 to 0.880, p<0.001). In the school-level, an IQR increase in FAR was found to be associated with a 2.0% reduction in the 2-year incidence rate of myopia (95% CI 1.3% to 2.6%, p<0.001).

Conclusions Exposure to higher FAR was associated with a decreased myopia incidence, providing insights into myopia prevention through school built environments in China.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous studies have reported that the prevalence of myopia in schoolchildren is increasing with urban environment, but the association between school built environment and myopia remains unclear.

WHAT THIS STUDY ADDS

⇒ In this cohort study involving 136 753 elementary school students across diverse built environments, a significant association between a higher floor area ratio and a decreased risk of myopia incidence was found.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Integrating floor area ratio into school planning may help to promote vision health among elementary school students in Chinese cities.

INTRODUCTION

The prevalence of myopia has reached epidemic proportions in East Asia,[1–3] particularly among urban children.[1 3] Although genetic and environmental factors contribute to childhood myopia, the surge in urban areas is primarily attributed to changes in environments and lifestyles, as supported by immigration studies.[4 5] However, the specific urban environmental factors responsible for this increase have only been partially identified, such as greenness.[6–9] The exposure to green space surrounding schools has been observed a negative association with myopia,[6 7] and better connectivity of greenness is correlated with a slower increase in myopia prevalence and a decreased risk of myopia onset.[8] The protective effect of outdoor time on incident myopia among schoolchildren is widely recognised in randomised clinical trials,[10–13] which may be benefited from the intensity of natural light and the spatial frequency of the outdoor environments.[12–14]

Evidence from both animal and human studies has consistently demonstrated a potential correlation between restricted space and myopia[15–18]; for instance, a higher prevalence of myopia was observed among soldiers working in submarines.[17] Therefore, we propose that the epidemic of childhood myopia may be linked to limited building space within schools due to prolonged exposure to such settings. Mechanisms underlying distinct optical properties in confined spaces have been supposed to elicit myopic signals on the retina,[18–22] including hyperopic defocus generated from indoor environments and nearby objects, and a deficiency in high spatial frequency similar to that in myopia-induced model. A more confined environment may also increase the fundamental accommodative demand experienced by its occupants and therefore cause myopia.[23] Despite the existing evidence, there is a paucity of evidence regarding built environments

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and myopia. Only studies conducted in Hongkong have investigated the association between home size and myopia.[19 21 24] However, these residential data were obtained from subjective self-reporting rather than objective measurement, and the association between school built environments and myopia has not been explored.

Floor area ratio (FAR), the ratio of the total floor area of buildings to the land area they occupied, serves as a comprehensive indicator for urban morphology, reflecting both building space therein and the land utilisation.[25 26] For schools with identical site areas, a lower value of FAR indicates a reduction in the total floor area for schools. A geographical information systems (GIS) is a computer system used for storing and managing geographically referenced information, which has been widely applied in various fields including natural, social and medical sciences.[27] By linking health data with maps through geographical or spatial connections, it helps us study the spatiotemporal distribution of various diseases and screen their risk factors at a population level, such as infectious diseases and cancer.[28] The current study has employed satellite images and open-source data to develop a GIS map,[29] enabling the modelling of school buildings and the convenient quantification of FAR, which is more objective and efficient, especially compared with data obtained through questionnaires. This longitudinal cohort study has investigated the association between FAR and myopia incidence in children from 108 primary schools in Shenzhen, offering innovative population-scale myopia prevention from a perspective of school planning and reconstruction.

METHODS

Study design and participants

Data were from the prospective cohort of the Environmental Health and Myopia Prevention and Control Project (national clinical trial (NCT) 04161326),[6] designed to examine the potential effect of environment factors on myopia.

As one of China's rapidly developing metropolises, Shenzhen has confronted the challenges posed by a burgeoning population and limited land resources, particularly in the realm of education. To address these issues, schools in Shenzhen were granted a higher level of FAR compared with other Chinese cities, making it an exemplary case for the current study. As previously presented,[6] annual eye examinations were conducted in 113 schools in Shenzhen from baseline (2016–2017) through the final period (2018–2019). The values of five boarding schools were excluded as outliers. Children who had undergone myopia treatment or had other conditions that could impact refraction, such as strabismus or ophthalmic surgery, were excluded. A total of 136 753 children in grades 1–4 from 108 schools were recruited for participation (figure 1). Out of the initial sample, a 2-year follow-up was completed by 115 883 children, with 101 624 being non-myopic at baseline. To collect potential confounding factors, we randomly selected a subset of 8400 children from 28 schools for questionnaire collection. Valid responses were obtained from 7996 participants, with 87.6% being non-myopic at baseline.

Measurements

Refraction

Eye examinations were performed at school by 12 trained technicians. Visual acuity was assessed monocularly using tumbling Early Treatment Diabetic Retinopathy Study charts at a distance of 4 m. Non-cycloplegic autorefraction was performed using Topcon RM6000 (Topcon, Japan), with three valid measurements on each eye and the average recorded. Annual examinations at each school were performed by the same set of examiners with the same equipment in the same academic year.

Floor area ratio

FAR is a fundamental metric for urban morphology, with a higher value representing larger school building space. The value

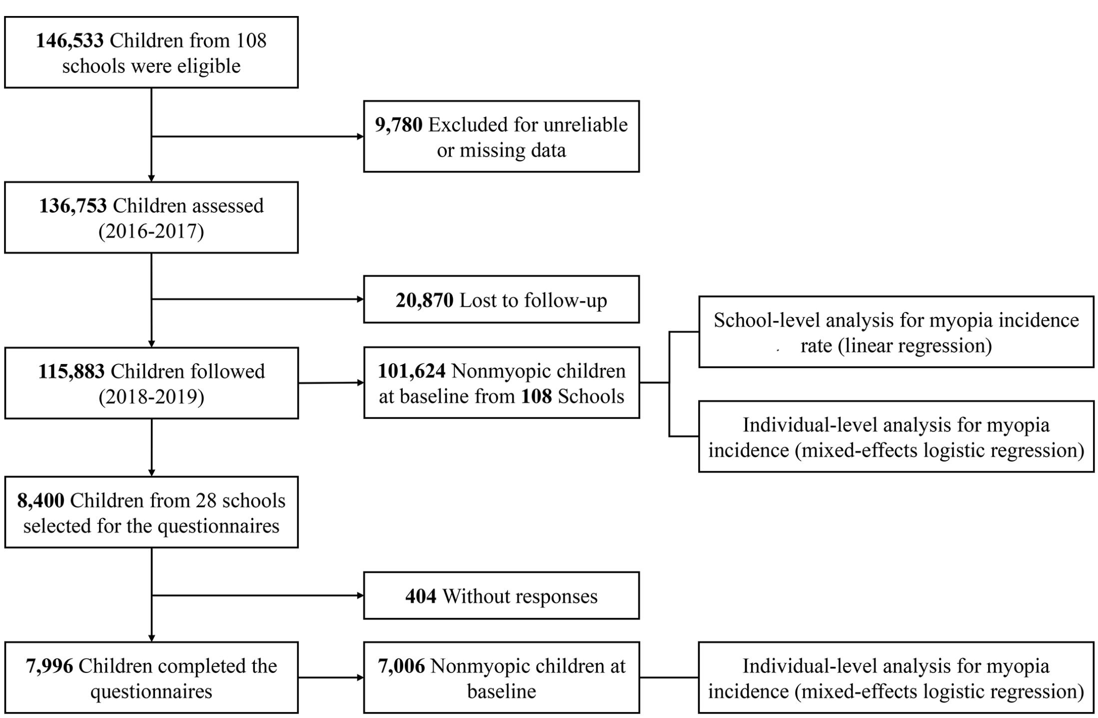

Figure 1 Flow chart of the study. SE, spherical equivalent.

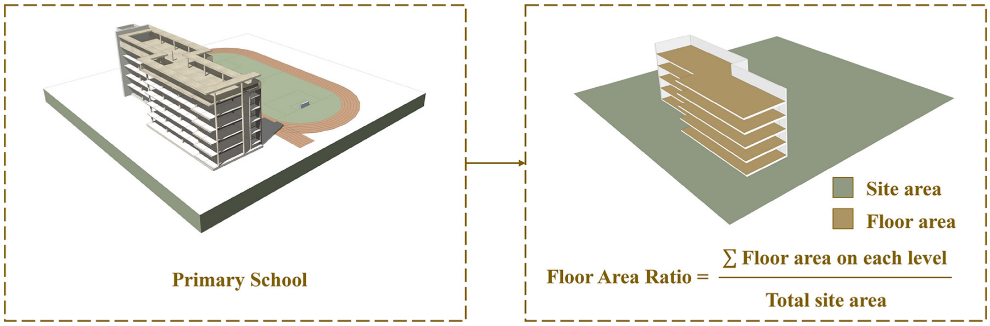

Figure 2 The calculation of FAR for each primary school. FAR is calculated by dividing the total floor area of buildings (represented in yellow) by the site area (represented in green). It should be noted that all school buildings included in this study were non-high-rise structures (less than nine floors). FAR, floor area ratio.

of FAR is calculated by dividing the total floor area of buildings by the land area within each school (figure 2).[25] The total floor area of a building is determined by multiplying the area of each floor by the floor number. The determination of building floor numbers involved two steps. First, we calculated an initial estimate of the floor number by dividing the building height by three metres, aligning with the minimum floor height (National Standard of the People's Republic of China, GB50099-2011). Second, we rectified discrepancies in floor numbers with reference to online 360°street-view photographs (http://map.qq.com, accessed on 10 October 2018), considering that certain building features such as decorative rooftop additions might not be excluded from overall height calculations.

For the determination of building heights, we adopted the traditional satellite stereo matching approach,[30] employing data from the Gaofen-2 satellite images of different view angles (online supplemental figure S1). This satellite can provide high resolution camera (0.8 m panchromatic and 3.2 m multispectral) data. By leveraging multiview three-dimensional reconstruction techniques, we constructed a fusion digital surface model (DSM), enabling the creation of high-precision urban models including height information. For building detection to filter floor plans, we employed the Sat2LOD2 open source software,[31] combining DSM with the street network from Open Street Maps (https://www.openstreetmap.org/, accessed on 15 May 2018) to aid in establishing more accurate floor plans (building footprint) (online supplemental figure S1). In order to test building segmentation performance in a Chinese megacity, we incorporated data from Shanghai,[32] which shares a similar strategic coastal location and dense buildings with Shenzhen, that includes reliable ground truth information. The achieved overall accuracy at the pixel level was 95.47%.

After delineating the school boundary, the value of FAR for each school was calculated using ArcGIS software (V.10.3, Environmental Systems Research Institute, Redlands, California, USA).

Green space and other potential confounding factors of myopia

The normalised difference vegetation index (NDVI) is a fundamental indicator of green space,[6 8 33] with higher positive values indicating greater levels of vegetative coverage. Details were described previously.[6] In brief, NDVI maps were derived from high-resolution satellite imagery accessed through the Resource and Environment Data Cloud Platform (http://www.resdc.cn/). The greenness exposure within each school was calculated using ENVI (V.5.3, Harris Geospatial Solutions, Boulder, Colorado, USA).

Potential confounding factors identified in previous studies were also assessed.[6] Age, sex and school socioeconomic status information were obtained from the education department and its affiliated schools. Information on parental myopia, children's mean screen time, reading time and outdoor time per day after school was acquired from questionnaires. Subdistrict-level gross domestic product (GDP) per capita was collected for each school catchment area from the local Bureau of Statistics. The average GDP values for the years 2016, 2017 and 2018 were recorded.

Outcomes

The 2-year cumulative myopia incidence was defined as a spherical equivalent (SE, sphere plus one half of cylinder) of at least −0.5 dioptres (D) at any visit after baseline.[34] The 2-year cumulative incidence rate of myopia was defined as the proportion of participants with myopia who did not have myopia at baseline. Data from the right eyes were used for analyses due to high correlations between SE of right and left eyes (Pearson, r=0.599, p<0.001).

Table 1 Description of visual, demographic, environmental characteristics of all participants (N=101 624)

Characteristics	All
SE at baseline, dioptres	0.025±0.285
Age at baseline, years	7.657±1.182
Sex	
Girl	44 454 (43.7)
Boy	57 170 (56.3)
Socioeconomic status	
Ordinary school	22 906 (22.5)
Key school	78 718 (77.5)
NDVI	0.201 (0.171 to 0.237)
GDP	
<US$15 000	56 861 (56.0)
≥US$15 000	44 763 (44.0)
Outcome	
Myopia incidence	26 391 (26.0)

Data were presented as means±SD deviation, number (%) or median (IQR).
GDP, gross domestic product; NDVI, normalised difference vegetation index; SE, spherical equivalent.

Table 2 The factors associated with risk of 2-year myopia incidence from the mixed-effects logistic regression models

Factors	OR (95% CI)	P value
Non-myopic individuals (N=101 624)		
FAR	0.898 (0.866 to 0.932)	<0.001
NDVI	0.834 (0.772 to 0.901)	<0.001
SE at baseline, dioptres	0.170 (0.149 to 0.194)	<0.001
Age, years	1.395 (1.378 to 1.413)	<0.001
Sex (ref: boy)		
Girl	1.473 (1.431 to 1.516)	<0.001
School socioeconomic status (ref: ordinary school)		
Key school	1.037 (0.921 to 1.168)	0.544
GDP (ref: <US$15 000)		
≥US$15 000	1.209 (1.096 to 1.335)	<0.001
Non-myopic individuals with questionnaire (N=7006)		
FAR	0.821 (0.766 to 0.880)	<0.001
NDVI	0.815 (0.736 to 0.903)	<0.001
SE at baseline, dioptres	0.369 (0.246 to 0.556)	<0.001
Age, years	1.360 (1.295 to 1.429)	<0.001
Sex (ref: boy)		
Girl	1.444 (1.286 to 1.620)	<0.001
School socioeconomic status (ref: ordinary school)		
Key school	1.094 (0.974 to 1.228)	0.128
≥US$15 000	1.172 (1.026 to 1.340)	0.020
Parental myopia (ref: no)		
Yes	1.361 (1.210 to 1.530)	<0.001
Outdoor time (ref: <2 hours/day)		
≥ 2 hours/d	0.549 (0.457 to 0.659)	<0.001
Reading time (ref: < 2 hours/day)		
2–4 hours/day	1.322 (1.157 to 1.509)	<0.001
≥ 4 hours/day	1.958 (1.396 to 2.747)	<0.001
Screen time (ref: <2 hours/day)		
≥ 2 hours/day	3.080 (2.444 to 3.882)	<0.001

Estimates were scaled to an IQR for FAR and a 0.1-unit for NDVI.
FAR, floor area ratio; GDP, gross domestic product; NDVI, normalised difference vegetation index; SE, spherical equivalent.

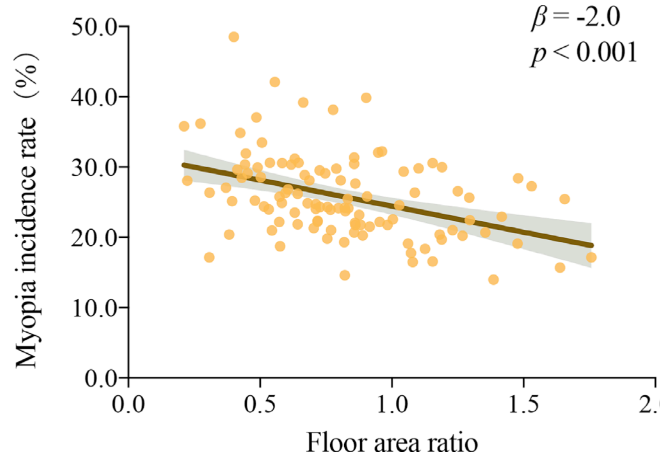

Figure 3 Association between floor area ratio and 2-year myopia incidence at school level. With an IQR increase in FAR, the myopia incidence rate decreased by 2.0% (95% CI 1.3% to 2.6%, p<0.001). FAR, floor area ratio.

Statistical analysis

In the descriptive analysis of baseline characteristics, the differences in baseline SE, age, sex, school socioeconomic status, GDP and NDVI between those followed up and those lost to follow-up were assessed using Mann-Whitney U test for continuous variables and χ^2 test for categorical variables.

In individual-level analyses, mixed-effects logistic regression models were employed to evaluate the association between FAR with myopia incidence. A random intercept term was used to account for the school clustering. Confounding factors included SE at baseline, age, sex, school socioeconomic status, GDP and NDVI. Further analysis was conducted by incorporating additional covariates including parental myopia, average screen time, reading time and outdoor activity time after school per day.

In school-level analysis, multiple linear regression model was performed to evaluate the associations between FAR with myopia incidence rate over 2 years. Confounding factors included mean SE at baseline, average age, percentage of boys, school socioeconomic status, GDP and NDVI.

The ORs and regression coefficients (βs) with corresponding 95% CIs (CIs) per IQR greater FAR were estimated. A $p<0.05$ for a two-tailed test denoted statistical significance. All statistical analyses were performed by using IBM SPSS Statistics software (V.26.0, IBM).

RESULTS

Characteristics of participants

A total of 108 schools in Shenzhen were included in the current study, after excluding 5 boarding schools. The exclusion criteria encompassed individuals with unreliable or missing data, those lost to follow-up and those who exhibited myopia at baseline. A total of 10 1624 children from grades 1 to 4 were included in the present analysis, with an average age of 7.657±1.182 years. Among them, 56.3% were boys (table 1) and 77.5% were from ordinary school. Among children followed and lost to follow-up, there were no differences in age (p=0.513), sex (p=0.970), SE (p=0.181) and school socioeconomic status (p=0.671).

The mean (SD) values of FAR at each school were 0.815 (0.332), ranging from 0.211 to 1.757. No associations were found between FAR and school-level characteristics at baseline, including mean SE (r=0.186, p=0.054), average age (r=−0.041, p=0.677), male per cent (r=−0.042, p=0.667), GDP (r=0.001, p=0.989) and NDVI (r=−0.027, p=0.782).

Association of FAR and individual-level outcome

In the analysis of 101 624 children without baseline myopia, an IQR increase in FAR was associated with a decreased risk of myopia incidence by 10.2% (95% CI 6.8% to 13.4%, p<0.001) over a 2-year period (table 2), with an adjustment of baseline SE, age, sex, school socioeconomic status, GDP and NDVI.

Out of the 8400 children whose parents were invited to participate in the questionnaire survey, a total of 7006 children responded, with 1669 (23.8%) of them developed myopia over 2 years (online supplemental table S1). Further analysis additionally adjusted for covariates, including parental myopia, average screen time, average reading time and average outdoor activity time after school per day. An IQR increase in FAR was associated with a 17.9% (95% CI 12.0% to 23.4%, p<0.001) decrease in the risk of myopia incidence (table 2).

Association of FAR and school-level outcome

For 108 included schools, the cumulative average incidence rate of myopia was 25.8% (ranging from 14.0% to 48.5%). In school-level analysis, an IQR increase in FAR was found to be associated with a 2.0% reduction in cumulative incidence rate of myopia (95% CI 1.3% to 2.6%, $p<0.001$) (figure 3), with an adjustment for baseline mean SE, average age, percentage of boys, school socioeconomic status, GDP and NDVI.

DISCUSSION

Using GIS technology to objectively assess built environment of primary schools, the prospective cohort study has indicated that greater FAR was associated with a decreased risk of myopia incidence among 101 624 children, after controlling for demographic, economic and greenness factors. It remained consistent in the analyses additional adjusting for parental myopia and behavioural factors, offering novel insights for population-based myopia prevention from the construction and renovation of schools.

Similar associations between building space exposure and myopia had been previously reported.[19 21 24] In a cross-sectional study involving 1075 children with an average SE of −1.21D,[24] living in homes smaller than 300 ft^2 was associated with a decrease in SE by −0.47D when compared with residing in homes larger than 600 ft^2. A further longitudinal study with a small sample of fifty subjects has revealed a negative association between home size and 1-year refractive progression.[19] However, the assessment of home size has relied on questionnaire-derived data, rather than objective measurement. In the current study, we have quantified the exposure to school built environment using GIS technology and revealed an association between greater FAR and a decreased risk of myopia incidence.

Optical properties of built environment could play a role in the association of FAR and myopia. One possible explanation is the defocus profile from indoor scenes. Indoor environments with limited distance and abundant nearby objects create unevenly dioptric profiles (greater variation in defocus distribution). Using a depth sensing camera to quantify defocus profile from near-work scenes at home,[20] a study involving 50 children aged 9.3 years has indicated that a more hyperopic scene defocus profile was associated with faster 1-year myopia progression, highlighting the importance of indoor environment on account of the variances of refraction.

Previous studies have investigated that FAR was associated with health outcomes, including mental illness and morbidity of uncontrolled diseases.[35–37] Generally, residing in communities with lower FAR can promote improved air quality, enhance the availability of green spaces and improve accessibility to activities,[38] thereby theoretically creating favourable living conditions. However, this may not be fully applicable in school settings because all selected schools had a low FAR level (ranging from 0.211 to 1.757) as a result of governmental restrictions on school building heights. To optimise eye protection in school environments, our suggestion is to maximise the floor area of buildings as much as possible to provide increased indoor space for activity, as well as to ensure sufficient green space outdoors.

There are several limitations. First, all selected schools were located in the same city due to the geographical limitation of the sample, which limits the study generalisability. However, we chose schools in Shenzhen because they provide a perfect example of school environments with diverse FAR that can well represent schools in dense cities in East Asia where have similar background. Second, areas that are rarely accessed by children, such as offices and security booths, are also taken into consideration. However, the proportion occupied by these areas was negligible and unlikely to significantly impact these findings. Third, direct audits of the buildings were not conducted school by school due to their time-consuming nature, potentially leading to discrepancies in the FAR. To ensure efficiency and accuracy in FAR calculations, we employed GIS technology to process FAR using data from high-resolution satellite images and OpenStreetMap. Fourth, we were also unable to incorporate other myopia-related factors, such as family income and parental education level, as confounder variables. Furthermore, the utilisation of non-cycloplegic refraction may result in an overestimation of SE.[39] Nevertheless, non-cycloplegic refraction examination is widely applied in epidemiological studies on myopia due to its high efficiency and safety. Prospective research is needed to further explore the causal relationship between building density and myopia.

Myopia is a multifactorial disease, and the aetiology of this high prevalence disease in the process of urbanisation has not been fully explained. We believe that built environment is not the sole cause of myopia. Factors such as outdoor activity time, educational intensity and environmental greenness also contribute to the increasing incidence of myopia. Our findings do not contradict traditional notions about the causes of myopia. We advocate for a school environment that promotes eye health by ensuring both sufficient indoor space and abundant green spaces.

CONCLUSION

Exposure to schools with higher FAR was associated with a decreased risk of myopia incidence. These findings stress the need to raise awareness among the public and urban planners of the potential impact of school built environments on eye health.

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