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Pathways from the campus-based built environment to obesity: Evidence from undergraduates in China

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ABSTRACT

Obesity is a global public health threat. Although studies have suggested that the built environment is related to obesity, scholars have paid less attention to the pathways from the built environment to young adults' obesity. To bridge this gap, we employed path analysis to examine whether food intake, exercise, and active travel mediate the association between the campus-based built environment and body mass index (BMI), based on a nationwide sample of 15,503 Chinese undergraduates mostly aged 18–23 years old. Our results showed that unhealthy food intake mediated the association. A higher number of points of interest, more green space, and fewer restaurants were negatively related to body mass index by inhibiting unhealthy food intake. Neither the duration of exercise nor active travel distance mediated the built environment-BMI association, although both were directly associated with the campus-based built environment. These findings suggest that improving the campus-based environment could contribute to a reduction in obesity risk among undergraduates by improving their diets.

1. Introduction

Healthy city planning aims to ensure the health and well-being of urban residents (Yang et al., 2018). However, obesity being a risk factor of numerous diseases (e.g., cardiovascular disease, type-II diabetes) threatens this goal. Studies have indicated that sociodemographics and behavioral characteristics play roles in obesity. However, the socio-ecological theory stresses that obesity not only relies on these person-level characteristics but also is affected by the environment (Sallis, Owen, & Fisher, 2015). Hence, urban planners believe that improving the built environment is an important way to prevent and control obesity (Garfinkel-Castro, Kim, Hamidi, & Ewing, 2017).

1.1. Pathways from the built environment to obesity

The built environment is an upstream determinant of obesity (Lakerveld & Mackenbach, 2017), but the underlying pathways remain ambiguous, and evidence concerning the possible mediation effects of energy expenditure and energy intake has been limited.

The first possible pathway is travel behavior. A compact built environment characterized by short travel distances between destinations, which encourages active travel (e.g., walking and cycling) and physical activity (Saelens & Handy, 2008), resulting in a lower risk of obesity (King & Jacobson, 2017). Van Dyck et al. (2010) found that utilitarian walking mediates the effect of obesity in Belgian adults. Sun, Yan, and Zhang (2017) found that higher population density and transit accessibility had a negative relationship with Chinese adults' body mass index (BMI) by inhibiting driving behavior. However, they also observed that population density is positively correlated with BMI after controlling for the mediating effect of travel modes, suggesting that there are other possible mediators of the built environment-obesity association.

The second possible pathway is exercise. Studies have shown that a compact built environment provides more sports facilities and higher-quality public spaces, leading to an increased level of recreational activity (Zhao & Wan, 2020) and a lower risk of obesity (Church, 2011). Empirically, Oliver et al. (2015) found that promoting physical activity is a pathway from street connectivity and destination accessibility to reduced obesity among adults in New Zealand. However, a dense built environment can also reduce sports facilities and public spaces per capita, leading to physical inactivity and obesity (Day, 2016; Sun & Yin, 2018). For example, Yin and Sun (2020) observed that a higher population density increases Chinese adults' obesity by reducing the duration

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of exercise.

The third possible pathway is food intake. A compact built environment means higher accessibility and availability of food, leading to food choices that can contribute to a healthier diet, which is key to reducing obesity (Romieu et al., 2017). However, a compact built environment also results in more restaurants that supply high-energy food, resulting in unhealthy food intake and obesity (Li, Harmer, Cardinal, Bosworth, & Johnson-Shelton, 2009). Only a few empirical studies have explored how the built environment influences obesity by food intake. For instance, Sullivan et al. (2016) explored the mediation effects of food intake and physical activity on the association, but reported no significant mediation effects.

1.2. Characteristics of Chinese undergraduates

Previous studies of the built environment-obesity association have focused on children and teenagers, adults, and the elderly (Feng, Glass, Curriero, Stewart, & Schwartz, 2010), ignoring the association in young adults. Although young adults aged 18 to 24 years old have the lowest obesity prevalence across age groups (Zhang et al., 2019), most young adults gain approximately 15 kg over the subsequent 15 years and fail to maintain a normal weight status, increasing the risk for obesity-related diseases later in life (Truesdale et al., 2006). Hence, the relationship between the built environment and obesity might differ between young adults and other age groups, but only limited studies have focused on the built environment-obesity associations in young adults.

Young adults, particularly undergraduates, are very different from other population groups. First, they are experiencing the last stage of puberty, during which they have a greater need for food intake because of their high metabolic rate and physical changes (Arnett, 1994). Second, they are also experiencing a critical stage in developing healthy behaviors in the transition to adulthood (Bishop, Walker, Herting, & Hill, 2020). Third, compared with children and teenagers who live with their parents, undergraduates live with classmates and usually pay less attention to healthy eating and overall health (Wang, Ou, Chen, & Duan, 2009). Fourth, compared to other adults, undergraduates are more sedentary, remaining still for approximately 11 h per day on average, which is even more than that of white-collar workers (Moulin, Truelove, Burke, & Irwin, 2021).

Additionally, residential self-selection (i.e., residents choosing their residences according to their travel preferences) leads to spurious correlations between the built environment and health outcomes. Some studies have addressed the residential self-selection problem by using public housing samples (Zang et al., 2019) or resettlement housing samples (Li, Sun, Yin, Zhang, & Liu, 2018), because people living in these nonmarket houses cannot choose their residential locations. Similarly, Chinese undergraduates have little residential choice. Although students can select cities and universities, the built environment is only rarely part of this selection (Bodycott, 2009; Li & Sun, 2018). Furthermore, Chinese undergraduates have little choice of their residential location because they are required to live on campus dormitories and study in classrooms on campus for reasons of safety and efficiency (Zhong, Zhao, Zou, & Mason, 2018).

1.3. Study motivations and conceptual framework

Several research gaps motivated us to conduct this study. First, although some studies have explored the pathways of the built environment-obesity association, they only examined the mediation effects of either energy expenditure (e.g., travel modes, exercise) or energy intake (food intake), which could only partially capture mediation effects. Hence, it is essential to identify how the built environment associates with obesity through energy expenditure and energy intake. Second, only a few studies have explored built environment-obesity associations in young adults. Third, from a methodological perspective, most previous results might have overestimated the built environmental effects due to the self-selection issue.

To address these gaps, this study aimed to 1) examine the underlying pathways of built environment-obesity associations; and 2) assess the association of the built environment with young adults' obesity after excluding self-selection bias. Fig. 1 presents our conceptual framework of how the obesity is related to both individual-level sociodemographics and the built environment. The built environment is thought to influence obesity indirectly by affecting individuals' behavior, whereas sociodemographic attributes directly affect personal behavior and obesity. In the current study, we particularly focused on undergraduates' BMI and the campus-based built environment (i.e., walkability, exercise environment, food environment). Personal behavior may mediate the association between the built environment and undergraduates' obesity, including energy expenditure (e.g., active travel and exercise) and energy intake (food intake).

2. Methods

2.1. Survey data

Data were obtained from a 2018 nationwide survey of Chinese undergraduates, mostly aged 18–23 years old, administered by the First Affiliated Hospital of Kunming Medical University. The survey data were based on stratified, multiple-stage, probability proportional to size sampling comprising the following steps. First, mainland China was divided into 29 province-level divisions (excluding the Tianjin municipality and the autonomous region of Tibet). Second, 2–4 universities within each province-level division were selected randomly. Third, 300 to 700 undergraduates within each university were recruited according to the number of undergraduates. Fourth, healthcare professionals from hospitals conducted face-to-face interviews with undergraduates. This procedure identified 23,488 participants from 90 university campuses located in 44 cities. The response rate was about 78 %. After removing undergraduates with missing values ($N = 2366$) and the freshmen, who only lived on campuses for fewer than two months ($N = 6132$), our analytical sample included 15,503 undergraduates. The Ethics Board of the First Affiliated Hospital of Kunming Medical University provided ethical approval (No. 2018-L-25).

2.2. Outcome variable

The outcome variable was an undergraduate's BMI computed by weight divided by height squared (kg/m^2). Healthcare professionals used a height and weight instrument in campus hospitals to measure BMI.

2.3. Campus-based built environmental variables

The campus-based built environment in this study refers to an area that supports undergraduates' daily needs and activities and encompasses the close surroundings. Its health-influencing spatial context was defined by means of a 1 km buffer around the centroids of each campus. On the one hand, this buffer size corresponds roughly to a 15-minute walking distance, which is in line with the planning guideline of community–life cycles. On the other hand, the 1-km buffer was commonly used in previous empirical studies (Liu, Wang, Zhou, & Wu, 2020; Yin, Cao, Sun, & Liu, 2023), conducive to comparing results across studies. Several studies have also suggested that the 1-km buffer is better than others (Barnett et al., 2020).

Following others (Dwicaksono, Brissette, Birkhead, Bozlak, & Martin, 2018; Keating, Guan, Piñero, & Bridges, 2005; Yang, He, Lu, Ren, & Huang, 2021), we included three groups of variables capturing the campus-based built environment. The first was walkability, which is often measured by population density, mixed land use, and street connectivity (Frank et al., 2010). Within each buffer, we determined population density by dividing the population size by the total land area (in

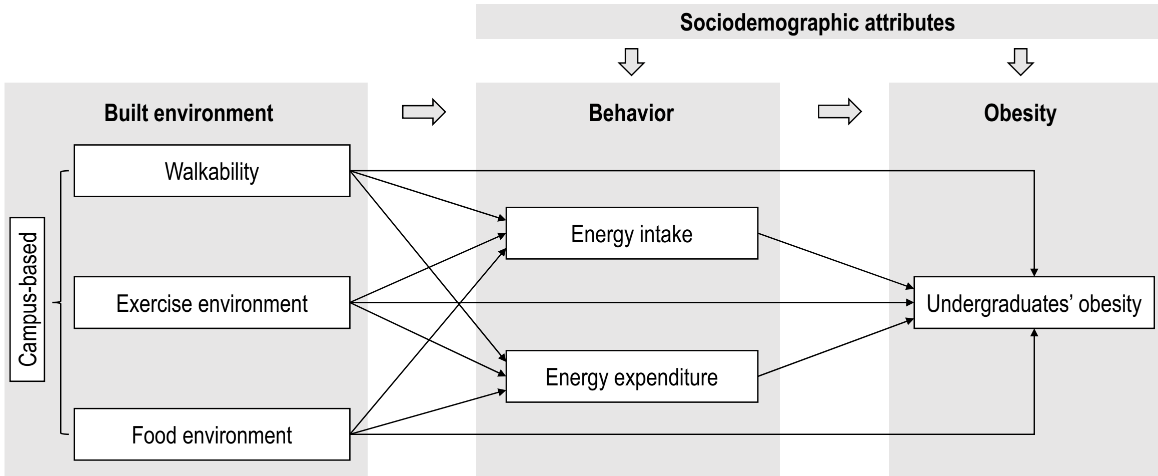

Fig. 1. Conceptual model.

km^2) based on the Worldpop dataset in 2018 (https://www.worldpop.org/). Mixed land use implies the potential accessible facilities and services (excluding transit stops) and was measured by the density of points of interest (POIs) surrounding a campus extracted from Amap in 2019 (https://lbs.amap.com/). Road density is a proxy for street connectivity and was measured by the length of streets (in km) divided by the buffer area (in km^2), obtained from Open Street Map in 2018 (https://www.openstreetmap.org/). Moreover, because students often walk to transit (Sun, Guo, & Yin, 2022), we also included transit accessibility, operationalized as the number of bus stops within each buffer based on Amap data in 2019.

The second was the exercise environment, including green space, parks, and sports facilities (e.g., football field), which are important space for undergraduates' moderate to vigorous physical activity (Roemmich, Balantekin, & Beeler, 2015; Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997). The average normalized difference vegetation index (NDVI) per buffer captures greenery and was computed from Sentinel data in 2018 (Yang et al., 2021). We extracted the distance to the nearest park and the number of sports facilities from the 2019 Amap data. The former was measured by the Euclidean distance from the campus to the nearest park in meters. Because the variable was skewed, we applied a log-transformation. The latter was computed using the number of sports facilities within a 1-km buffer surrounding the campus.

The third was the food environment. We captured food accessibility by counting the number of food stores located in the surroundings of the campus from Amap in 2019. Three types of food stores were included restaurants, dessert stores, and fruit stores (An, 2016; Leal, Bean, Thomas, & Chaix, 2012; Poulos & Pasch, 2015). The number of restaurants was defined by the number of fast-food restaurants and Chinese full-service restaurants per buffer. The number of dessert stores was determined by the number of stores selling sugary food per buffer (e.g., cake bakeries, bubble tea shops, and ice cream stores). The number of fruit stores was measured by the number of stores selling fresh fruit within the buffer.

2.4. Mediators

Mediators of the association between the campus-based built environment and BMI included energy intake and energy expenditure, which are important contributors to obesity (Hill, Wyatt, & Peters, 2012). We included three mediators. First, unhealthy food intake is a proxy for undergraduate energy intake, including salty, oily, and sweet food consumption, which are closely related to obesity (Moss, 2013). In particular, we asked undergraduates to answer questions such as "How much salty food do you eat in general?" Similarly, we asked about their oily and sweet food intake. The responses were scored from none (0) to very much (5). The variable unhealthy food intake was calculated by totaling the scores of the three food types.

Second, we measured energy expenditure by the duration of exercise and active travel distance. The exercise duration was computed as follows (Eq. (1)):

$$E = EF \times ED \times 60 \tag{1}$$

where E represented the total duration of indoor and outdoor exercise per week in minutes. EF represented the frequency of exercise using six response categories ranging from none (0), once per month (1/30), once per two weeks (1/14), once per week (1/7), two or three times per week (2.5/7), to every day (1). ED represented the duration of exercise each time classified into $\leq$1 h (0.5), 1–2 h (1.5), 2–4 h (3), and > 4 h (5).

Third, active travel distance was computed by Eq. (2):

$$ln(AT) = ln\left(\sum_{i}^{7} TF_i \times TD_i \times TM_i\right) \tag{2}$$

where AT indicated the total active travel distance per week in meters. We summed the total travel distance on foot and bike for travel purpose i, including traveling for studying, exercising, shopping, visiting friends, relaxing, seeing a doctor, and working. TF indicated travel frequency, which was grouped into similar response categories as those for the frequency of exercise. TD indicated the travel distance of a trip in meters and was grouped into $\leq$1 km (0.5), 1–3 km (2), >3–5 km (4), >5–10 km (7.5), and > 10 km (15). TM indicated the travel mode. It equaled 1 if travel was on foot or by bike; otherwise it was 0.

2.5. Covariates

Following earlier studies on Chinese undergraduates' behavior and obesity (Sun, Guo, & Yin, 2022; Yang et al., 2021), we included the following covariates: gender (male = 1, female = 0); age; ethnicity (Han = 1, non-Han = 0); hukou status before enrollment in universities (urban = 1, rural = 0); major (natural science, engineering, agriculture, or medicine = 1, others = 0); monthly allowance from parents (in yuan); and marital status (married = 1, others = 0). To adjusted for unobserved city-specific factors (e.g., the climate, culture), we included city-specific fixed effects (Yin, Cao, & Sun, 2020). Controlling for these covariates not only can partly relieve the effect of self-selection but also can improve model accuracy and goodness of fit (Angrist & Pischke, 2008).

2.6. Analysis approach

We used path analysis to explore how the campus-based built environment relates to BMI mediated by unhealthy food intake, duration of exercise, and active travel distance. The model was defined as follows:

$$\begin{cases} FI = \sum a_{FI,i} BE_{FI,i} + \sum b_{FI,i} CV_{FI,i} + \varepsilon_{FI,i} \\ E = \sum a_{E,i} BE_{E,i} + \sum b_{E,i} CV_{E,i} + \varepsilon_{E,i} \\ AT = \sum a_{AT,i} BE_{AT,i} + \sum b_{AT,i} CV_{AT,i} + \varepsilon_{AT,i} \\ BMI = \sum a_{WS,i} BE_{WS,i} + \sum b_{WS,i} CV_{WS,i} + m_1 FI + m_2 E + m_3 AT \end{cases} \tag{3}$$

where the dependent variable was *BMI*. Unhealthy food intake (*FI*), duration of exercise (*E*), and active travel distance (*AT*) were the three mediators. *BE* indicated the campus-based built environment, and *CV* represented covariates, including sociodemographic attributes and city-specific fixed effects. The model was saturated because we captured all potential pathways. We used cluster-robust standard errors at the campus level because individuals were nested within the same campuses, as previous studies did (Okulicz-Kozaryn & Mazelis, 2018; Primo, Jacobsmeier, & Milyo, 2007; Sun, Yin, & Yao, 2022). Moreover, we conducted a sensitive analysis by changing the BMI to a dummy variable indicating whether an undergraduate is overweight (including obesity; i.e., BMI $\geq$ 24 kg/m^2).

We examined the mediating effects by examining the significance of $a \times m$ (Zhao, Lynch, & Chen, 2010). If statistically significant, there is an indication of a mediation effect, and vice versa. We used a Monte Carlo approach with 50,000 replications to test the significance level of $a \times m$ (Jose, 2013). The analyses were performed in Stata, version 15, by means of the 'sem' and 'medsem' commands.

Table 1
Descriptive statistics of the sample.

Undergraduate characteristics	Mean (SD)/%	Campus-based built environment and dependent variables	Mean (SD)
Sociodemographics		Walkability	
Gender		Population density	10,500 (10476)
Male	45 %	POI density	193 (151)
Female	55 %	Road density	4.94 (2.17)
Ethnicity		Number of bus stops	18 (15)
Han ethnicity	87 %	Exercise environment	
Others	13 %	NDVI	0.25 (0.09)
Age	20.57 (1.57)	Distance to the nearest park	2135 (2890)
Hukou status		Number of sports facilities	17 (14)
Urban hukou	61 %	Food environment	
Rural hukou	39 %	Number of restaurants	240 (185)
Major		Number of dessert stores	3 (5)
Natural science, engineering, agriculture, or medicine	85 %	Number of fruit stores	20 (18)
Others	15 %	Mediators and outcome	
Allowance	1204 (649)	Unhealthy food intake	7.17 (2.44)
Marital status		Duration of exercise	201 (254)
Married	0.5 %	Active travel distance	3910 (5831)
Single	99.5 %	BMI	20.54 (2.56)

3. Results

3.1. Descriptive statistics

Table 1 shows the characteristics of undergraduates and the campus-based built environment. Approximately 45 % of undergraduates were male, and 87 % were of Han ethnicity. Undergraduates were, on average, 21 years old. Before enrollment in the university, 61 % of them had an urban hukou, indicating that their households were registered in cities. 85 % majored in the natural sciences, engineering, agriculture, or medicine. Undergraduates' average monthly allowance was approximately 1200 yuan. Only 0.5 % of undergraduates were married.

The average score of unhealthy food intake was 7, the duration of exercise was 201 min/week, and the average active travel distance was 3910 m/week. The mean BMI was 20.5 kg/m^2. Approximately 10 % of undergraduates were overweight or obese (BMI $\geq$ 24 kg/m^2) based on Chinese thresholds (Hu et al., 2017).

On average, the population density, POI density, and road density were 10.5 thousand people/km^2, 193 counts/km^2, and 4.94 km/km^2, respectively. The mean NDVI score was 0.25. There were 18 bus stops and 17 sports places surrounding campuses within the 1 km buffers on average. The average distance to the nearest park was approximately 2.1 km. There were 240 restaurants, 3 dessert stores, and 20 fruit stores on average within the 1-km buffers.

3.2. Model results

Fig. 2 shows associations among the campus-based built environment, the mediators, and BMI, adjusted for sociodemographic attributes and city-specific fixed effects (full results shown in Appendix Table A). The comparative fit index (CFI) was 1 (>0.95), root mean square error of approximation was 0 (<0.05), the standardized root mean squared residual was 0.002 (<0.08), and the R^2 was 0.21. These indicators suggested a suitable goodness of fit and were consistent with previous path analysis results (Yang & Zhou, 2020; Yin, Guo, & Sun, 2022).

Higher POI density was negatively associated with unhealthy food intake. NDVI had a negative association with unhealthy food intake, whereas the number of sports facilities had a positive association with unhealthy food intake. The number of restaurants was positively related to unhealthy food intake. In terms of sociodemographics, male sex, non-Han ethnicity, and older students were negatively associated with unhealthy food intake. Undergraduates who were from urban areas and had higher allowances showed higher levels of unhealthy food intake.

Population density had a positive relationship with the duration of exercise. More fruit stores were negatively associated with the duration of exercise. Undergraduates who were of Han ethnicity tended to have higher BMI.

Population density and road density had positive associations with active travel distance, whereas the number of bus stops was negatively related to active travel distance. More sports facilities had a positive relationship with active travel distance, but more dessert stores and fruit stores had negative associations with active travel distance. All undergraduates' sociodemographic attributes showed null associations with active travel distances.

After including the mediators, we found that unhealthy food intake was positively associated with BMI. Active travel distance was negatively related to BMI at the 10% significant level. However, there was no association between the duration of exercise and BMI. Moreover, population density, the number of restaurants, and the number of dessert stores showed positive associations with BMI. POI density and the number of sports places were negatively related to BMI. Regarding sociodemographic attributes, undergraduates who were male, were older, had urban hukou, and majored in the natural sciences, engineering, agriculture, or medicine had higher BMI.

Table 2 shows the indirect and total effects of the built environment on obesity. Unhealthy food intake seemed to be a mediator of the built

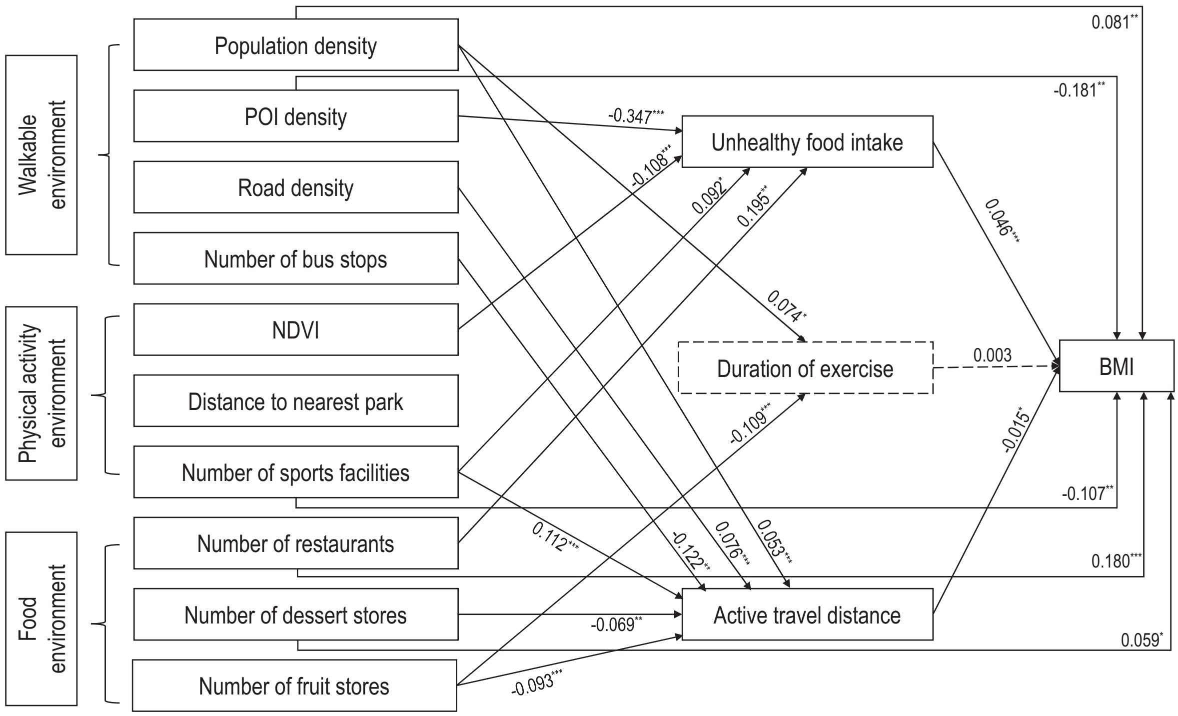

Fig. 2. Pathways from the campus-based built environment to BMI
Note: Coefficients are shown in standardized forms. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. The model is adjusted for sociodemographic attributes and city-specific fixed effects. Dashed borders indicate that mediating effects on BMI are insignificant.

Table 2
Mediation and total effects.

	Food intake → BMI	Exercise → BMI	Active travel → BMI	Total effects
Population density	0.002	−0.000	−0.001	0.082**
POI density	−0.016**	−0.000	−0.001	−0.198***
Road density	0.002	−0.000	−0.001	0.031
Number of bus stops	0.000	0.000	0.002	−0.009
NDVI	−0.005**	0.000	0.000	−0.031
Distance to nearest park	0.002	0.000	0.000	0.002
Number of sports facilities	0.004	0.000	−0.002	−0.105**
Number of restaurants	0.009**	−0.000	0.001	0.190***
Number of dessert stores	0.003	−0.000	0.001	0.063*
Number of fruit stores	−0.001	0.000	0.001	−0.039

Note: Coefficients are standardized. Significance levels of mediating effects are computed based on Zhao et al. (2010) approach using the Monte Carlo test with 50,000 replications.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$

environment-BMI association. In particular, POI density and NDVI had negative associations with BMI by reducing unhealthy food intake. More restaurants showed a positive relationship with BMI by increasing unhealthy food intake. Neither the duration of exercise nor active travel distance appeared to be mediators.

In terms of the total effects of the built environment, population density, the number of restaurants, and the number of dessert stores were still positively related to BMI. POI density and the number of sports facilities had negative relationships with BMI.

3.3. Sensitivity analysis

To test whether our findings were robust, we changed the dependent variable from BMI to overweight. We found the two models had similar results (full results shown in Appendix Table B). The only difference is the road density is positively associated with BMI in the overweight model. Moreover, as active travel distance was significant associated with overweight at the 1% level, it might have mediation effects on the built environment-overweight relationship, although it was not a significant mediator in the built environment-BMI association.

4. Discussion

4.1. Main findings and interpretation

This study contributed to the literature by identifying the pathways from the campus-based built environment to undergraduates' obesity, using a nationwide sample of undergraduates in China. Our findings suggested that energy intake, which has often been ignored in the literature, plays an important mediation role in the association between campus-based built environments and undergraduates' obesity, whereas we did not observe the mediation effects of energy expenditure.

The relationship between the campus-based built environment and BMI was mediated by unhealthy food intake. We found that higher POI density was negatively associated with unhealthy food intake, suggesting that mixed land use could promote a healthy diet among undergraduates. One possible reason is that mixed land use improves healthy food accessibility and availability (Garfinkel-Castro & Ewing, 2022). More green space had a negative association with unhealthy food intake. This result was in line with Martin, Pahl, White, and May (2019), who found that a higher level of green space had negative associations with unhealthy food intake by inhibiting the intense desire to eat. More sports facilities were weakly positively related to unhealthy food intake. This association might have occurred because people often need to supplement salt before and after exercise (Kackley et al., 2020). More restaurants were positively associated with unhealthy food intake. This finding was congruent with previous studies (French, Story, Neumark-Sztainer, Fulkerson, & Hannan, 2001; Li et al., 2009; Trapp et al., 2015). It could mean that restaurants often provide food with high salt, sugar, and fat, resulting in more unhealthy food intake (Moss, 2013). Moreover, unhealthy food intake was positively associated with BMI. Unhealthy food intake consisted of foods high in salt, sugar, and fat, which usually occur in energy-dense options. A higher intake of salty food had a positive association with the deposition of body fat, resulting in a higher BMI (Ma, He, & MacGregor, 2015). A higher intake of sweet food was positively related to a higher BMI through increasing hepatic lipogenesis (Samuel, 2011). Third, oily food is usually fried, palatable, and rich in fats. It was positively associated with a greater intake of energy-dense food and lower satiety (Guallar-Castillón et al., 2007).

The campus-based built environment had significant associations with the duration of exercise and active travel distance. Among walkability attributes, population density had a positive relationship with both the duration of exercise and active travel distances, consistent with previous studies of adults in the United States (Troped, Wilson, Matthews, Cromley, & Melly, 2010) and Australia (Garden & Jalaludin, 2009). However, this finding contradicted previous results based on high-density Chinese cities, which showed that population density had negative relationships with physical activity in adolescents (Xu et al., 2010), urban adults (Yin & Sun, 2020), and middle-aged and older adults (Wang, Feng, Xue, Liu, & Wu, 2019). These studies argued that higher population density was negatively related to physical activity due to fewer per capita facilities and public spaces for exercising and perceived overcrowding (Day, 2016). However, university campuses are usually equipped with many sports facilities, and higher population density tended to increase the number of these facilities, which could satisfy undergraduates' diversified demands for physical activity. Furthermore, higher population density implied that more undergraduates participated in sports, as physical education is required in universities, leading to an atmosphere and social norm of being physically active. Some studies have found that people tend to exercise more if they see others exercising (Addy et al., 2004). Road density was positively associated with active travel distance. Higher road density provided more choices of travel routes and more attractive landmarks on campuses, which were also positively related to active travel (Saelens & Handy, 2008). The number of bus stops had negative associations with active travel distance. One possible reason was that higher transit accessibility shortened the active travel distance from the place of origin to the transit stop, leading to a shorter distance of active travel (Tao, Wang, & Cao, 2020).

Among exercise environment elements, the number of sports facilities was positively related to active travel distance, implying that recreational and transportation physical activities had additive effects instead of substitution effects (Kang, Moudon, Hurvitz, & Saelens, 2018). That is, undergraduates had longer active travel distances within the campus having more sports places, which was possible because undergraduates had higher frequencies of active travel to reach sports places, leading to longer active travel distances.

Regarding the food environment, the number of fruit stores was negatively associated with the duration of exercise. One possible reason was that more fruit stores reduced the intake of unhealthy foods, implying that a healthy diet might have substitution effects for physical activity among undergraduates who wanted to maintain their weight status. More dessert and fruit stores had negative relationships with active travel distance, which might be because greater accessibility to food stores reduces total travel distance, resulting in shorter active travel distances.

The duration of exercise was not significantly related to BMI, implying that physical activity might have a limited contribution to young adults' BMI than food intake. This result was in line with prior studies (Dun et al., 2021; Sullivan et al., 2016). Considering that physical activity had both positive and negative effects on BMI, the insignificant associations might be because the two effects canceled each other out. In particular, more exercise had a negative relationship with BMI through increasing metabolic rate (Yang & Zhou, 2020), but people were more likely to choose eating food as a reward after exercise due to hunger, leading to increasing BMI (Martins, Morgan, Bloom, & Robertson, 2007). Moreover, although active travel distance was only significantly associated with lower BMI at the 10% levels, it had substantive effects on reducing overweight. This implies that transportation physical activity is important to overweight prevention in young adults.

Some built environment elements had direct effects on undergraduates' BMI, suggesting that they could affect BMI directly or via other pathways. Population density had a positive association with BMI. High population density was positively related to air and noise pollution, contributing to a higher BMI (Yin et al., 2020). Higher population density tends to increase the risk of mental illness (Ghazali, Marzukhi, Leh, & Othman, 2020), which is another possible cause of overweight and obesity (Sinha & Jastreboff, 2013). In contrast, POI density was negatively related to BMI. This finding suggested that mixed land use could provide more attractive destinations, which may promote undergraduates' stroll and shopping, leading to higher physical activity and reducing BMI. The number of sports places was negatively related to BMI. More sports places could have a negative relationship with undergraduates' BMI by improving their mental health (VanKim & Nelson, 2013). The number of restaurants and the number of dessert stores were positively associated with BMI. Considering that food delivery is convenient in China, more restaurants and dessert stores provided more choices of delivery food. It not only reduced physical activity but also increased total energy intake, resulting in higher BMI.

4.2. *Strength and limitations*

Our study had several strengths. First, our study is one of the first examining the mediation effects of both energy expenditure and energy intake on the built environment-obesity association. Second, we focused on undergraduates who were young adults experiencing a transition from childhood to adulthood. This population group has received little attention so far. Third, based on a large sample, our study also provides robust statistical evidence by mitigating self-selection issues. Finally, BMI was objectively measured with the help of healthcare professionals, rather than relying on individual self-reports. It improves the accuracy of BMI measurements by excluding the effects of beautifying self-images (Olfert et al., 2018).

This study also had several limitations. First, based on cross-sectional data, the results did not allow for causal statements (Martin, Ogilvie, & Suhrcke, 2014). Future studies may use longitudinal designs to identify causalities. Second, the self-reported food intake and physical activity data might not be fully accurate due to recall bias, although they are usually adopted in the literature (Yang et al., 2021). Third, due to the data restrictions, this study only tested three mediators of the built environment-obesity association, which may not capture all the pathways from the built environment to obesity. Fourth, considering that the association of the built environment with BMI and behavior mediators may differ in buffer size (Sun, Yao, & Yin, 2022), more studies are needed to identify the most effective buffer size for intervening in undergraduates' obesity.

5. Conclusions

The campus-based built environment was related to undergraduates' obesity. In particular, the built environment-BMI associations were mediated by unhealthy food intake related to salty, oily, and sweet foods. Some campus-based built environmental factors (e.g., population density, POI density, sports facilities, restaurants, and dessert stores) had direct effects on undergraduates' BMI. However, our results did not provide evidence that physical activity was among the mediators, although the built environment correlates with both the duration of exercise and active travel distance.

These findings suggest that modifications in the built environment around campuses could be a means of reducing undergraduates' obesity risk. First, improving the campus-based built environment could reduce undergraduates' risks of obesity. Hence, policy makers may adopt some interventions to relieve the overdense population, reduce restaurants around campuses, promote mixed land use, and build more sports places that are conducive to reducing young adults' obesity. Second, it is necessary to promote healthy diets for young adults to prevent and control obesity. From the viewpoints of improving the built environment, urban planners need to consider promoting land use diversity, planting more vegetation, and increasing the threshold of opening restaurants, which could be useful strategies to promote healthy diets. Third, an improvement of the campus-based built environment is an important strategy for promoting undergraduates' physical activity, which could help prevents many chronic diseases beyond obesity (Duggal, Niemiro, Harridge, Simpson, & Lord, 2019; Warburton, Nicol, & Bredin, 2006). Urban planners may consider improving population and road densities and building more sports facilities to increase young adults' physical activities.

CRediT authorship contribution statement

Chun Yin: Conceptualization, Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. **Marco Helbich:** Conceptualization, Writing - review & editing. **Haoran Yang:** Conceptualization, Data curation, Supervision, Formal analysis, Methodology, Software, Project administration, Funding acquisition, Writing - original draft, Writing - review & editing. **Bindong Sun:** Supervision, Funding acquisition, Writing - review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Table A
Relationship among the campus-based built environment, mediators, and BMI (Direct effects).

	Unhealthy food intake	Duration of exercise	Active travel distance	BMI
Mediators				
Unhealthy food intake				0.046***
Duration of exercise				−0.003
Active travel distance				−0.015*
Built environment				
Population density	0.046	0.074*	0.053***	0.081**
POI density	−0.347***	0.054	0.046	−0.181**
Road density	0.051	0.055	0.076***	0.030
Number of bus stops	0.001	−0.068	−0.122**	0.007
NDVI	−0.108***	−0.051	−0.027	−0.026
Distance to nearest park	0.051	−0.047	−0.012	−0.001
Number of sports places	0.092*	−0.082	0.112***	−0.107**
Number of restaurants	0.195**	0.000	−0.038	0.180***
Number of dessert stores	0.066	0.016	−0.069**	0.059*
Number of fruit stores	−0.015	−0.109***	−0.093***	−0.040
Sociodemographic attributes				
Male	−0.106***	0.002	−0.018	0.303***
Han ethnicity	0.023**	0.015*	−0.010	−0.004
Age	−0.040***	0.007	0.005	0.030***
Urban hukou	0.018*	0.010	0.004	0.043***
Major	−0.016	−0.010	−0.013	0.039***
Allowance	0.050***	0.001	0.002	−0.004
Married	0.006	−0.008	0.003	−0.008
Fixed effects of cities	Yes	Yes	Yes	Yes

(continued on next column)

Table A (*continued*)

Note: Coefficients are shown in standardized forms. Clustered standard errors at the campus level are used.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table B
Relationship among the campus-based built environment, mediators, and overweight (Direct effects).

	Unhealthy food intake	Duration of exercise	Active travel distance	Overweight
Mediators				
Unhealthy food intake				0.280***
Duration of exercise				0.014
Active travel distance				−0.245***
Built environment				
Population density	0.046	0.074*	0.053***	1.216**
POI density	−0.347***	0.054	0.046	−2.506***
Road density	0.051	0.055	0.076***	1.003***
Number of bus stops	0.001	−0.068	−0.122**	−0.445
NDVI	−0.108***	−0.051	−0.027	−0.297
Distance to nearest park	0.051	−0.047	−0.012	0.103
Number of sports places	0.092*	−0.082	0.112***	−1.608***
Number of restaurants	0.195**	0.000	−0.038	2.357***
Number of dessert stores	0.066	0.016	−0.069**	1.277***
Number of fruit stores	−0.015	−0.109***	−0.093***	−0.516
Sociodemographic attributes				
Male	−0.106***	0.002	−0.018	2.678***
Han ethnicity	0.023**	0.015*	−0.010	0.025
Age	−0.040***	0.007	0.005	0.230*
Urban hukou	0.018*	0.010	0.004	0.526***
Major	−0.016	−0.010	−0.013	0.211
Allowance	0.050***	0.001	0.002	0.022
Married	0.006	−0.008	0.003	0.015
Fixed effects of cities	Yes	Yes	Yes	Yes

Note: Clustered standard errors at the campus level are used.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

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