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Disentangling residential self-selection from the influence of built environment characteristics on adiposity outcomes among undergraduate students in China

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ABSTRACT

Although many studies have confirmed the effects of the built environment on adiposity outcomes in the general population, evidence for young adults is scarce. Furthermore, most prior studies are prone to residential self-selection bias due to the nature of cross-sectional research design, which makes the built environment–adiposity relationship spurious. In this study, we explored the associations between the built environment and three objectively measured adiposity outcomes for a large representative sample of 20,227 undergraduate students from 89 university campuses in China. The adiposity outcomes were measured by body mass index (BMI), waist circumstance (WC), and waist-to-height ratio (WHtR). The residential self-selection bias was largely mitigated because these students are required to live in campus dormitories. As shown by multilevel models, street connectivity, population density, and Normalized Difference Vegetation Index (NDVI) within and around the campus environment were negatively associated with the odds of adiposity to different extents. Furthermore, the adiposity outcomes of male and low cost-of-living undergraduates were more likely to be affected by built environment characteristics compared to female and high cost-of-living undergraduates. Hence, to deliver effective environment interventions to curb the prevalence of adiposity among undergraduate students, policymakers and university managers are advised to create a more carefully conceived campus environment.

1. Introduction

Many countries are facing the difficult challenge of the prevalence of overweight and obesity, and the associated health-related problems (Lachowycz & Jones, 2011; Ewing et al., 2003; Hamidi & Ewing, 2020). Excessive weight can increase the risk for chronic diseases, such as type II diabetes (Egede & Zheng, 2002), and cardiovascular diseases (Bastien et al., 2014), and can therefore overburden healthcare systems. It was estimated that adiposity accounts for at least 2% of the total healthcare costs across different countries (Swinburn et al., 2011).

Maintaining a healthy body weight has additional benefits for young adults. For instance, it increases their propensity for establishing romantic relationships and finding employment opportunities (Johansson et al., 2009; Pearce et al., 2002). More importantly, young adults who are overweight or obese carry a higher risk of being obese in later years (Engeland et al., 2004). Therefore, maintaining a healthy weight for undergraduate students is a public health priority (Yang et al., 2017). However, the rate of obesity among adolescents and young adults is increasing rapidly in developing countries, ranging from 2.3% to 12% (Poobalan & Aucott, 2016). In China, because of rapid urbanization and

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the subsequent transformation in lifestyles (i.e., more sedentary behaviors and unhealthy dietary habits) over the last four decades, the rate of obesity among adolescents and young adults has increased from 0.1% in 1976 to 8.5% in 2016 (Global Health Observatory Data Repository, 2017). Meanwhile, the number of undergraduate students in China has reached to 16.9 million in 2018 (National Bureau of Statistics of China, 2019). Given the large population of undergraduate students in China and fast-growing obesity rate among them, it is necessary to investigate the adiposity determinants and to create a tailored intervention to mitigate this unhealthy trend. The relevant knowledge output could also be applicable to other developing countries in the world when addressing the prevalence of adiposity among undergraduate students.

Using the built environment as an intervention has been increasingly recognized as a crucial method to reverse the fast-changing determinants of adiposity (Ewing et al., 2003; Ding & Gebel, 2012). There is accumulating evidence about the relationships between the built environment and adiposity (King & Jacobson, 2017). Numerous relevant studies have identified key adiposity-linked built environment characteristics, such as residential density (Sun & Yin, 2018), street connectivity (Rutt & Coleman, 2005), accessibility to facilities and restaurants (Campbell et al., 2007; MacDonald et al., 2010), and proximity to greenness (Nichani et al., 2020).

However, the present research remains limited in several aspects. First, the relationship between the built environment and adiposity for young adults is not well studied, although it has been documented that the transition period from adolescence to adulthood is critical to developing a life-long healthy lifestyle (Bishop et al., 2020). Second, most studies have incorporated self-reported or sole adiposity outcomes, which are subject to recall bias and social-desirability bias (Jia et al., 2019; Nichani et al., 2020). Third, most built environment–adiposity studies are prone to the bias of residential self-selection (Feng et al., 2010; Ding & Gebel, 2012). This bias means that the residential locations chosen by individuals largely depend on their attitudes and preferences, thus, the observed relationship between the built environment and weight outcomes may be explained by underlying personal attitudes and preferences. For example, a person with positive attitudes toward health and active lifestyles may intentionally choose to live in a greener or walkable neighborhood that facilitates physical activities. The residential self-selection bias makes the observed built environment–adiposity association spurious and uncertain (Sallis et al., 2009; Zick et al., 2013). Fourth, a better understanding of which population groups might be more vulnerable to the impact of environmental constraints is important for targeting interventions (Ding & Gebel, 2012), however, these potential disparities have not been explicitly examined in the context of China.

To address these issues, we conducted a large-scale national survey of 20,227 undergraduate students from 89 university campuses in China. This study contributes to the understanding of existing knowledge in three aspects. First, the requirement for undergraduate students to reside in campus dormitories provides us with a unique opportunity to address the self-selection bias, as these students cannot act upon their personal attitudes and preferences in selecting a living environment. To the best of our knowledge, this is the first nationwide study that mitigates the residential self-selection bias in the built environment–adiposity association. Second, we attempted to investigate whether individual characteristics (i.e., gender and socioeconomic status) may modify the effects of the built environment on adiposity. Third, three aspects of adiposity outcomes were objectively collected by trained healthcare professionals in this study: body mass index (BMI), waist circumstance (WC), and waist-height ratio (WHtR). Hence, this study aims to guide policymakers to make tailored interventions for targeted population groups not only for China but also for other fast developing countries from an international perspective.

2. Literature review

2.1. Built environment and adiposity

The prevalence of overweight and obesity over the last few decades is a major public health concern (Ewing et al., 2003; Feng et al., 2010; Lachowycz & Jones, 2011). Based on the energy balance framework, individual excessive body weight occurs when energy intake exceeds energy expenditure (Schoeller, 2009). The built environment affects adiposity both by influencing energy consumption through physical activities and by altering energy intake through food environments (Ding & Gebel, 2012; Rutt & Coleman, 2005). It has been recognized that some built environment features—such as residential density (Sun & Yin, 2018), street connectivity (Jia et al., 2019), greenspace (Lu et al., 2018), and food environment (Campbell et al., 2007)—are integral in shaping adiposity. In the context of China, emerging studies have unraveled the influence of the neighborhood-level built environment on adiposity. For instance, residential density is positively associated with being overweight among adolescents (Xu et al., 2010), and adolescents who are exposed to diverse food environments exhibit a higher likelihood of being overweight (Hua et al., 2014).

Although the effects of the built environment have been widely recognized, there are some ambiguities in the relationships between the built environment and adiposity, and the evidence is inconsistent (Feng et al., 2010; Sarkar, 2017). This inconsistence may be partly due to the following reasons. First, prior studies generally used a self-reported or single indicator (i.e., BMI) to measure adiposity outcomes (Nichani et al., 2020). The built environment may be associated with different adiposity indicators to different extents (McCormack et al., 2018; Sriram et al., 2016). Second, most prior studies only sampled respondents within a few small-scale neighborhood settings, thereby limiting statistical reliability and generalizability (Sarkar, 2017). Apart from this, the influence of the built environment on excessive body weight may be more significant within some groups of respondents (Frank et al., 2008; Jia et al., 2019; Nichani et al., 2020), while few prior studies have verified whether the differences of individual characteristics may modify the effects in China, especially for young adult groups. Hence, undertaking studies of geographically diverse settings with objectively measured adiposity measures are needed to provide more rigorous evidence to inform interventions that support healthy body weight.

2.2. Residential self-selection bias

Residential self-selection refers to the selection of household dwellings and associated built environment characteristics being constrained by personal preference and lifestyle or social inequity (i.e., of income and car ownership) (Feng et al., 2010). There is a consensus that both built environment and self-selection affect individual adiposity outcomes (Feng et al., 2010; Ewing et al., 2003). Many studies have suggested that the observed effects of the built environment are confounded by the role of residential self-selection (Sallis et al., 2009; Zick et al., 2013). For instance, Smith et al. (2016) reported that obese women tend to move to neighborhoods with the highest obesity rates due to the convenient environment (i.e., accessible stores), which was consistent with the hypothesis of non-random residential selection. Sarkar (2017) suggested that obese residents may selectively relocate to greener areas, which leads to the underestimation of the effects of greenery on the prevalence of obesity.

Overall, there are three major approaches to mitigate residential self-selection bias in built environment-health studies. First, respondents' preferences and attitudes can be measured via questionnaires, and then controlled in statistical models (Bohte et al., 2009; Sallis et al., 2009). Second, quasi-longitudinal and quasi-experimental data are efficient for exploring the causal relationship between urban environment and individual behaviors (Braun et al., 2016; Hirsch et al., 2014; Zick et al., 2013). The third approach is to investigate participants with little freedom in choosing residential location (Schwanen & Mokhtarian, 2005). Undergraduate students living in campus dormitories or low-income residents living in public housing estates are among the viable research participants, as their preferences and attitudes are typically not factored into residential choices (Zang et al., 2019).

2.3. Characteristics of undergraduate students in China

The campus environments and corresponding management modes in China are unique (Zhan et al., 2016). To reduce students' living costs and facilitate management, universities provide dormitories for most students and enforce compulsory dormitory enrollment (He, 2015). Consequently, undergraduate students have little freedom to choose their residential locations. Additionally, their dormitories are generally located within or near the campus, and most of their routine activities (i.e., learning, eating, and living) takes place within or around their campuses (Zhan et al., 2016). Thus, we then suppose that the campus environment is important in shaping adiposity outcomes.

To address the abovementioned research gaps, we proposed a conceptual framework for better understanding the effects of the built environment on adiposity outcomes (Fig. 1). The effects of individual attributes and preferences on health and health-related lifestyles have been widely recognized (Ding & Gebel, 2012). They not only directly shape the health behavior of individuals, but also influence their selection of a living environment, and exert heterogeneous opportunities on environment exposure (Feng et al., 2010; Smith et al., 2016). Thus, the observed built environment–adiposity associations in cross-sectional studies may be spurious due to such residential self-selection bias (Zick et al., 2013). Using a large representative sample in China, this study aims to examine the linkages between the built environment and adiposity outcomes among undergraduate students. Potential residential self-selection bias was mitigated as undergraduate students in China have little freedom to choose their residential locations, and the "independent effects" of the built environment on adiposity outcomes could be confidently observed. Second, this study attempts to investigate whether an individual's characteristics modify the association between the built environment and adiposity. Third, using three adiposity indicators objectively measured by trained healthcare professionals, the bias associated with self-reported data can be reduced.

3. Data and method

3.1. Dataset

In this paper, individual information was derived from a nationwide university-based survey in China, conducted by the First Affiliated Hospital of Kunming Medical University in 2018 (Ethical number: 2018-L-25). The survey used a multiple-stage stratified sampling method. First, excluding Tianjin and Tibet, a total of 29 provinces/municipalities in mainland China were selected. Second, two to four universities in each province/municipality were selected. Third, a range of 300–700 undergraduate students in each university were recruited with probabilities proportionate to undergraduate students' population size. Face-to-face interviews were conducted by a larger number of healthcare professionals from more than 100 hospitals. Ultimately, a total of 23,488 undergraduate students were included (Fig. 2).

A self-reported and structured questionnaire survey was conducted via face-to-face interview between healthcare professionals and respondents. Individual interviews contained a wide range of information. The first questionnaire was used to collect personal information, lifestyle, and health status, and was completed by the respondents. The second questionnaire was based on medical examination, which was collected by trained healthcare professionals. Information on height, weight, waist circumference, and other anthropometric indicators was recorded. After omitting data with missing values and outliers, our valid sample size comprised 20,227 undergraduate students from 89 campuses.

3.2. Variables

3.2.1. Adiposity outcomes

Many studies used BMI as a feasible proxy for measuring adiposity (Flegal et al., 2009). However, BMI may miscalculate body fatness because it measures excess body fat indirectly (CDC, 2020). Consequently, some researchers recommended using waist circumference and waist-to-height-ratio to measure body fat, which may better predict

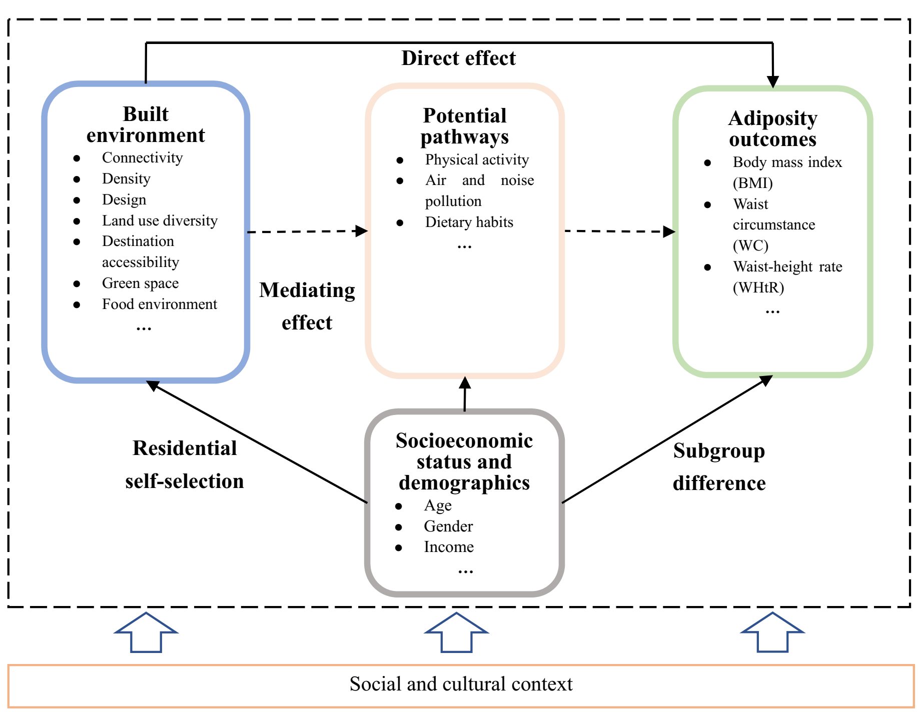

Fig. 1. Conceptual framework of the impact of built environment on adiposity outcomes.

Fig. 2. The distribution of sampled undergraduate students and typical campuses in this study.

varied health threats (Huang, Liu, et al., 2020; Sarkar, 2017).

In the survey, all students' height, body weight, and waist circumference were measured by healthcare professionals with calibrated equipment (tapes and digital weight scales). Three aspects of adiposity were measured by variables: being overweight (represented by BMI), abdominal obesity (represented by waist circumference), and waist-to-height-ratio (Janssen et al., 2004). Following previous studies (Sarkar, 2017; Huang, Yang, et al., 2020), the BMI score was calculated as weight (kg) divided by height squared (m^2); waist circumference was defined by the circumstance of the waist (cm); and waist-to-height-ratio was measured by the ratio of waist circumference (cm) to height (cm). Specifically, being overweight is defined as BMI $\geq$ 24 kg/m^2 (NHFPC, 2010). A sex-based classification was also adopted to define abdominal obesity (male $\geq$85 cm and female $\geq$80 cm) (Huang, Yang, et al., 2020). Furthermore, WHtR $\geq$ 0.5 is the threshold of a higher risk of WHtR (Browning et al., 2010).

3.2.2. *Built environment variables*

University campuses in China provide a unique research opportunity because undergraduate students with different individual factors (e.g., socioeconomic status, lifestyles, and preference for residential environment) are exposed to the same environment. Such campuses also have some distinct characteristics (Liu et al., 2018). As most routine activities of students are concentrated on the campuses, surrounding areas generally have a high urban density (Zhan et al., 2016). Additionally, most campuses or their surrounding areas provide various services and facilities, such as restaurants, supermarkets, and bus stops.

Widely used in prior studies, this study defined the area of a campus environment with a radius of 1000 from the center point of campus (Liu et al., 2019). Greenspace data were retrieved from the Sentinal-2 satellite data with a spatial resolution of 10 m by 10 m (Kaplan & Avdan, 2017). We collected cloud-free satellite images in September 2018, and excluded large water bodies from the images. The overall vegetation level was measured with the Normalized Difference Vegetation Index (NDVI), which was based on land surface reflectance of red and near-infrared (NIR) parts of the spectrum (Huete et al., 2010). It ranges between −1 and 1, with higher values indicating a higher level of green vegetation.

$$NDVI = (NIR - RED)/(NIR + RED)$$

Furthermore, we collected information on campus-based street connectivity, bus station density, food environment, and population density. The road network data were derived from Open Street Map in 2018 (https://www.openstreetmap.org/). Street connectivity was defined as the density of road intersections/junctions (Xie et al., 2019). High street connectivity implies a walking-friendly environment that promotes physical activity (Xu, Wen, & Wang, 2015). Information on food environment and bus stations was measured by Point of Interests data from Gaode map in 2019 (https://lbs.amap.com/), one of the largest map providers in China. It contained the density of fast-food restaurants (KFC, McDonald's, etc.), as well as bus stations. The population density was acquired from Worldpop in 2018 (https://www.worldpop.org/), with a resolution of 100 * 100 m. We also controlled the level of urbanization, and divided all campuses into urban or suburban.

3.2.3. Covariates

Individual-level covariates may also affect adiposity, because individual characteristics (i.e., age, gender, and socioeconomic status) could influence both energy intake (i.e., food budget) and expenditure (i.e., travel mode, sedentary behavior) (Ding & Gebel, 2012; Feng et al., 2010). Following prior studies in China (Sun & Yin, 2018; Xu et al., 2010), a series of individual covariates were collected and controlled. They comprise gender (coded as male and female), *hukou* status[1] before enrollment in universities (coded as rural and urban *hukou*), individual monthly living cost (<1000 RMB, 1000–2000 RMB, and >2000 RMB), age (continuous variables), mental health (continuous variables), self-reported sleeping quality (continuous variables), and time on campus (first-year students[2] vs. others). Furthermore, we collected information on individual lifestyles, such as physical activity (categorical variables), tobacco use (coded as non-smoker and smoker), and alcohol use (coded as non-drinker and drinker). Specifically, depression was measured using the PHQ-9 scale (Kroenke & Spitzer, 2002) which adds 9 items together for a sum score, ranging from 0 to 27, with a higher score indicating a higher level of depression. Physical activity was based on the self-reported frequency and duration of moderate-to-vigorous physical activity in the previous month. Based on the amount of moderate-to-vigorous physical activity recommended by the World Health Organization (WHO, 2011), respondents were classified into two groups: ≥150 min and <150 min per week.

3.3. Methods

Because of the hierarchical data structure (students were nested in universities), multilevel models were used to investigate the association between the built environment and different aspects of adiposity (Sarkar, 2017). As previously mentioned, three indicators were transformed into binary variables to define students' adiposity. Intra-class correlation coefficient (ICC) was used to determine whether multilevel models were necessary. The ICC for the null model indicated that the clustering total variance of individuals within campus ranged from 0.08 to 0.09 among different adiposity indicators. This confirmed the necessity of using multilevel models. The Akaike Information Criterion (AIC) value gauged the balance between its fitness of power and degree of freedom of each model (Sun et al., 2018). Logistic models were used, and odds ratios (ORs) and 95% confidence intervals (CIs) were reported. The results of the variance inflation factor (VIF) demonstrated that the VIF was less than 7, indicating that there was no serious multicollinearity. All statistical analyses were performed using STATA 13.0.

4. Results

4.1. Descriptive results

Table 1 presents the descriptive statistics of all variables. The mean age of undergraduate students was 20.01 years (SD ± 1.74) and 44.52% of them were male (Table 1). The monthly living costs of 93.37% of students was less than 2000 Yuan. Approximately 60% of students were from urban areas before being enrolled in colleges, and one-quarter of them were first-year students. Regarding their health-related status, the average level of depression was 5.11 (SD ± 4.44), and sleep quality was 3.59 (SD ± 0.88). With respect to adiposity outcomes, BMI, WC, and WHtR were normally distributed with a mean value of 20.56 kg/m^2, 72.99 cm, and 0.44, respectively. These results were consistent with a recent study that the adiposity prevalence among undergraduate students was lower than other population groups (Yang et al., 2017).

Table 1
Descriptive statistics of 20,227 undergraduate students in China.

Variables	All samples proportion/ mean (SD)	Male proportion/ mean (SD)	Female proportion/ mean (SD)
Dependent variable			
Body mass index (BMI)	20.56 (2.72)	21.43 (2.95)	19.87 (2.30)
Waist circumstance (WC)	72.99 (9.89)	77.40 (10.28)	69.45 (7.95)
Waist-to-height ratio (WHtR)	0.44 (0.05)	0.45 (0.06)	0.43 (0.05)
Independent variables			
Gender (%)			
Male	44.52	100	
Female	55.48		100
Age	20.01 (1.74)	20.11 (1.77)	19.94 (1.71)
Whether smoking (%)			
Being or have been a smoker	7.92	15.87	1.54
Never	92.08	84.13	98.46
Whether using alcohol (%)			
Being or have been a drinker	42.95	60.51	28.86
Never	57.05	39.49	71.14
Monthly living costs (%)			
Low living costs (less than 1000 Yuan)	50.61	50.10	51.03
Middle living costs (1000–2000 Yuan)	42.76	43.05	42.53
High living costs (more than 2000 Yuan)	6.63	6.85	6.44
Hukou status (%)			
Urban *hukou* before enrolled in universities	61.40	62.71	60.34
Rural *hukou* before enrolled in universities	38.60	37.29	39.66
Whether first-year students (%)			
Fist-year students	27.37	26.62	27.98
Sophomore and above	72.63	73.38	72.02
Sleep quality	3.59 (0.88)	3.59 (0.91)	3.58 (0.85)
Depression	5.11 (4.44)	4.86 (4.58)	5.31 (4.32)
Physical activity (hour)	3.44 (4.78)	3.53 (4.93)	3.37 (4.65)
Number of campus	89	87	88
Number of individuals	20,227	9009	11,218

[1] *Hukou* refers to permanent residency rights in a local area, and influences many associated social welfare and government-provided services, including education attainment, medical service, and employment.

[2] It should be noted that first-year students maintain a shorter duration in the campus environment than their counterparts. Additionally, senior students spend more time on campus during vacations for the preparation of graduate examination and job-seeking. Thus, it is necessary to control the disparity of exposure time to the campus environment between different groups.

Table 2 summarizes different aspects of built environmental variables in the 89 campuses. In terms of street connectivity, the average connection was 27.65 per km^2. Logarithm population density was 8.14. The density of bus transit and fast-food restaurants was 7.19 and 35.81 per km^2, respectively. NDVI was expressed in terms of an interquartile increment, and the average NDVI was 0.23, with an inter-quarter range of 0.09.

4.2. Main results

Table 3 demonstrates the association between the built environment and different aspects of adiposity. After adjusting for all other variables, NDVI is negatively associated with the odds of being overweight (OR = 0.920, CI: 0.84, 1.00) and abdominal obesity (OR = 0.881, CI: 0.76, 1.02). Similarly, road connectivity is negatively associated with being overweight (OR = 0.992, CI: 0.98, 1.00), abdominal obesity (OR = 0.989, CI: 0.98, 1.00), and WHtR ≥0.5 (OR = 0.988, CI: 0.98, 1.00). Population density is negatively associated with the odds of being overweight (OR = 0.920, CI: 0.85, 1.00) and WHtR ≥ 0.5 (OR = 0.902, CI: 0.82, 1.00). In addition, students in urban campuses were correlated with the lower odds of being overweight (OR = 1.228, CI: 0.98, 1.53). It should also be noted that there were no significant associations between bus station density, fast food restaurants, and any aspect of adiposity outcomes.

In terms of covariates, individual characteristics played profound roles as expected. Specifically, only male and fist-year students had a higher risk of adiposity in three outcome measures. Urban *hukou* status and sleep quality were positively and significantly correlated with overweight and abdominal obesity. Older students were more likely to become overweight and WHtR ≥ 0.5. Additionally, high cost-of-living was positively correlated with abdominal obesity. Depression and mid cost-of-living were positively associated with being overweight.

4.3. Stratified analysis

Previous studies revealed that the association between built environment and adiposity differed by various socio-demographic subgroups (Frank et al., 2008; Nichani et al., 2020). We then performed several stratified analyses to test the heterogeneous effects of the built environment among different subgroups. Results from stratified analyses for genders are presented in Table 4. Model 4a demonstrated that road connectivity (OR = 0.990, CI: 0.98, 1.00) and NDVI (OR = 0.900, CI: 0.81, 1.00) were negatively associated with the odds of being overweight for male students. Model 5a supported that population density was negatively associated with the odds of waist circumstance for male respondents. Model 6a indicated that population density (OR = 0.877, CI: 0.77, 1.00), road connectivity (OR = 0.984, CI: 0.97, 1.00), and NDVI (OR = 0.853, CI: 0.73, 1.00) were negatively associated with WHtR ≥ 0.5 for male respondents. Conversely, only population density was negatively correlated with being overweight for female students. To summarize, male students were more likely to be affected by built environment characteristics than their female counterparts.

Regarding stratified analyses for socioeconomic status (Table 5), associations between population density (OR = 0.900, CI: 0.81, 1.00), bus station density (OR = 1.018, CI: 0.99, 1.00), and lower odds of being overweight were observed for low cost-of-living groups. Model 8a demonstrated the role of street connectivity in alleviating the probability of abdominal obesity for low cost-of-living groups. Model 9a confirmed the protective effects of high density and NDVI on a high risk of WHtR among low cost-of-living groups. In contrast, only NDVI was negatively correlated with being overweight and WHtR ≥ 0.5 for medium and high cost-of-living groups. In summary, the effects of built environment characteristics on adiposity outcomes vary by different cost-of-living groups.

Table 2
Descriptive statistics of built environment characteristics by campus.

Variable	Mean (SD)
Road connectivity	27.65 (14.19)
Logarithm population density	8.14 (1.49)
Bus transit density	7.19 (7.64)
Fast-food restaurant density	35.81 (29.86)
Variable	**Median (IQR)**
NDVI (0–1)	0.23 (0.09)
Number of campus	89

Table 3
Multi-level regression models: the association between built environment and undergraduate students' adiposity outcomes.

Independent variables	DV: body mass index	DV: waist circumstance	DV: waist-to-height ratio
	Model 1	Model 2	Model 3
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Mid living costs (vs. low)	1.154*** (1.04, 1.28)	1.087 (0.98, 1.21)	0.963 (0.87, 1.06)
High living costs (vs. low)	1.066 (0.87, 1.30)	1.278** (1.06, 1.54)	0.927 (0.76, 1.13)
Drinking	1.082 (0.98, 1.20)	1.060 (0.96, 1.17)	0.998 (0.91, 1.10)
Smoking	1.112 (0.96, 1.30)	1.016 (0.86, 1.19)	0.984 (0.84, 1.16)
Age	1.051*** (1.02, 1.09)	1.039 (1.01, 1.07)	1.052*** (1.02, 1.09)
First-year student (vs. others)	1.297*** (1.14, 1.48)	1.286*** (1.13, 1.46)	1.280*** (1.13, 1.45)
hukou status (vs. rural)	1.389*** (1.25, 1.55)	1.155*** (1.04, 1.28)	1.054 (0.96, 1.16)
Gender (vs. female)	4.765*** (4.24, 5.35)	2.325*** (2.10, 2.58)	1.957*** (1.78, 2.16)
Physical activity	1.015 (0.92, 1.12)	1.002 (0.99, 1.01)	1.005 (1.00, 1.01)
Depression	1.013** (1.00, 1.02)	1.003 (0.99, 1.01)	1.008 (1.00, 1.02)
Sleep quality	1.116*** (1.05, 1.18)	1.072*** (1.02, 1.13)	1.041 (0.99, 1.10)
Population density (Ln)	0.920** (0.85, 1.00)	0.920 (0.83, 1.02)	0.902** (0.82, 1.00)
Fast food restaurant density	0.998 (0.99, 1.00)	1.000 (0.99, 1.00)	1.000 (1.00, 1.00)
Bus transit density	1.005 (0.99, 1.02)	1.006 (0.99, 1.02)	1.005 (0.99, 1.02)
Road connectivity	0.992** (0.98, 1.00)	0.989* (0.98. 1.00)	0.988** (0.98, 1.00)
NDVI	0.920* (0.84, 1.00)	0.881* (0.76, 1.02)	0.928 (0.81, 1.07)
Urban area (vs. suburban area)	1.228* (0.98, 1.53)	0.907 (0.64, 1.29)	0.897 (0.64, 1.25)
Constant	0.016*** (0.01, 0.05)	0.061*** (0.02, 0.23)	0.042*** (0.02, 0.11)
Log Likelihood	−6004.790	−6544.023	−6967.254
AIC	12,047.58	13,126.05	13,972.51
n	20,227		

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

5. Discussion

5.1. Relationship between built environment characteristics and adiposity

After mitigating residential self-selection bias, this study determined that the urban built environment is significantly related to three aspects of adiposity—BMI, WC, and WHtR. These findings confirmed that protective campus-based built environments significantly decrease the probability of adiposity, even for young adults. Moreover, the results of

Table 4
Multi-level regression models: results of heterogeneous effects by gender using stratified analysis.

Gender	DV: body mass index		DV: waist circumstance		DV: waist-to-height ratio	
	Model 4a	Model 4b	Model 5a	Model 5b	Model 6a	Model 6b
	Male OR (95% CI)	Female OR (95% CI)	Male OR (95% CI)	Female OR (95% CI)	Male OR (95% CI)	Female OR (95% CI)
Population density (Ln)	0.941 (0.86, 1.03)	0.890** (0.80, 0.99)	0.882* (0.78, 1.00)	0.971 (0.84, 1.13)	0.877** (0.77, 1.00)	0.959 (0.85, 1.09)
Fast food restaurant density	0.998 (0.99, 1.00)	1.001 (0.99, 1.00)	0.999 (0.99, 1.00)	1.000 (0.99, 1.00)	1.000 (0.99, 1.00)	1.002 (0.99, 1.00)
Bus transit density	1.002 (0.99, 1.01)	1.013 (0.99, 1.03)	1.006 (0.99, 1.02)	1.002 (0.98, 1.02)	1.003 (0.98, 1.02)	1.004 (0.99, 1.02)
Road connectivity	0.990** (0.98, 1.00)	1.002 (0.99, 1.01)	0.984** (0.97, 1.00)	0.995 (0.98, 1.02)	0.984** (0.97, 1.00)	1.012 (0.90, 1.13)
NDVI	0.900** (0.81, 1.00)	0.955 (0.84, 1.08)	0.822*** (0.70, 0.97)	1.012 (0.83, 1.23)	0.853* (0.73, 1.00)	1.032 (0.85, 1.09)
Urban area (vs. suburban area)	1.224 (0.95, 1.57)	1.257 (0.95, 1.67)	0.956 (0.65, 1.40)	0.972 (0.62, 1.53)	0.947 (0.64, 1.40)	0.969 (0.64, 1.47)
Constant	0.014*** (0.01, 0.04)	0.119*** (0.02, 0.73)	0.131*** (0.03, 0.65)	0.068*** (0.01, 0.48)	0.166** (0.03, 0.81)	0.046*** (0.01, 0.20)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	−1898.99	−4082.98	−3735.84	−2786.94	−3761.79	−3189.25
AIC	8217.07	3833.98	7507.67	5609.87	7559.58	7766.68
n	9009	11,218	9009	11,218	9009	11,218

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 5
Multi-level regression models: results of heterogeneous effects by socioeconomic status using stratified analysis.

Socioeconomic status	DV: body mass index		DV: waist circumstance		DV: waist-to-height ratio	
	Model 7a	Model 7b	Model 8a	Model 8b	Model 9a	Model 9b
	Low living cost OR (95% CI)	Medium and high living cost OR (95% CI)	Low living cost OR (95% CI)	Medium and high living cost OR (95% CI)	Low living cost OR (95% CI)	Medium and high living cost OR (95% CI)
Population density (Ln)	0.900** (0.81, 1.00)	0.943 (0.85, 1.04)	0.909 (0.80, 1.04)	0.942 (0.82, 1.08)	0.896* (0.79, 1.01)	0.907 (0.80, 1.03)
Fast food restaurant density	0.998 (0.99, 1.00)	1.000 (0.99, 1.00)	1.000 (0.99, 1.00)	0.999 (0.99, 1.00)	1.002 (0.99, 1.00)	1.000 (0.99, 1.00)
Bus transit density	1.018* (0.99, 1.00)	0.999 (0.99, 1.02)	1.005 (0.98, 1.03)	1.005 (0.99, 1.02)	1.005 (0.98, 1.03)	1.002 (0.98, 1.02)
Road connectivity	0.993 (0.98, 1.00)	0.990 (0.98, 1.00)	0.983** (0.97, 1.00)	0.994 (0.98, 1.00)	0.984** (0.97, 1.00)	0.991 (0.98, 1.00)
NDVI	0.944 (0.84, 1.06)	0.900* (0.81, 1.00)	0.903 (0.76, 1.08)	0.886 (0.81, 1.00)	1.019 (0.86, 1.21)	0.857* (0.73, 1.00)
Urban area (vs. suburban area)	1.208 (0.91, 1.61)	1.264 (0.98, 1.64)	0.956 (0.63, 1.45)	0.877 (0.60, 1.29)	0.855 (0.57, 1.28)	0.938 (0.65, 1.36)
Constant	0.011*** (0.01, 0.15)	0.021*** (0.01, 0.09)	0.034*** (0.01, 0.11)	0.057*** (0.01, 0.32)	0.055 (0.01, 0.26)	0.126 (0.02, 0.67)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	−2878.41	−3248.94	−3248.94	−3303.46	−3641.59	−3328.04
AIC	5790.81	6531.88	6531.88	6640.93	7317.17	6690.09
n	10,239	9988	10,239	9988	10,239	9988

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

this study further challenged the claims that the built environment's significant influence on adiposity is due to self-selection (Zick et al., 2013).

The findings of this study revealed that street connectivity and urban greenery are associated with being overweight among undergraduate students, which is supported by prior studies (Jia et al., 2019; Sarkar, 2017). We also determined that increased population density can reduce the propensity of being overweight and WHtR ≥ 0.5 (Nichani et al., 2020). It should be noted that the effects of population density contradict several recent findings in China (Sun & Yin, 2018; Xu et al., 2010). These divergent results may be attributed to the unique characteristics of undergraduate students and the campus environment. As students are not allowed to use cars on campus, they rely on active travel and public transport (Zhan et al., 2016). Thus, the dense urban environment may encourage more active travel, and further decrease the odds of being obese (Lopez, 2007; Rundle et al., 2007). Another plausible explanation is that previous results were confounded by residential self-selection bias. People with adiposity tend to live in higher density environments, which provide them with convenient and accessible facilities (Sallis et al., 2009). Therefore, the observed positive associations between urban density and extra body weight in other studies may be confounded by individuals' preferences for the living environment, rather than a causal effect of urban density on adiposity. Hence, more research evidence from studies addressing residential self-selection bias is needed to further inform policy-making.

Additionally, several recent studies from Western settings adopted multiple adiposity indicators and associated them with built environment factors (Nichani et al., 2020; Sarkar, 2017). They emphasized that built environment attributes were significant in explaining adiposity outcomes, while the strength and significance were not identical for different adiposity outcomes. Consistent with previous findings, we observed the divergent effect of the built environment on different adiposity outcomes; waist circumstance was more likely to be influenced by the surrounding built environment. It was plausible that height, one component of BMI and WHtR, was less likely to be influenced by built characteristics (McCormack et al., 2018). Thus, these results represented weaker explanatory power than WC. In the future, the mechanism between environment and different adiposity outcomes should be further investigated.

5.2. The influence of individual factors

It is noteworthy that undergraduate students' individual characteristics are significant in predicting adiposity outcomes. Specifically, students with a medium or high cost-of-living have increased odds of adiposity as compared to students with a low cost-of-living. They have more food choices and sedentary opportunities (i.e., using a taxi for commuting and digital products for sedentary activity) available to them (Yang et al., 2017). Students with urban residence status (*hukou*) before enrollment into universities are more likely to gain adiposity, possibly because they experience more sedentary time and calorie intake prior to enrollment in universities (Chen et al., 2011). Interestingly, fist-year students tend to be more obese. During the year prior to enrollment into universities, these students are more likely to maintain a sedentary lifestyle as they prepare for the national college entrance examination. In addition, the recreational and exercise facilities provided on university campuses and the active lifestyles maintained by undergraduates help senior students attain a healthier body weight.

Moreover, we confirmed that the relationship between the built environment and extra body weight was more pronounced for male and low socioeconomic students. It is plausible that the environment–adiposity association varies due to several individual factors, such as life stage, gender, lifestyle, and body composition (Sriram et al., 2016). In terms of undergraduate students, female students may pay more attention to their body weight, which could reduce the impact of campus environmental constraints. Furthermore, some prior studies revealed that the low socioeconomic group was more vulnerable to the impact of the built environment (Frank et al., 2007; Sarkar, 2017). This study verified that socioeconomic modification exists even for young adults. Students with a high cost-of-living may have much larger activity spaces and visit other parts of a city more frequently in their leisure time (i.e., visit a shopping mall in city center), as compared to those with a low cost-of-living. Therefore, the campus environment had a smaller effect on students with a high cost-of-living. Consequently, we should be prudent in generalizing the influence of the built environment on adiposity of undergraduate students with different characteristics.

5.3. Implications for urban design and planning

To curb the growing trend of undergraduate students' adiposity, this study indicated some important planning and public health implications, not only for China but also for other fast-growing developing countries. First, our results confirm the importance of walkable and green environment to reduce adiposity, which is consistent with those findings in developed countries (Ding & Gebel, 2012). Therefore, when creating new campuses or improving already existing ones, campus managers and designers should increase walkability and greenery to stimulate students' active travel and other outdoor activities. Second, the campus environment has a greater influence on some subgroups, especially, males and low socioeconomic students. Campus administrators should disseminate and pay special attention to healthy lifestyles of university students. Third, as students are frequently exposed to surrounding urban areas, and density of campuses are high, planners are obliged to make integrated planning between universities and nearby areas. For instance, facilities and street networks should be planned as a whole. Fourth, the association between urban density and different dimensions of adiposity are complex, and the results may vary based upon different research designs, regions, or even subgroups (Yin et al., 2020). Urban planners should be cautious about its effect on preventing adiposity in different contexts.

5.4. Strengths and limitations

This study has three major strengths. First, it is one of the first studies to disentangle residential self-selection bias from the effects of the built environment on adiposity outcomes in China with a large representative sample size. Second, we have adopted three objective adiposity measures, which can reduce the errors associated with using BMI as the sole outcome or that of using self-reported data. Third, we verified that gender and socioeconomic status can modify the built environment–adiposity relationships among undergraduate students in China.

The following limitations of this study should be noted. First, our findings are based on cross-sectional analysis, and only show associations rather than causal relationships. Studies based on longitudinal survey data or panel data are needed to identify causal relationships. Second, first-year students may not live in the campus environment long enough. Hence, this environment still has a limited impact on their adiposity outcomes. Our results also indicate that being a first-year student or not demonstrates a significant disparity in terms of adiposity outcomes. Third, the actual exposure to the campus environment was not accurately measured, as different students may be exposed to different parts of a campus for variable durations. Future studies may measure fine-grained spatial-temporal exposure to the campus environment with innovative tools, such as portable GPS. Fourth, the mediating mechanisms between the built environment and adiposity were not explored. Future studies may examine, for example, how sedentary lifestyles, stress, or physical activities mediate the environment–adiposity relationship. Fifth, although the campus environment is important in shaping adiposity outcomes, during breaks many students might reside away from the campuses (i.e., stay with their parents in their hometown). Further research should control student exposure to residential locations during vacations.

6. Conclusion

Based on a large representative sample of 20,227 undergraduate students in China, this study helps us understand the influence of the built environment on young adults' adiposity outcomes. Our findings indicated that after mitigating the influence of residential self-selection bias, campus characteristics (i.e., density, street connectivity, and NDVI) were associated with BMI, WC, and WHtR to different extents. Apart from that, we found stronger associations between the built environment and extra body fat for male and low cost-of-living students. Hence, to implement effective environment interventions to curb the prevalence of adiposity, policymakers are advised to create more urban greenspaces and walkable campus environments for undergraduate students.

Ethnic approval

First Affiliated Hospital of Kunming Medical University: 2018-L-25.

CRediT authorship contribution statement

Haoran Yang: Conceptualization, Methodology, Supervision, Writing - review & editing. Dongsheng He: Conceptualization, Methodology, Analysis, Original draft. Yi Lu: Methodology, Supervision, Writing - review & editing. Chao Ren: Review & editing. Xu Huang: Review & editing. All authors read, contributed to, and approved the manuscript.

Declaration of competing interest

None.

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