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Trajectories of night light exposure and risk of overweight and obesity: a 15-year longitudinal cohort study of 218,239 Chinese children

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Abstract

Background Light at night (LAN) is found to be associated with elevated overweight and obesity in broad population. However, evidence for the long-term LAN exposure trajectories and its influence to weight gain remained limited, especially to school-aged children who experience critical physical development. We aimed to analyze variations in body weight among children with different LAN exposure profiles, and how varying levels of LAN exposure influenced children's overweight (including obesity) risk overt time.

Methods Children who had ≥ 5 school health examinations between 2005 and 2020 in Zhongshan were recruited in this population-based longitudinal study. LAN data of each child at each survey year were modeled with group-based trajectory model and named as sharp rise (reference; 5.5%), mild rise, high stable (69.7%), and decline. Differences of overweight incidence between groups were analyzed.

Results Among 218,283 children (1,318,542 measurements; 53.1% boys; baseline mean [SE] age, 9.1 [2.5]), 12,050 (5.5%) were categorized in the sharp rise group and 152,030 (69.7%) in the stable high group. In the 189,011 participants categorized as normal or underweight at baseline, the overall incidence of overweight during follow-up was 8.80/1000 person-years (95% CI: 8.69, 8.91). Compared to the sharp rise group, the hazard ratios (HR) for developing overweight were 1.67 (95% CI: 1.28, 2.18) for boys and 1.56 (95% CI: 1.21, 2.01) for girls in stable high group, followed by the mild rise group. The HRs in decline group were non-significant. Overall, the stable high trajectory of LAN exposure accounted for 40.24% (range: 22.14, 54.14) of overweight risk in boys and 36.09% (range: 17.79, 50.31) in girls, while the mild rise group contributed approximately 23% to the overall risk.

Conclusions Higher LAN exposure trajectories, especially at early school age, had persistent effect to overweight and obesity risk in school-aged children. Interventions to reduce LAN exposure during school age may help reduce excessive weight gain in children.

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Keywords Artificial light at night, Adolescent health, Overweight and obesity, Longitudinal study, Group-based trajectory study

Background

Overweight and obesity are significant risk factors for children's health and have rapidly evolved over the past decades to become one of the most pressing global health issues [1, 2]. Between 1985 and 2019, the average weight of adolescents worldwide increased much faster than their height, with China experiencing a particularly rapid increase in body mass index (BMI) among older teenagers [3]. Previous studies have indicated that changes in BMI during school age are closely correlated with the risk of obesity and other metabolic diseases in adulthood, making this a critical period for obesity prevention [4–7]. A deeper understanding of the intrinsic and extrinsic factors that contribute to BMI changes during this time is essential for informing effective public health strategies.

The causes of obesity are multifactorial. Alongside diet, exercise, genetics, and early life adversity factors that are currently being well studied [8, 9], environmental factors, particularly light at night (LAN), have recently garnered attention due to their direct relationship with economic development [10]. A cross-sectional study in 2016 identified LAN as a statistically significant and positive predictor of overweight and obesity, explaining 67% to 73% of the worldwide prevalence of adult overweight and obesity in over 80 countries [11]. As interest in the relationship between LAN and obesity has grown, more population studies have emerged. For example, a cohort study of community-dwelling older adults in the USA found that habitual night light exposure was associated with a higher prevalence of cardiovascular risk factors, including obesity, diabetes, and hypertension [12]. Similarly, another large cohort study of 43,722 women in the USA and Puerto Rico reported that exposure to artificial light during night sleep was associated with increased weight, independent of sleep duration, quality, or other sleep-related factors [13]. Smaller studies in younger adults and countries outside the USA, as well as several systematic reviews, have also reported a relationship [14–16]. However, most of these studies captured LAN exposure at a single time point. To date, little is known about how changes in LAN exposure over time affect BMI, particularly during the school-age years when BMI undergoes rapid development.

To address these knowledge gaps and uncover the long-term effects of LAN on children's BMI, we conducted a large-scale longitudinal study of school-aged children from Guangdong Province, China. Our research aimed to model the trajectories of LAN exposure throughout school years and to analyze variations in BMI levels among children with different LAN exposure profiles. Additionally, we examined the incidence of overweight and obesity among children classified as normal weight at baseline, evaluating how varying levels of LAN exposure influenced their risk of developing these conditions overt time.

Methods

Study population

We utilized data from the Zhongshan Student Health Examination cohort in Zhongshan, Guangdong Province, China. This dataset encompasses annual health examinations of children from all the 354 public primary and secondary schools (the number of schools fluctuated over time) in Zhongshan, forming an ongoing retrospective dynamic cohort. Additional file 1: Figure S1 illustrates the distribution of these schools across Zhongshan City, along with the corresponding LAN density for the years 2005 and 2020. Detailed descriptions of the dataset have been previously published [4]. On average, the cohort sees approximately 10,000 new students entering each year, with a similar number exiting. All health examinations were administered by Zhongshan Health Care Center for Primary and Secondary Schools and conducted by qualified medical professionals.

For the present study, we analyzed data from 218,239 children who attended primary and secondary schools in Zhongshan between 2005 and 2020, and who participated in at least five annual health examinations Fig. 1. The Zhongshan Health Care Center for Primary and Secondary School authorized the use of the dataset, ensuring all personal information was de-identified prior to authorization. Therefore, the present analysis met the exemption criteria and was approved by the Institution Review Board of Peking University (IRB B00001052-20011-exempt).

Measures

Children's sex (boys or girls) and date of birth were recorded in the school registry system. Age at each examination was calculated as (date of examination − date of birth)/365.25. Height and weight were measured following standardized procedures in accordance with the National Survey on the Constitution and Health of Chinese Students [10]. BMI was calculated as weight (kg)/height^2 (m^2) and converted into z scores. Missing BMI values were imputed using linear interpolation, with 1806

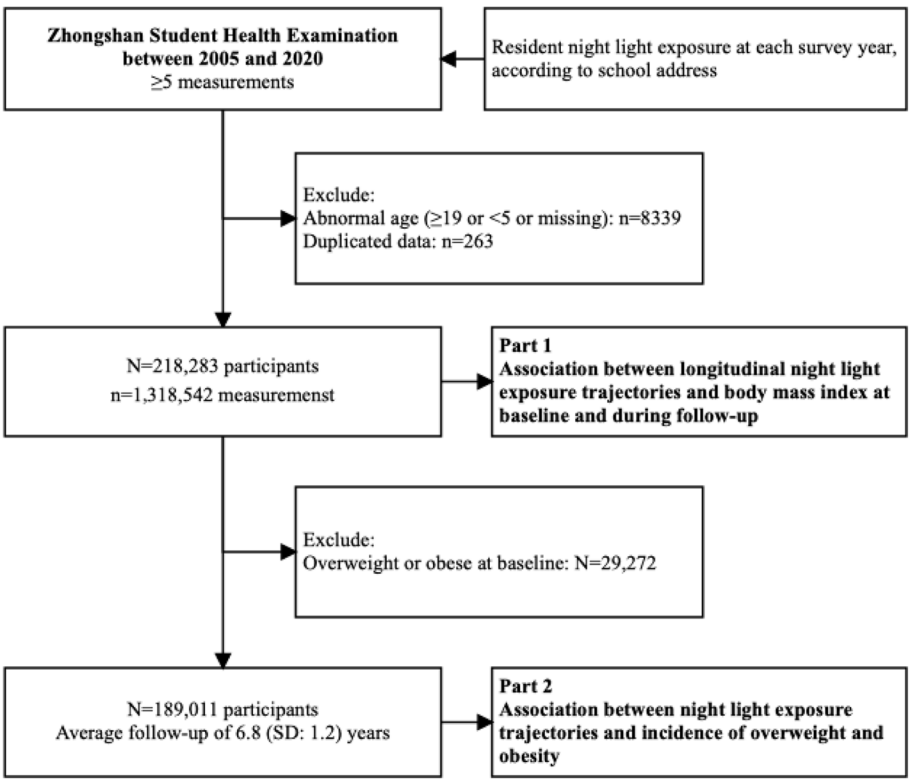

Fig. 1 Diagram of participant recruitment

measurements from 1511 participants imputed. Children's weight status at baseline and at each follow-up examinations was categorized as underweight, normal, overweight, or obese, according to the growth reference from the World Health Organization [17].

LAN data were derived from the improved continuous time-series DMSP-OLS-like dataset for the subdistricts where the schools attended by the participants were located from 2005 to 2020. This dataset combines calibrated Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) data (before 2013) and the simulated data (after 2013) from the Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite (SNPP-VIIRS) [18]. The DMSP-OLS data were calibrated using a quadratic model with a "pseudo-invariant pixel" method to minimize discontinuities and improve accuracy. The SNPP-VIIRS data were resampled to a 1 km to 5 km resolution using a kernel density method, followed by a logarithmic transformation to reduce variance in radiation values. A sigmoid model was then applied, based on an "S-curve" relationship between DMSP-OLS and transformed SNPP-VIIRS data, with region-specific coefficients to account for socio-economic differences across China. The improved DMSP-OLS-like dataset demonstrated a strong linear correlation with official statistics at the national levels, with average R-squared values of 0.931.

The LAN levels for each subdistrict where the participants were located annually between 2005 and 2020 were extracted using the nearest neighbor method, based on the latitude and longitude coordinates of the school addresses. Students' LAN exposures were matched to the year of their annual health examinations and the corresponding school address where they were enrolled during that year. The spatial resolution of the LAN data was 5 km and could effectively capture detailed lighting patterns of each subdistrict and have been used in previous epidemiological studies [19]. The mean LAN values were transformed into units of radiance ($nW/cm^2/sr$).

Statistical analysis

We employed group-based trajectory models to identify distinct patterns of LAN exposure during school age among all participants [20, 21]. The trajectories were modeled using a censored normal distribution, following established procedures outlined in previous studies [22, 23]. Firstly, we conducted a one-trajectory model and use the Bayesian information criteria (BIC) to evaluate whether the LAN exposure trajectory was linear, quadratic, or cubic. We then incrementally increased

the number of trajectory groups, repeating the process until the best-fit model was identified. Model selection was primarily guided by the absolute value of BIC, supplemented by the following criteria: a mean posterior probability greater than 0.7 for each group; odds of correct classification based on the posterior probabilities of group membership exceeding 5; and a minimum group size of 5% of total participants to ensure a relatively balanced group representation. The best-fit model identified four cubic trajectories with four groups, which exhibited the lowest BIC values and adequate sample size in each group. Parameters for modeling process were displayed in Additional file 1: Table S1. Based on the trajectory trends, we labeled the groups as sharp rise, mild rise, stable high, and decline. Given our hypothesis that LAN exposure is associated with an increased risk of overweight and obesity, and considering that the sharp rise group had the lowest level of LAN exposure at baseline, we selected the sharp rise group as the reference group for all subsequent analyses.

Characteristics of participants were summarized using means (with standard deviation, SD) or frequencies (%) by LAN exposure trajectory groups. We employed linear regression models to assess the differences in BMI *z* scores across LAN exposure trajectory groups at both baseline and the endpoint. Additionally, we used random effects population-averaged linear model to examine differences throughout the entire follow-up period. The unique identity number was included as a random effect to account for repeated BMI measurements of the same participants over the follow-up period. To estimate the incidence risks of overweight (including obesity) among the four LAN exposure trajectory groups in children who were not overweight or obese at baseline, we utilized Cox parametric survival regression models. Hazard ratios (HR) and 95% confidence intervals (CI) were reported. All analyses were conducted using two-level regression models to account for the hierarchical structure of participants at the school level. Living residence (urban or rural) was adjusted in all models.

We conducted five sensitivity analyses to confirm the robustness of our findings. First, we excluded children classified as underweight at baseline to assess the incidence of overweight and obese among the four LAN trajectory groups during the follow-up period. Second, we analyzed the incidence of obesity alone during follow-up, excluding children who were obese at baseline. Third, we excluded participants with imputed BMI measurements and duplicated the above analysis. Fourth, to further account for all stable, unobserved, district-level confounding factors, we leveraged within-district variation over time to more convincingly isolate the potential effect of LAN exposure. Accordingly, district-fixed effects were included in the model. Finally, to evaluate whether the influence of LAN exposure trajectories on overweight and obese persists, we assessed the relationship between LAN exposure trajectory groups and the prevalence of overweight and obesity at the endpoint using logistic regression models for participants classified as normal weight or underweight at baseline. Additionally, we conducted a cross-lagged panel model to examine the influence of baseline LAN exposure on the risk of overweight at the endpoint.

Analyses were conducted using Stata version 16.0 (Stata Corp LP, College Station, TX) between February and August 2024.

Results

A total of 218,283 children (1,318,542 measurements; 53.1% boys), with baseline age of 9.1 (SD: 2.5) years, were included in this analysis. The average follow-up time was 6.8 (SD: 1.8) years. The trajectories of children's residential LAN exposure are shown in Fig. 2. Among the participants, 20,952 (9.6%) were categorized in the sharp rise group, 41,318 (18.9%) in the mild rise group, 135,595 (62.1%) in the stable high group, and 20,418 (9.4%) in the decline group.

At baseline, the prevalence of overweight and obese was 10.1%, 13.7%, 13.2%, and 13.2% in sharp rise, mild rise, stable high, and decline groups, respectively ($P < 0.001$). At the endpoint, the average age of participants was 16.0 (SD: 2.0) years and slightly differed across the LAN exposure trajectory groups. In the 189,011 participants categorized as normal weight or underweight at baseline, the overall incidence of overweight and obesity during follow-up was 8.80 per 1000 person-years (95% CI: 8.69, 8.91). The incidence of overweight and obesity was lowest in the sharp rise group, at 6.10 per 1000 person-years (95% CI: 5.84, 6.39), and highest in the stable high group, at 9.95 per 1000 person-years (95% CI: 9.80, 10.10) (Table 1). Changes in weight status from baseline to the endpoint across different LAN trajectory groups are displayed in Additional file 1: Fig. S2.

Children's BMI *z* scores differed significantly between LAN trajectory groups both at baseline and throughout the follow-up periods. The age and sex specific BMI *z* scores of each group are presented in Additional file 1: Table S2. At baseline, compared to the sharp rise group, BMI *z* scores were higher by 0.19 (95% CI: 0.06, 0.31), 0.17 (95% CI: 0.09, 0.26), and 0.18 (95% CI: 0.09, 0.27) in the mild rise, stable high, and decline groups, respectively, for boys. In girls, the differences were 0.10 (95% CI: 0.005, 0.19), 0.09 (95% CI: 0.02, 0.15), and 0.10 (95% CI: 0.03, 0.17) for the same groups. At the endpoint, the differences in BMI *z* scores were no longer significant for the decline group. Compared to sharp rise group, BMI *z*

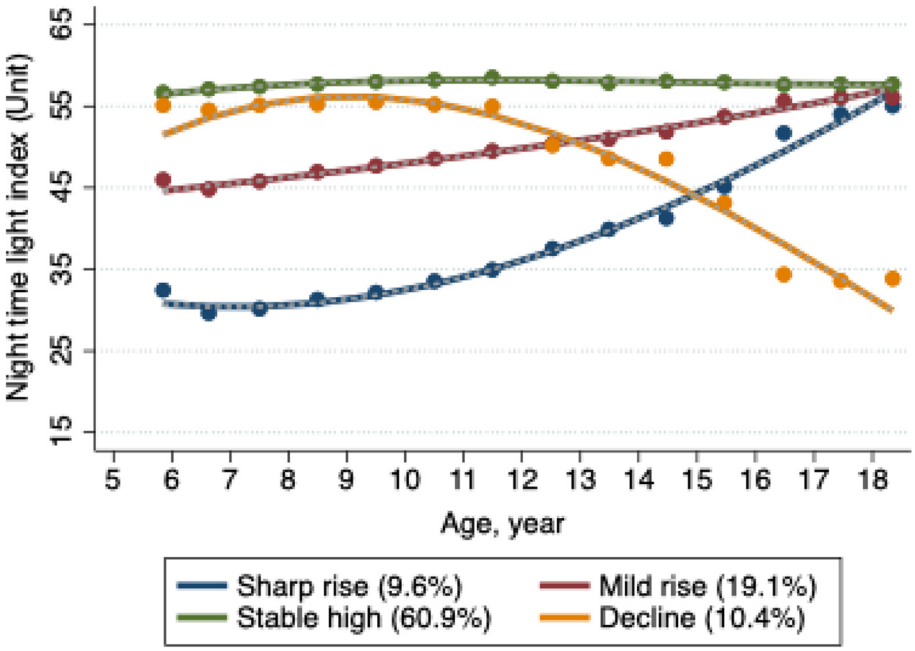

Fig. 2 Trajectories of residential night light exposure during childhood (age 5 to 18)

Table 1 Characteristics of participants at baseline and during follow-up, by residential night light exposure groups

Characteristics	Total	Distinct resident night light trajectory groups				*P* for difference
		Sharp rise	Mild rise	Stable high	Decline	
Sample size	218,283	20,952 (9.6)	41,318 (18.9)	135,595 (62.1)	20,418 (9.4)	
Number (%) of boys	115,871 (53.1)	10,724 (51.2)	22,129 (53.6)	72,606 (53.6)	10,412 (51.0)	< 0.001
Baseline age, mean (SD)	9.1 (2.5)	10.4 (2.7)	9.5 (2.4)	8.7 (2.3)	10.1 (2.6)	< 0.001
BMI *z* score at baseline, mean (SD)	− 0.37 (1.17)	− 0.45 (1.10)	− 0.30 (1.17)	− 0.32 (1.19)	− 0.30 (1.16)	< 0.001
Baseline weight status, number (%)						< 0.001
Normal	175,520 (80.4)	17,432 (83.2)	33,295 (80.6)	108,335 (79.9)	16,458 (80.6)	
Thinness	13,491 (6.2)	1402 (6.7)	2394 (5.8)	8431 (6.2)	1264 (6.2)	
Overweight	19,160 (8.8)	1460 (7.0)	3707 (9.0)	12,094 (8.2)	1899 (9.3)	
Obese	10,112 (4.6)	658 (3.1)	1922 (4.7)	6735 (5.0)	797 (3.9)	
Age at endpoint, mean (SD)	16.0 (2.0)	16.6 (1.8)	16.2 (1.8)	15.7 (2.0)	16.8 (1.6)	< 0.001
Follow-up year, mean (SD)	6.8 (1.8)	6.2 (1.9)	6.7 (1.7)	7.0 (1.8)	6.7 (1.9)	< 0.001
BMI *z* score at endpoint, mean (SD)	− 0.36 (1.09)	− 0.47 (1.05)	− 0.38 (1.08)	− 0.32 (1.11)	− 0.47 (1.02)	< 0.001
Weight status at endpoint, number (%)						< 0.001
Normal	179,932 (82.4)	17,763 (82.9)	34,266 (82.9)	110,359 (81.4)	17,544 (85.9)	
Thinness	12,032 (5.5)	1228 (5.9)	2268 (5.5)	7387 (5.5)	1149 (5.6)	
Overweight	19,195 (8.8)	1423 (6.8)	3474 (8.4)	12,981 (9.6)	1318 (6.5)	
Obese	7124 (3.3)	538 (2.6)	1311 (3.2)	4868 (3.6)	407 (2.0)	
Overweight and obesity incidence, per 1000 person-year*	8.80 (8.69, 8.91)	6.10 (5.84, 6.39)	8.04 (7.80, 8.27)	9.95 (9.80, 10.1)	6.15 (5.87, 6.45)	< 0.001

Weight status was defined by body mass index *z* scores according to the 2007 version of growth reference by World Health Organization

*Only in participants who were at normal weight or thinness at baseline

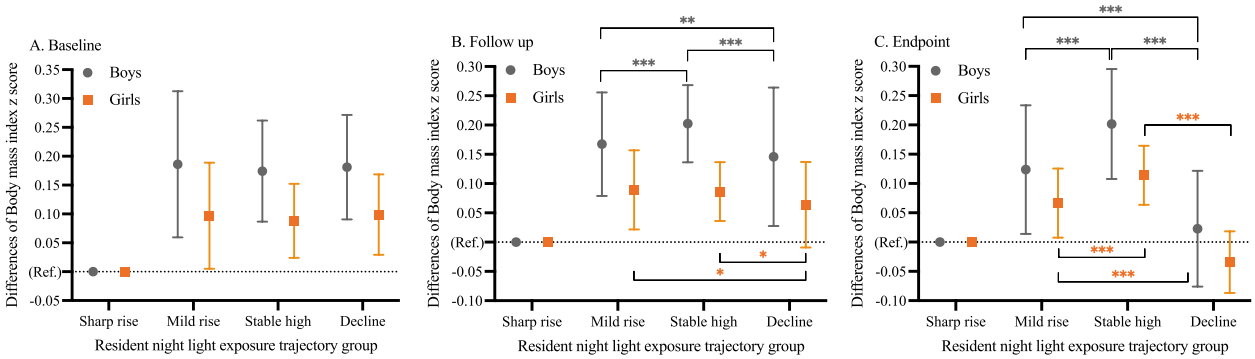

Fig. 3 Differences of BMI *z* scores among boys and girls across residential night light exposure trajectory groups during childhood. Note: **A** Differences of BMI *z* scores at baseline; **B** differences of BMI *z* scores during follow-up; **C** differences of BMI *z* scores at endpoint. Model were adjusted for living residence (urban or rural); level 1, individual; level 2, school district. BMI, body mass index. ***$P < 0.001$; *$P < 0.05$

scores in stable high group were higher by 0.20 (95% CI: 0.11, 0.30) for boys and 0.11 (95% CI: 0.06, 0.16) for girls. These scores were also significantly higher than that of mild rise and decline groups (Fig. 3).

Among children classified as normal weight or underweight at baseline, the risk of developing overweight and obesity varied significantly during follow-up across LAN exposure trajectory groups. The age specific incidence of overweight and obesity is presented in Additional file 1: Table S2. Notably, the sharp rise group exhibited both the earliest onset and the highest peak incidence of overweight. Compared to the sharp rise group, children in the stable high group had the greatest HRs, with an HR of 1.67 (95% CI: 1.28, 2.18) for boys and 1.56 (95% CI: 1.21, 2.01) for girls. This was followed by the mild rise group, with an HR of 1.29 (95% CI: 0.99, 1.70) for boys and 1.30 (95% CI: 0.98, 1.74) for girls. Children in the decline group had similar risk of overweight and obesity as the reference group. Compared to the sharp rise group, the stable high trajectory of LAN exposure accounted for 40.24% (range: 22.14, 54.14) of the risk for overweight and obesity in boys and 36.09% (range: 17.79, 50.31) in girls. The mild rise groups contributed approximately 23% to the overall risk (Table 2). Results from sensitivity analyses (Additional file 1: Tables S3, S4, and S5) were consistent with the main results. When the district of school was set as fixed effect in the model, the children with persist high night light exposure still had significant greater risk of overweight and obesity during follow-up (Additional file 1: Table S6). Furthermore, at the endpoint, the risk of overweight and obesity remained highest in the stable high group, with HRs of 1.50 (95% CI: 1.33, 1.69) for boys and 1.56 (95% CI: 1.33, 1.83) for girls, followed by the mild rise group. Children in the decline group exhibited similar to those in the sharp rise group (Additional file 1: Table S7).

Discussion

In this longitudinal study involving over 200,000 children and 1.2 million person-years of data, we discovered that the majority of children were exposed to high levels of night light from a young age. Our findings indicate that, compared to children with sharp rise LAN exposure trajectories, which begun with a relatively low LAN exposure, the children with higher LAN exposure faced a greater risk of developing overweight and obesity, particularly during the early school years. Throughout the follow-up, persistent exposure to elevated LAN trajectories was associated with a higher prevalence and incidence of overweight and obesity, with effects lasting into

Table 2 Results of two-level Cox regression model on incidence of overweight and obesity during childhood among children from distinct resident night light exposure trajectory groups

Night light trajectory	Boys			Girls		
	Hazard ratio (95% CI)	*P* value	PAR (min–max)	Hazard ratio (95% CI)	*P* value	PAR (min–max)
Sharp rise	1 (reference)			1 (reference)		
Mild rise	1.29 (0.99, 1.70)	0.064	22.60 (−1.84, 41.17)	1.30 (0.98, 1.74)	0.066	22.79 (−2.66, 42.45)
Stable high	1.67 (1.28, 2.18)	< 0.001	40.24 (22.14, 54.14)	1.56 (1.21, 2.01)	< 0.001	36.09 (17.79, 50.31)
Decline	1.02 (0.78, 1.35)	0.720	2.37 (−28.38, 25.76)	0.94 (0.72, 1.24)	0.667	−6.21 (−39.66, 19.23)

PAR, population attributable rate. Model were adjusted for living residence (urban or rural) and baseline body mass index; level 1, individual; level 2, school district

the teenage years. These results were consistent when we analyzed the risk of obesity alone, rather than the combined risk of overweight and obesity. To the best of our knowledge, this is the first study to identify trajectory subgroups of long-term childhood LAN exposure through extensive follow-up and report their association with the risk of developing overweight and obesity during school age. The study incorporated data from nearly all primary and secondary school students in Zhongshan, a city covering approximately 1780 km^2 with a population of 4.4 million residents, between 2005 and 2020, thereby ensured high population representativeness.

The relationship between LAN exposure and excessive body weight has been well-documented, though primarily in cross-sectional studies [13, 24]. Longitudinal studies examining the potential causal relationship between LAN exposure and obesity incidence are relatively scarce. One large cohort study from the USA with over 200,000 participants reported that LAN exposure in middle to elder age was associated with a greater obesity risk in later life [25], although it did not account for changes in LAN exposure trajectories over time, which may contribute to varying risks of overweight and obesity. Another cohort study involving about 1000 elderly individuals in Japan found that increased LAN exposure was independently associated with a 10.0% rise in BMI over a decade of follow-up [26]. In contrast, our analyses focused on school-aged children, a critical period for growth and BMI changes. The general population exhibited a consistent rise-and-fall pattern in overweight/obesity incidence across the studied age range [4]; we additionally identified distinct temporal disparities among LAN exposure groups. Specifically, children with higher LAN exposure during early school-age years experienced an earlier onset and peak in overweight incidence. The overweight incidence peak for the reference (sharp rise) group closely aligned with the age at which LAN exposure levels began to escalate, suggesting that the impact of LAN on weight gain could occur within relatively short timeframes. This underscores the critical need for heightened public awareness and proactive measures to minimize night light exposure in daily environments.

In addition to confirming earlier findings that higher LAN exposure is linked to an increased risk of overweight and obesity, we found that individuals with low LAN exposure at childhood, even if exposed to higher levels later on, still had a lower risk of overweight and obese compared to those with consistently high exposure. Moreover, as the LAN exposure decreased over time, the risk of obesity declined accordingly. This suggests that interventions targeting LAN exposure reduce the risk of developing overweight and obesity. Schools and parents can help create a better sleep environment by adjusting indoor lighting sources, limiting the use of electronic screens an hour before bedtime, using blackout curtains in the bedroom, reducing excessive lighting, and promoting habits such as sleeping in complete darkness [27]. Critically, the robustness of our district-fixed effects models—which rigorously control for unobserved, time-invariant differences between districts—provides strong evidence that interventions reducing LAN exposure can be effectively implemented with confidence at the district level to lower obesity risk.

Evidence from cross-sectional study also suggested that sufficient physical activity may alleviate negative effects of bedroom LAN exposure on cardiometabolic risks among young adults [28], while more cautious and longitudinal intervention studies are needed to determine whether this holds true for young school-aged children. Among the different exposure trajectories identified, we found that children in the sharp rise group (the group that started out low and then gradually increased) had the lowest risk of overweight and obesity in later life. The main difference between this group and the other groups occurred during the early years of schooling, which is the earliest period that could be tracked in this study. In line with evidence from previous study suggesting that early school age is a critical period for differentiation of BMI trajectories [29], we infer that exposure to nighttime lights may play a more important role in the development of overweight and obesity at an earlier age than during adolescence. Further data from studies covering an earlier period of life are needed to explore this association.

There were significant sex differences in the impact of LAN exposure trajectories on the risk of overweight and obesity. Previous studies have indicated that LAN exposure may have a greater effect on fat mass, visceral fat area, waist circumferences, and body fat percentage in males compared to females [30–32]. The present study supports these findings, showing that the effects of LAN on overweight and obesity were more persistent in boys than in girls. Boys who were consistently exposed to high levels of LAN faced a continued risk of overweight and obesity into late teenage years. This sex difference may be related to the distinct ways males and females respond to stimuli affecting circadian rhythms, which could be delayed due to ALN exposure and could cause decreased melatonin secretion [33]. The impact on circadian phase was more pronounced in males than in females [34]. Animal studies also suggest significant physiological changes in males' cardiovascular system associated to LAN exposure [35]. Additionally, the interactions between sex hormones and melatonin may play a role in these sex differences, although evidences remains ambiguous [36, 37]. Differences in behavioral patterns between sexes, such as longer screen time in boys, may also contribute to the

different risk of weight gain under similar exposure of LAN [38, 39]. Taken together, however, most of the current research focuses on middle-aged and older adults, and there is a lack of high-quality causal and mechanism-related studies on children.

To date, the mechanisms by which LAN exposure contributes to obesity remain unclear. One plausible pathway involves the disruption of the circadian rhythm, leading to alterations in cortisol and melatonin secretion [40]. Suppressed melatonin levels, in particular, can impair metabolic regulation and energy balance, while disrupted cortisol level can alter serum levels of ghrelin, melatonin, and serum leptin [35, 41]. Recent findings suggest that prolonged exposure to artificial light may directly increase body fat mass by reducing the activity of brown adipose tissue, which plays a crucial role in thermogenesis and energy expenditure [42]. Social factors, such as the economic development of resident, also appear to modify the relationship between LAN exposure and childhood overweight and obesity, with stronger associations observed in less economically advantaged areas [43]. Though it is evident that exposure to LAN has been linked to other health risks, including diabetes, cancer, and depression [44, 45]. Consequently, scientists are advocating for reducing nighttime light exposure, especially in urban environments, to enhance human health and societal well-being [27]. More comprehensive and individualized measurements of light exposure, along with continuous tracking of health outcomes, are essential for developing more targeted and effective health promotion strategies for this purpose.

Limitations

There are several limitations. First, the LAN data were extracted based on school addresses, which may not accurately represent individual-level exposure. However, since most school-aged children attend schools near their residences, school-based LAN levels are likely a reasonable proxy for residential LAN exposure. Additionally, the use of certain types of curtains in classrooms and bedrooms could confound the observed associations. It is also worth noting that individual-level LAN exposure, particularly indoors, may be more susceptible to reverse causation and is challenging to address through general health promotion strategies [46]. Studies focusing on average residential LAN exposure may provide relevant evidence for broader obesity prevention initiatives. Second, we were unable to account for important confounders, such as diet, physical activity, sleep health, and mental health well-being, which are directly linked to obesity risk, although sensitivity analyses supported the robustness of our findings, particularly among boys and those with higher early exposure levels. We aim to include these variables in future studies to provide a more comprehensive understanding of the relationship between light exposure profiles and obesity risk. Additionally, we lacked data on pubertal development, such as Tanner staging, which could influence BMI due to variations in the timing of pubertal growth rates among individuals. Consequently, we were unable to control for the potential confounding effects of pubertal development on the association between LAN exposure and overweight or obesity. Future research should incorporate measures of pubertal development to better address these individual differences and enhance the understanding of the observed associations. Finally, while our study included all school-aged children in one southeastern Chinese city from 2005 to 2020, the results may not fully capture the broader influence of LAN exposure on children's overweight and obesity risks.

Conclusions

In this longitudinal study involving over 200,000 children and 1.2 million person-years of data, we found that a substantial proportion of children were exposed to high levels of LAN from an early age. Our findings indicate that children with higher LAN exposure trajectories face an increased risk of overweight and obesity, especially during their early school years. Moreover, continuous exposure to elevated LAN levels was associated with a higher prevalence and incidence of these conditions, with effects persisting into the teenage years. These findings underscore the need for targeted interventions to reduce LAN exposure in school-aged children, as a strategy to mitigate obesity risk.

Abbreviations

DMSP-OLS	Defense Meteorological Satellite Program's Operational Linescan System
BIC	Bayesian information criteria
BMI	Body mass index
CI	Confidence intervals
HR	Hazard ratios
LAN	Light at night
SNPP-VIIRS	Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04262-0.

Additional file 1: Fig. S1 Distribution of included schools and corresponding light at night density during the study period in Zhongshan City, China. Fig. S2 Weight status at baseline and endpoint for participants with distinct resident night light exposure trajectories. Fig. S3 Cross-lagged panel model analysis on light at night exposure and overweight risk at baseline and endpoint. Table S1 Parameters of group-based trajectory modeling process. Table S2 Age and sex specific BMI and incident overweight and obesity by residential night light exposure groups. Table S3 Cox regression model on risk of overweight and obesity during childhood among children from distinct resident night light exposure trajectory

groups (children who were thinness at baseline were excluded). Table S4 Cox regression model on risk of obesity during childhood among children from distinct resident night light exposure trajectory groups. Table S5 Cox regression model on risk of overweight and obesity during childhood among children from distinct resident night light exposure trajectory groups (measurements with imputed body mass index were removed). Table S6 Cox regression model on risk of overweight and obesity during childhood among children from distinct resident night light exposure trajectory groups (district-fixed model). Table S7 Logistic regression model on risk of overweight and obesity at endpoint among children from distinct resident night light exposure trajectory groups (children who were overweight or obese at baseline were excluded).

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Authors' contributions
X.W. and M.C. developed the research question, carried out the main data analyses, and drafted the manuscript. D.S.T. conducted data clean and provided critical language revision. J.H. provided critical revision on both methodology and language. Y.J., B.D., and W.L. supervised data collection, clean, and analyses. All authors reviewed the manuscript drafts, critically revised the manuscript, and approved the final version of the manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The use of anonymous data in the present study was authorized by Zhongshan Health Care Center for Primary and Secondary School. All personal information was de-identified prior to authorization; therefore, only de-identified data were analyzed in our present study. The present study was reviewed and approved by the Institution Review Board of Peking University for waiver of informed consent, with the approval number IRB B00001052-20011-exempt.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Bentham J, Di Cesare M, Bilano V, Bixby H, Zhou B, Stevens GA, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet. 2017;390:2627–42.
2. Bixby H, Bentham J, Zhou B, Di Cesare M, Paciorek CJ, Bennett JE, et al. Rising rural body-mass index is the main driver of the global obesity epidemic in adults. Nature. 2019;569:260–4.
3. Rodriguez-Martinez A, Zhou B, Sophiea MK, Bentham J, Paciorek CJ, Iurilli ML, et al. Height and body-mass index trajectories of school-aged children and adolescents from 1985 to 2019 in 200 countries and territories: a pooled analysis of 2181 population-based studies with 65 million participants. The Lancet. 2020;396:1511–24.
4. Wang X, Dong B, Huang S, Ma Y, Zou Z, Ma J, et al. Body mass index trajectory and incident hypertension: results from a longitudinal cohort of Chinese children and adolescents, 2006–2016. Am J Public Health. 2020;110:1689–95.
5. Allen NB, Krefman AE, Labarthe D, Greenland P, Juonala M, Kähönen M, et al. Cardiovascular health trajectories from childhood through middle age and their association with subclinical atherosclerosis. JAMA Cardiol. 2020;5:557–66.
6. Attard SM, Herring AH, Howard AG, Gordon-Larsen P. Longitudinal trajectories of BMI and cardiovascular disease risk: the national longitudinal study of adolescent health. Obesity. 2013;21:2180–8.
7. Buscot MJ, Thomson RJ, Juonala M, Sabin MA, Burgner DP, Lehtimäki T, et al. Distinct child-to-adult body mass index trajectories are associated with different levels of adult cardiometabolic risk. Eur Heart J. 2018;39:2263–2270a.
8. Kipping RR, Jago R, Lawlor DA. Obesity in children. Part 1: epidemiology, measurement, risk factors, and screening. BMJ. 2008;337:922–7.
9. Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. N Engl J Med. 2010;362:485–93.
10. Dong Y, Jan C, Ma Y, Dong B, Zou Z, Yang Y, et al. Economic development and the nutritional status of Chinese school-aged children and adolescents from 1995 to 2014: an analysis of five successive national surveys. Lancet Diabetes Endocrinol. 2019;7:288–99.
11. Rybnikova NA, Haim A, Portnov BA. Does artificial light-at-night exposure contribute to the worldwide obesity pandemic? Int J Obes. 2016;40:815–23.
12. Kim M, Vu TH, Maas MB, Braun RI, Wolf MS, Roenneberg T, et al. Light at night in older age is associated with obesity, diabetes, and hypertension. Sleep. 2023;46:1–10.
13. Park YMM, White AJ, Jackson CL, Weinberg CR, Sandler DP. Association of exposure to artificial light at night while sleeping with risk of obesity in women. JAMA Intern Med. 2019;179:1061–71.
14. Xu YX, Yu Y, Huang Y, Wan YH, Su PY, Tao FB, et al. Exposure to bedroom light pollution and cardiometabolic risk: a cohort study from Chinese young adults. Environmental Pollution. 2022;294:118628.
15. Lin L-Z, Zeng X-W, Deb B, Tabet M, Xu S-L, Wu Q-Z, et al. Outdoor light at night, overweight, and obesity in school-aged children and adolescents. Environ Pollut. 2022;305: 119306.
16. Mao B, Luo C, Li S, Zhang J, Xiang W, Yang Y. Exposure to light at night (LAN) and risk of overweight/obesity, hypertension, and diabetes: a systematic review and meta-analysis. Int J Environ Health Res. 2025;35(4):1003–17. https://doi.org/10.1080/09603123.2024.2378941.
17. de Onis M. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 2007;85:660–7.
18. Wu Y, Shi K, Chen Z, Liu S, Chang Z. Developing improved time-series DMSP-OLS-like data (1992–2019) in China by integrating DMSP-OLS and SNPP-VIIRS. IEEE Trans Geosci Remote Sens. 2022;60:1–14.
19. Wang W, Wang F, Yang C, Wang J, Liang Z, Zhang F, et al. Associations between heat waves and chronic kidney disease in China: the modifying role of land cover. Environ Int. 2024;186: 108657.
20. Jones BL, Nagin DS. A Note on a Stata Plugin for Estimating Group-based Trajectory Models. Sociol Methods Res. 2013;42(4):608–13. https://doi.org/10.1177/0049124113503141.
21. Nagin DS, Odgers CL. Group-based trajectory modeling in clinical research. Annu Rev Clin Psychol. 2010;6:109–38.

22. Nagin DS. Group-Based Modeling of Development. Cambridge: Harvard University Press; 2005. Print.
23. Nagin DS. Group-based trajectory modeling: an overview. Ann Nutr Metab. 2014;65:205–10.
24. Xu Y, Zhang J, Ding W. Association of light at night with cardiometabolic disease: a systematic review and meta-analysis. Environ Pollut. 2024;342: 123130.
25. Zhang D, Jones RR, Powell-Wiley TM, Jia P, James P, Xiao Q. A large prospective investigation of outdoor light at night and obesity in the NIH-AARP diet and health study. Environ Health. 2020;19:74.
26. Obayashi K, Saeki K, Kurumatani N. Ambient light exposure and changes in obesity parameters: a longitudinal study of the HEIJO-KYO cohort. J Clin Endocrinol Metab. 2016;101:3539–47.
27. Zielinska-Dabkowska KM, Schernhammer ES, Hanifin JP, Brainard GC. Reducing nighttime light exposure in the urban environment to benefit human health and society. Science. 2023;380:1130–5.
28. Xu Y, Zhou Y, Huang Y, Yu Y, Li J, Huang W, et al. Physical activity alleviates negative effects of bedroom light pollution on blood pressure and hypertension in Chinese young adults. Environ Pollut. 2022;313: 120117.
29. Wang X, Hu J, Huang S, Yang Z, Dong Y, Dong B, et al. Exploring overweight risk trajectories during childhood and their associations with elevated blood pressure at late adolescence: a retrospective cohort study. Hypertension. 2022;79:1605–13.
30. Xu YX, Zhang AH, Yu Y, Wan YH, Tao FB, Sun Y. Sex-specific association of exposure to bedroom light at night with general and abdominal adiposity in young adults. Ecotoxicol Environ Saf. 2021;223:112561.
31. Xu Y, Zhang A, Yu Y, Wan Y, Tao F, Sun Y. Sex-specific association of exposure to bedroom light at night with general and abdominal adiposity in young adults. Ecotoxicol Environ Saf. 2021;223: 112561.
32. Zhang X, Zheng R, Xin Z, Zhao Z, Li M, Wang T, et al. Sex- and age-specific association between outdoor light at night and obesity in Chinese adults: a national cross-sectional study of 98,658 participants from 162 study sites. Front Endocrinol (Lausanne). 2023;14:14.
33. Wei T, Li C, Heng Y, Gao X, Zhang G, Wang H, et al. Association between night-shift work and level of melatonin: systematic review and meta-analysis. Sleep Med. 2020;75:502–9.
34. Xu Y, Huang Y, Ding W, Zhou Y, Shen Y, Wan Y, et al. Exposure to real-ambient bedroom light at night delayed circadian rhythm in healthy Chinese young adults: a cross-sectional study. Environ Res. 2024;251: 118657.
35. Alaasam VJ, Liu X, Niu Y, Habibian JS, Pieraut S, Ferguson BS, et al. Effects of dim artificial light at night on locomotor activity, cardiovascular physiology, and circadian clock genes in a diurnal songbird. Environ Pollut. 2021;282: 117036.
36. Tamarindo GH, Gobbo MG, Taboga SR, Almeida EA, Góes RM. Melatonin ameliorates degenerative alterations caused by age in the rat prostate and mitigates high-fat diet damages. Cell Biol Int. 2021;45:92–106.
37. Cipolla-Neto J, Amaral FG, Soares José Maria J, Gallo CC, Furtado A, Cavaco JE, et al. The crosstalk between melatonin and sex steroid hormones. Neuroendocrinology. 2022;112:115–29.
38. Whiting S, Buoncristiano M, Gelius P, Abu-Omar K, Pattison M, Hyska J, et al. Physical activity, screen time, and sleep duration of children aged 6–9 years in 25 countries: an analysis within the WHO European Childhood Obesity Surveillance Initiative (COSI) 2015–2017. Obes Facts. 2020;14:32–44.
39. Nagata JM, Abdel Magid HS, Pettee GK. Screen time for children and adolescents during the coronavirus disease 2019 pandemic. Obesity. 2020;28:1582–3.
40. Rahman SA, Wright KP, Lockley SW, Czeisler CA, Gronfier C. Characterizing the temporal dynamics of melatonin and cortisol changes in response to nocturnal light exposure. Sci Rep. 2019;9:19720.
41. Al-Rawi N, Madkour M, Jahrami H, Salahat D, Alhasan F, BaHammam A, et al. Effect of diurnal intermittent fasting during Ramadan on ghrelin, leptin, melatonin, and cortisol levels among overweight and obese subjects: a prospective observational study. PLoS One. 2020;15(8):e0237922.
42. Kooijman S, Van Den Berg R, Ramkisoensing A, Boon MR, Kuipers EN, Loef M, et al. Prolonged daily light exposure increases body fat mass through attenuation of brown adipose tissue activity. Proc Natl Acad Sci U S A. 2015;112:6748–53.
43. Dang J, Shi D, Li X, Ma N, Liu Y, Zhong P, et al. Artificial light-at-night exposure and overweight and obesity across GDP levels among Chinese children and adolescents. Nutrients. 2023;15: 939.
44. Ward EM, Germolec D, Kogevinas M, McCormick D, Vermeulen R, Anisimov VN, et al. Carcinogenicity of night shift work. Lancet Oncol. 2019;20:1058–9.
45. Windred DP, Burns AC, Rutter MK, Ching Yeung CH, Lane JM, Xiao Q, et al. Personal light exposure patterns and incidence of type 2 diabetes: analysis of 13 million hours of light sensor data and 670,000 person-years of prospective observation. The Lancet Regional Health Europe. 2024;42:100943.
46. Paksarian D, Rudolph KE, Stapp EK, Dunster GP, He J, Mennitt D, et al. Association of outdoor artificial light at night with mental disorders and sleep patterns among US adolescents. JAMA Psychiat. 2020;77:1266–75.

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