The Association Between Living Environmental Factors and Adolescents’ Body Weight

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Research article

Keywords: Excessive body weight, Living Environmental Factors, Adolescents

DOI: https://doi.org/10.21203/rs.3.rs-89301/v1

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Abstract

Background

The effect of living environment on public health has received increasingly scholarly attention. This study aims to explore the relationship between adolescents' body weight and their living environmental factors.

Methods

This cross-sectional study comprised 1362 middle-school students from Nanjing and 826 from Changzhou in China. We further collected information on living environmental factors based on their home address and ran a univariate logistic analysis for each variable to explore potential correlations.

Results

Approximately 25% (n=303) of students from Nanjing and 26% (n=205) of students from Changzhou were excessively overweight. In Nanjing, students’ BMI (Body Mass Index) showed a strong negative correlation with the number of sports venues in their neighbourhood (OR: 0.61, 95%CI: 0.40-0.94). In Changzhou, we observed a positive correlation between adolescents’ body weight and the number of bus stops in their neighbourhood (OR:1.53, 95%CI:1.06-2.21).

Conclusions

The living environment factors were independently associated with teenagers’ excessive body weight, and the environmental risk factors might be associated with political management. Public policies change students’ living environments, finally affecting individual behaviours and health outcomes.

Introduction

With the recent global urbanization and the continuing industrial development, the number of obese children has demonstrated a ten-fold increase from approximately 11 million in 1975 to 124 million in 2016, with additional 216 million overweight individuals around the world.\(^1\) Regretfully, over the recent three decades, little progress has been achieved in treating or preventing the excessive body weight.\(^2\) It is reported that in China, the prevalence of childhood obesity increased from 0.5% in 1985 to 7.3% in 2014, with a rising prevalence of overweight from 2.1% to 12.2%.\(^3\) It is therefore obligatory for scholars to rethink the strategies for obesity and overweight prevention and treatment.

According to previous statistical analysis, overweight and obese individuals were divided into different groups, leading to underestimating the sever of the overweight issues.\(^4\) Policymakers and doctors just paid attention to the severe obesity patients, ignoring health-care costs incurred by overweight group. There were only a few overweight patients to link their terrible physiological situations with their excessive BMI.\(^4\) Overweight students and their parents, to some extent, did not realize that excessive body weight related to multiple adverse health outcomes, including an elevated risk of developing type 2
diabetes, cardiovascular diseases, and other physical and mental illnesses.\textsuperscript{5, 6} The economic burden of overweight and obesity has also reached at US$2 trillion, matching that of smoking and all military conflict.\textsuperscript{7} Therefore, the whole range of excessive BMIs should be considered, as opposed to simply concentrating on the obesity group.

Considering that the individual genetic and lifestyle factors attribute in part to the global increase in the prevalence of obesity and overweight in recent years, the multifactorial nature of overweight has attracted much attention to researching on\textsuperscript{8, 9} modifiable environmental characteristics. Living environmental factors influence students' life behaviours and affect their energy intake and consumption, leading to different health outcomes. It is reported that an increased number of fitness facilities were associated with a reduction in teenagers' body weight, which provided more opportunities to access to recreational facilities to increase their daily exercise.\textsuperscript{10, 11} Pineda E emphasized the distance to the nearest fast-food restaurant elevated the risk of overweight and obesity, especially in low-family-income students.\textsuperscript{12} A straightforward hypothesis is that the environmental characteristics, including the presence of cycle paths, sidewalks, active public transportation\textsuperscript{13}, green spaces, and the degree of urbanization, are related to childhood body weight. In particular, access to open green spaces led to increased physical activities as well as decreased screen time which would perhaps explain the reduced risk of students' excessive BMI.\textsuperscript{14-16}

Although the significant relationship between the environmental factors and adolescents’ excessive body weight has been well addressed by the current research, there are still several essential aspects that have not been scrutinized, such as parents’ attitudes towards students doing outdoor activities and influence from large scale municipal works projects. The majority of studies on the relationship between the built environment and childhood excessive body weight, in addition, were mainly conducted in developed countries.\textsuperscript{17} It was worthy to note that China, a nation with a highly authoritative government, has equipped with the fast-growing food delivery industry, the prosperity of sports marketing, full capacity running transportation system; this has resulted in different opportunities to access to health food or changing citizens’ life behaviours.\textsuperscript{17, 18} However, to date, there has been little research systematically assessing the relationship between living environmental factors and childhood body weight in China, which is valuable for future environment design and city planning to reverse the tide of childhood excessive body weight.

In light of the foregoing, this study, focusing on the whole excessive body weight children, examines the living environmental factors in an urban Chinese context and evaluates how these living environmental factors relate to the risk of childhood excessive BMI. Findings may potentially contribute to the body of knowledge and inform the development of multi-sectoral intervention strategies.

**Methods**

Study design and participants
We conducted this population-based study in Nanjing and Changzhou, with a combined population of more than 1.5 million residents aged under 15 years old. These two cities have a similar economic and cultural background, but Nanjing has a larger population and more prosperous built environment setting compared with Changzhou. Therefore, we ran a parallel analysis for each city respectively.

The cross-sectional survey was conducted in all districts in Changzhou and 9 districts in Nanjing. We randomly selected one junior high school from each district, then chose three classes from each school, and one class for each grade (i.e., Year 7-9). We excluded residential students who lived in the school dormitories and those participants without any information on commuting to school, yielding a sample size of 1911 students from Nanjing and 1244 from Changzhou. We further excluded participants who did not provide complete data on home address, weight, and height. The final study population comprised 1362 students from Nanjing and 826 from Changzhou.

Ethics

Before we conducted this survey, the written consent from participants and their parents were already obtained. Moreover, all information regarding the participants and their families remained confidential. The data were collected from June to October in 2018, and this study was approved by China Institute of Sports Science ethics committee (Ethical code: CISSIRD-201604).

Study outcome

We categorized Body Mass Index (BMI) of the study participants into normal weight group and excessive body weight group (combined overweight and obesity) according to the latest State Students Health Standards. We excluded a total of 182 underweight students (127 from Nanjing, 55 from Changzhou) from the analysis. We ran sensitivity analysis and did not find material change.

Study factors

In order to explore the impact of the domestic living environment on childhood excessive body weight, we used the Geography Information System (ArcGIS 9.1) to calculate the number of bus stops, scenic spots, sports venues, food spots, and recreational areas in 500 meters distance from their home address. In this research, beside bus stops, we defined another four aspects in advance, food spots including restaurants, cafeteria, bubble tea stores, coffee shops, and street food spots; scenic spots covering parks, historical place, and ancient temple; sports venues including sports facilities centre, public sports playgrounds, fitness trail, and stadium; recreation areas covering shopping centers, zoos, museums, carnie, and aquaria. We further categorized the number of bus stops as over 20 or not, scenic sites as over 3 or not, and the availability of sports venues and recreational areas as yes or no.

We also collected the controlling factors to modify the results, such as age, gender, daily physical activities, intake frequency of sweetened food and sugar beverage drink, parental BMI, parental smoking
history, overall satisfaction with living environments, fitness time of parents themselves, family economic status, and so on, which might affect teenagers’ body weight.

Statistical Analysis

We employed Stata 14.0 for all data analysis. The number and proportion of variables of interest among the sampled population were calculated. We conducted multiple imputation for missing values before running a univariate logistic analysis for each environmental variable and the outcome to explore the strength of the association. Environmental variables of the p-value of less than 0.25 for the crude odds ratio (OR) were modelled with multivariate logistic regression for each city respectively, in order to control for other covariates. Priori confounders included age, sex and other sociodemographic variables. We used the likelihood ratio test to test if the difference between the full model and the reduced model was statistically significant. We also used mixed-effect logistic models for each city for sensitivity analysis to examine if regional (district-level) variabilities would contribute to the childhood overweight. We observed little clustering effects with negligible intraclass coefficients. We considered a p-value of 0.05 as statistically significant.

Results

Excessive body weight was more prevalent in males than females (31% vs 18% in Nanjing, 31% vs 20% in Changzhou) (Tables 1 and 2). The prevalence of excessive body weight increased with the frequency of consuming barbeque food among Nanjing students (Table 1), which was not observed among Changzhou students (Table 2).

Study Site 1: Nanjing

More students had parents with normal BMI range, less parental encouragement for exercise (51.4% n=635), a father with smoking history (61.1%, n=754), and were satisfied with their living environment (78.6%, n=971 among students; 75.3%, n=930 among their parents). Students lived in a residential address with over 20 bus stops (90.6%, n=1119), over 3 scenic sites (75%, n=926), with any sport venues (88.4%, n=1092) and any recreational areas (91.6%, n=1131) within 500-meter distance, accounted for a large majority of the study population. The median number of food outlets was 207 with a range from 0 to 2179.

Compared with students residing in a place without any sport venues, those who having access to sport venues near their residential places are less likely to gain excessive body weight (OR: 0.61, 95%CI: 0.40-0.94, p=0.027), after controlling for other factors (Table 3). In addition to the sport venues, male students (OR: 2.01, 95%CI: 1.49-2.71, p<0.0001), those having an excessive BMI parent (OR: 1.87, 95%CI: 1.38-2.52, p<0.0001 for father; OR: 1.78, 95%CI: 1.20-2.62, p=0.004 for mother), from lower socioeconomic background (OR: 0.70, 95%CI: 0.52-0.94, p=0.017), having higher frequency of barbeque food consumption (OR: 1.18, 95%CI: 1.01-1.38, p=0.037), and having medium strength activity of longer than 30 minutes (OR: 1.40, 95%CI:1.04-1.90, p=0.025) were more likely to gain excessive body weight.
Study Site 2: Changzhou

In contrast, more students had parents with normal BMI range, less parental encouragement for exercise (54.2% n=432), fathers without smoking history (55.3%, n=322), and were satisfied with their living environment (91.3%, n=728 for students themselves; 81.6%, n=650 for their parents). Students lived in a residential address with over 20 bus stops (70.3%, n=560) and over 3 scenic sites (93.4%, n=744) accounted for the majority of the study population. Only six students resided in a place without any recreational areas. The median number of food outlets was 362 with a range from 22 to 1069.

Univariate analysis identified that those were males, either having an excessive BMI parent or residing in a place with over 20 bus stops within 500-meter distance, were positively associated with being excessive body weight (p<0.05) (Table 2). The effects of these factors remained after controlling for other covariates (Table 4). Using multilevel mixed-effect models, we did not observe statistically significant regional variations at district levels (interclass correlation< 0.01, p>0.05).

Discussion

In this geographically diverse sampling of adolescents from the junior high schools, our results illustrated consistent evidence that residential environment factors were independently correlated with overweight. It was interesting to note that the level of transportation systems had an impact on Changzhou students, and the availability of sports venues on Nanjing students, which was in line with the development of city policies and guidelines in recent years. Nanjing was the host city for the 2nd Summer Youth Olympic Game in 2014, and the local administrations were dedicated to developing the best global sports and entertainment venues as well as enhance the sports culture. After the Game, its heritage was transferred for public activities and the culture prevailed. According to the 2016 government report, additional efforts would be invested to mend fitness trails to grow from 420 kilometers to 863 kilometers, provide 691 playgrounds, and establish 341 sports facilities during the period from 2017 to 2035. Lacking comparable sports venues and culture, Changzhou is famous for its well-organized public transportation system with low bus fare, expanding public transportation network, and high daily passenger capacity. However, our findings were contrary to the previous results that more numbers of bus stops would lead to a high prevalence of childhood excessive body weight. The convenient public transportation system did not show a positive impact on individuals’ traveling habits. However, it is beyond the capacity of this brief research to fully contextualize this complex issue and further qualitative research is needed to explore the hidden reasons for this weird phenomenon.

Mendenhall argued that macro-level political elements would influence chronic diseases on their clustering at the population level and consequently would affect syndrome pathologies at the individual level. This implies that decisive policies are able to reverse the upwards trend of overweight or obesity by modifying civil planning and access to facilities, especially for vulnerable younger children with constrained resources. The young adolescents’ excessive body weight not only relates to simply eating and exercising habits, but also encompasses important aspects of social and environmental situations,
which might exacerbate their health outcomes and inequity.\textsuperscript{25, 26} Facing with limited access to resources due in part to family financial burden and personal study load, provision of free sports facilities, ideally near residential neighbourhood, might be effective to offer extra opportunities for adolescents to attain the unstructured exercise during their off-school time.\textsuperscript{27} Additional exercise is necessary to finally make up the time of daily active exercise to catch up with the recommended levels of physical activities, which is currently not met in school-aged adolescents by large.\textsuperscript{28}

It was worthy to notice that the Changzhou subway project was conducted from April 2015, and line 1 was finished in Sep 2019, the completion of line 2 will be at the beginning of 2021. In the former investments, researchers indicated the subway construction process was the “predawn darkness” for traffic system, and the long period of metro construction would bring numerous environmental and social issues for this city.\textsuperscript{29} Usually, subways lines have coincided with the urban traffic-intensive hubs. It was inevitable that construction enclosure occupied the parts of crossroad and motorway, and damaged some traffic lights, decreasing the surrounding safety.\textsuperscript{30} Subway construction posed a huge extra burden on surface transportation, causing traffic congestion. Chaos traffic surroundings set barriers for citizens to access to public transportation, which might influence their health behaviors towards more active lifestyles, with the implication of more likely to be excessive body weight.\textsuperscript{30} Based on local government 2018 reports, the car ownership per capita of Nanjing and Changzhou was almost the same, 0.25 and 0.24 per capita respectively.\textsuperscript{31} It was also noteworthy the nearly perfect public transportation system did not create the walkability of residential surroundings and decrease personal car-dependence.

In addition to the built environment factors, other factors, including parental excessive BMI, family income, being male, and barbeque food consumption, were found associated with young adolescents’ excessive body weight, which were consistent with previous findings.\textsuperscript{12, 32-34} For example, genetic factors influenced fat distribution as well as daily energy expenditure, energy intake, and habitual physical activities.\textsuperscript{12} It is also speculated that families with higher incomes could have more access to healthy food and live healthier lifestyles.\textsuperscript{35} However, the lack of comparable exposure data limited our ability to confirm such relationships. Other limitations include the lack of crime data (for the security reason, we did not gain the data from police departments) in relation to young adolescents’ residential areas, we were not able to explore whether satisfaction with neighbourhood safety would impact on young adolescents’ physical activities.\textsuperscript{36} Moreover, the nature of cross-sectional data limits the causal-effect inference, and therefore results should be interpreted with caution. Further qualitative researches are needed to explore the motivations and hidden reasons for personal behaviours.

Excessive body weight in school-aged children in China remains a public health issue. Further efforts to reduce the childhood excessive body weight are warranted.\textsuperscript{37} Future studies using trial data or investigation of individual and parental beliefs and behaviours can further explore the role of environmental factors and the effects of local policies in particular availability of sports venues and access to the public transportation network in relation to childhood excessive body weight.
Conclusion

In conclusion, this study indicates that the living environment factors were independently associated with excessive body weight. The findings among students from Nanjing and Changzhou varied due to different local policies. Therefore, we hypothesis that, to some extent, the environmental risk factors, e.g. numbers of bus stations and sports venues, might be associated with political management, which will finally affect individual behaviours and personal health outcomes. Given the fact that teenagers’ excessive body weight is still a significant health concern, further researches and proactive measures are required to attenuate the problem.

Abbreviations

Not applicable

Declarations

Acknowledgements

The data collecting tasks received support from Changzhou and Nanjing education departments and local secondary schools. All authors made contributions to each part of the project, participated in project designing, helped to analyze the data, and guided me to modify the final essay.

Funding

This project was mainly funded by China Institute of Sports Science, numbers: Basic Research Funds 17-44,18-27,19-04.

Availability of data and material

Datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by China Institute of Sports Science ethics committee, Ethical code: CISSIRD-201604. Before we conducted this survey, the written consent from participants and their parents were already obtained. Moreover, all information regarding the participants and their families remained confidential.

Competing interests

No competing financial interests exist.

Consent for publication
This manuscript is approved by all authors for publication

Authors’ contributions

All authors provided critical input and approved the final version. Wei Du, Siyi Huang and Hanwen Zhang were responsible for the study design and data collecting. Sasa conducted data analysis and interpretation. Siyi Huang and Xinyi Wu finished the literature review aspects. Based on the suggestion from Wei Du, Siyi Huang, Sasa and Xinyi Wu wrote the first draft of this manuscript. Chongmin Jiang, Yan Zhao, and Jie Yang provided the critical revision of the manuscript for important intellectual content.

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Tables

Table 1. Study population characteristics, by Body Mass Index – normal vs overweight, Nanjing
| Variables | Normal | Overweight | Total | Crude OR [95%CI] | P |
|-----------|--------|------------|-------|-----------------|---|
| BMI       | No. (%) | No. (%)    | No. (%) |                 |   |
| Age       | No. (%) | No. (%)    | No. (%) |                 |   |
| ≤12       | 232 (77) | 69 (23)    | 301 (24.4) | 1.28 [0.9,1.8] | 0.15 |
| 13        | 333 (72) | 127 (28)   | 460 (37.2) | 0.91 [0.6,1.3] | 0.63 |
| 14        | 244 (79) | 66 (21)    | 310 (25.1) | 1.12 [0.7,1.7] | 0.62 |
| ≥15       | 123 (75) | 41 (25)    | 164 (13.3) |                 |   |
| Sex       | No. (%) | No. (%)    | No. (%) |                 |   |
| Female    | 514 (82) | 113 (18)   | 627 (50.8) |                 |   |
| Male      | 418 (69) | 190 (31)   | 608 (49.2) | 2.07 [1.6,2.7] | <0.0001 |
| Dietary and Exercise factors | | | | |
| Medium strength activity | | | | |
| ≤30 min/d | 600 (78) | 172 (22)   | 772 (62.5) |                 |   |
| > 30 min/d | 332 (72) | 131 (28)   | 463 (37.5) | 1.38 [1.1,1.8] | 0.018 |
| Sweeten food | | | | |
| never     | 232 (75) | 76 (25)    | 308 (24.9) | 1.02 [0.9,1.1] | 0.72 |
| 1-2 times/month | 278 (77) | 83 (23)    | 361 (29.2) | | |
| 1-2 times/week | 250 (74) | 89 (26)    | 339 (27.4) | | |
| 2-3 times/week | 114 (75) | 39 (25)    | 153 (12.4) | | |
| every day  | 36 (77)  | 11 (23)    | 47 (3.8)   | | |
| unknown    | 22 (81)  | 5 (19)     | 27 (2.2)   | | |
| BBQ        |  | | | 1.19 [1,1.4] | 0.012 |
| never     | 389 (78) | 109 (22)   | 498 (40.3) | | |
| 1-2 times/month | 358 (75) | 117 (25)   | 475 (38.5) | | |
| 1-2 times/week | 106 (71) | 43 (29)    | 149 (12.1) | | |
| 2-3 times/week | 46 (70)  | 20 (30)    | 66 (5.3)   | | |
| every day  | 10 (59)  | 7 (41)     | 17 (1.4)   | | |
| unknown    | 23 (77)  | 7 (23)     | 30 (2.4)   | | |
| Snacks              | 0.98 [0.9, 1.1] | 0.77 |
|---------------------|-----------------|------|
| never               | 188 (73)        | 68 (27) | 256 (20.7) |
| 1-2 times/month     | 213 (76)        | 66 (24) | 279 (22.6) |
| 1-2 times/week      | 256 (77)        | 78 (23) | 334 (27) |
| 2-3 times/week      | 148 (75)        | 50 (25) | 198 (16) |
| every day           | 96 (75)         | 32 (25) | 128 (10.4) |
| unknown             | 31 (78)         | 9 (23)  | 40 (3.2)  |

**Family factors**

| Economic status    | 0.76 [0.6, 1] | 0.03 |
|--------------------|---------------|------|
| lower              | 409 (73)      | 148 (27) | 557 (45.1) |
| medium             | 407 (78)      | 117 (22) | 524 (42.4) |
| higher             | 33 (87)       | 5 (13)  | 38 (3.1)  |
| unknown            | 83 (72)       | 33 (28) | 116 (9.4) |

| Father's BMI       |               |      |      |
|--------------------|---------------|------|------|
| normal             | 517 (80)      | 131 (20) | 648 (52.5) | __    |
| overweight         | 271 (68)      | 126 (32) | 397 (32.1) | 1.83 [1.4, 2.4] | <0.0001 |
| underweight        | 31 (79)       | 8 (21)  | 39 (3.2)  | 1.02 [0.5, 2.3] | 0.96   |
| unknown            | 113 (75)      | 38 (25) | 151 (12.2) | 1.33 [0.9, 2] | 0.181  |

| Mother's BMI       |               |      |      |
|--------------------|---------------|------|------|
| normal             | 643 (77)      | 187 (23) | 830 (67.2) | __    |
| overweight         | 98 (64)       | 55 (36)  | 153 (12.4) | 1.93 [1.3, 2.8] | <0.0001 |
| underweight        | 84 (82)       | 19 (18)  | 103 (8.3)  | 0.78 [0.5, 1.3] | 0.35   |
| unknown            | 107 (72)      | 42 (28)  | 149 (12.1) | 1.35 [0.9, 2] | 0.13   |

| Parents' encouragement for exercise |               |      |      |
|------------------------------------|---------------|------|------|
| less encourage                     | 473 (74)      | 162 (26) | 635 (51.4) | __    |
| more encourage                     | 401 (77)      | 120 (23) | 521 (42.2) | 0.88 [0.7, 1.2] | 0.38   |
| unknown                            | 58 (73)       | 21 (27)  | 79 (6.4)   |      |

| Father fitness time               |               |      |      |
|-----------------------------------|---------------|------|------|
| Less                              | 469 (76)      | 145 (24) | 614 (49.7) | __    |
| more | 273 (75) | 90 (25) | 363 (29.4) | 1.02 [0.8,1.4] | 0.92 |
| unknown | 190 (74) | 68 (26) | 258 (20.9) | | |

**Mother fitness time**

| less | 459 (76) | 146 (24) | 605 (49) | | |
| more | 391 (75) | 133 (25) | 524 (42.4) | 1.05 [0.8,1.4] | 0.74 |
| unknown | 82 (77) | 24 (23) | 106 (8.6) | | |

**Father smoking**

| no | 346 (80) | 87 (20) | 433 (35.1) | | |
| yes | 552 (73) | 202 (27) | 754 (61.1) | **1.46 [1.1,1.9]** | **0.01** |
| unknown | 34 (71) | 14 (29) | 48 (3.9) | 1.64 [0.8,3.2] | 0.15 |

**Mother smoking**

| no | 858 (76) | 270 (24) | 1128 (91.3) | | |
| yes | 8 (67) | 4 (33) | 12 (1) | 1.59 [0.5,5.3] | 0.45 |
| unknown | 66 (69) | 29 (31) | 95 (7.7) | 1.4 [0.9,2.2] | 0.15 |

*Environmental factors*

**Bus stops**

| ≤20 | 88 (76) | 28 (24) | 116 (9.4) | | |
| >20 | 844 (75) | 275 (25) | 1119 (90.6) | 0.98 [0.6,1.5] | 0.92 |

**Scenic sites**

| 0-3 | 236 (76) | 73 (24) | 309 (25) | | |
| >3 | 696 (75) | 230 (25) | 926 (75) | 1.07 [0.8,1.4] | 0.67 |

**Sport venues**

| no | 97 (68) | 46 (32) | 143 (11.6) | | |
| yes | 835 (76) | 257 (24) | 1092 (88.4) | **0.65 [0.4,0.9]** | **0.025** |

**Recreational areas**

| no | 84 (81) | 20 (19) | 104 (8.4) | | |
| yes | 848 (75) | 283 (25) | 1131 (91.6) | 1.4 [0.8,2.3] | 0.19 |

**Food spots (median)**

| 198 [0,2087] | 216 [0,2179] | 207 [0,2179] | 1 [1,1] | 0.27 |
### Satisfaction towards living environment

|                | Less Satisfied | More Satisfied | Unknown | Total |
|----------------|----------------|----------------|---------|-------|
| Less satisfied | 165 (73)       | 226 (18.3)     | 25 (27) | 212 (18) |
| More satisfied | 740 (76)       | 971 (78.6)     | 231 (24) | 1542 (130) |
| Unknown        | 27 (71)        | 38 (3.1)       | 11 (29) | 48 (4) |

Parents' satisfaction towards living environment

|                | Less Satisfied | More Satisfied | Unknown | Total |
|----------------|----------------|----------------|---------|-------|
| Less satisfied | 159 (75)       | 213 (17.2)     | 54 (25) | 426 (36) |
| More satisfied | 710 (76)       | 930 (75.3)     | 220 (24) | 1860 (158) |
| Unknown        | 63 (68)        | 92 (7.4)       | 29 (32) | 92 (7.4) |

**Table 2. Study population characteristics, by Body Mass Index – normal vs overweight, Changzhou**
| Variables | Normal | Overweight | Total | Crude OR [95%CI] | P |
|-----------|--------|------------|-------|------------------|---|
| Age       |        |            |       |                  |   |
| ≤ 13      | 139 (74) | 49 (26)  | 188 (23.6) | __ |   |
| 14        | 420 (74) | 146 (26) | 566 (71) | 0.99 [0.7,1.4] | 0.94 |
| 15        | 33 (77)  | 10 (23)   | 43 (5.4)  | 0.86 [0.4,1.9] | 0.70 |
| Sex       |        |            |       |                  |   |
| Female    | 326 (80) | 84 (20)   | 410 (51.4) | __ |   |
| Male      | 266 (69) | 121 (31)  | 387 (48.6) | 1.77 [1.3,2.4] | 0.001 |

**Dietary and Exercise factors**

Medium strength activity

| ≤ 30 min/d | 185 (75) | 62 (25) | 247 (31) | __ |   |
| > 30 min/d | 407 (74) | 143 (26) | 550 (69) | 1.05 [0.7,1.5] | 0.79 |

Sweeten food

| never      | 172 (75) | 57 (25) | 229 (28.7) |   | 1.03 [0.9,1.2] | 0.65 |
| 1-2 times/month | 165 (77) | 49 (23) | 214 (26.9) |   |   |   |
| 1-2 times/week | 147 (68) | 68 (32) | 215 (27) |   |   |   |
| 2-3 times/week | 68 (83) | 14 (17) | 82 (10.3) |   |   |   |
| every day    | 18 (69)  | 8 (31)  | 26 (3.3)  |   |   |   |
| unknown      | 22 (71)  | 9 (29)  | 31 (3.9)  |   |   |   |

BBQ

| never      | 264 (78) | 76 (22) | 340 (42.7) |   | 1.1 [0.9,1.3] | 0.3 |
| 1-2 times/month | 205 (71) | 85 (29) | 290 (36.4) |   |   |   |
| 1-2 times/week | 69 (73)  | 26 (27) | 95 (11.9)  |   |   |   |
| 2-3 times/week | 27 (82)  | 6 (18)  | 33 (4.1)   |   |   |   |
| every day    | 4 (57)   | 3 (43)  | 7 (0.9)    |   |   |   |
| unknown | 23 (72) | 9 (28) | 32 (4) |
| Snacks | | | |
| never | 154 (73) | 57 (27) | 211 (26.5) |
| 1-2 times/month | 144 (74) | 51 (26) | 195 (24.5) |
| 1-2 times/week | 154 (77) | 45 (23) | 199 (25) |
| 2-3 times/week | 77 (72) | 30 (28) | 107 (13.4) |
| every day | 41 (76) | 13 (24) | 54 (6.8) |
| unknown | 22 (71) | 9 (29) | 31 (3.9) |

**Family factors**

| Economic status | 0.89 [0.7,1.2] | 0.44 |
| lower | 199 (73) | 75 (27) | 274 (34.4) |
| medium | 260 (75) | 85 (25) | 345 (43.3) |
| higher | 30 (79) | 8 (21) | 38 (4.8) |
| unknown | 103 (74) | 37 (26) | 140 (17.6) |

**Father's BMI**

| normal | 315 (78) | 87 (22) | 402 (50.4) | _ |
| overweight | 193 (67) | 93 (33) | 286 (35.9) | 1.74 [1.2,2.5] | 0.001 |
| underweight | 21 (88) | 3 (13) | 24 (3) | 0.52 [0.2,1.8] | 0.30 |
| unknown | 63 (74) | 22 (26) | 85 (10.7) | 1.26 [0.7,2.2] | 0.40 |

**Mother's BMI**

| normal | 418 (79) | 110 (21) | 528 (66.2) | _ |
| overweight | 60 (53) | 54 (47) | 114 (14.3) | 3.42 [2.2,5.2] | <0.0001 |
| underweight | 63 (79) | 17 (21) | 80 (10) | 1.03 [0.6,1.8] | 0.932 |
| unknown | 51 (68) | 24 (32) | 75 (9.4) | 1.79 [1.1,3] | 0.031 |

**Parents' encouragement for exercise**

| less encourage | 324 (75) | 108 (25) | 432 (54.2) | _ |
| more encourage | 200 (72) | 76 (28) | 276 (34.6) | 1.1 [0.8,1.6] | 0.57 |
| unknown | 68 (76) | 21 (24) | 89 (11.2) |
|                        | less | more | unknown |
|------------------------|------|------|---------|
| **Father fitness time**|      |      |         |
| less                   | 286  | 102  | 388     |
| more                   | 265  | 91   | 356     |
| unknown                | 41   | 12   | 53      |
| **Mother fitness time**|      |      |         |
| less                   | 306  | 110  | 416     |
| more                   | 235  | 75   | 310     |
| unknown                | 51   | 20   | 71      |
| **Father's history of smoking** |      |      |         |
| no                     | 240  | 82   | 322     |
| yes                    | 325  | 116  | 441     |
| unknown                | 27   | 7    | 34      |
| **Mother's history of smoking** |      |      |         |
| no                     | 563  | 193  | 756     |
| yes                    | 6    | 0    | 6       |
| unknown                | 23   | 12   | 35      |

**Environmental factors**

|                      |      |      |         |
|----------------------|------|------|---------|
| **Bus stops**        |      |      |         |
| ≤ 20                 | 189  | 48   | 237     |
| >20                  | 403  | 157  | 560     |
| **Scenic sites**     |      |      |         |
| 0-3                  | 43   | 10   | 53      |
| >3                   | 549  | 195  | 744     |
| **Sport venues**     |      |      |         |
| no                   | 1    | 0    | 1       |
| yes                  | 591  | 205  | 796     |
| **Recreational areas** |      |      |         |
| no                   | 4    | 2    | 6       |
|                  | yes   | 203 (26) | 791 (99.2) | 0.69 [0.1,3.8] | 0.67 |
|------------------|-------|----------|-------------|----------------|------|
| Food spots (median) | 362 [22,1068] | 372 [22,1031] | 362 [22,1068] | 1 [1,1] | 0.88 |

| Students’ satisfaction towards living environment | | | | | |
|-------------------------------------------------|---------|--------|----------------|--------|------|
| less satisfied                                  | 37 (64) | 21 (36) | 58 (7.3)       | __     |      |
| more satisfied                                  | 548 (75) | 180 (25) | 728 (91.3)     | 0.59 [0.3,1] | 0.06 |
| unknown                                         | 7 (64) | 4 (36) | 11 (1.4)       |        |      |

| Parents' satisfaction towards living environment | | | | | |
|-------------------------------------------------|---------|--------|----------------|--------|------|
| less satisfied                                  | 52 (74) | 18 (26) | 70 (8.8)       | __     |      |
| more satisfied                                  | 477 (73) | 173 (27) | 650 (81.6)     | 1.04 [0.6,1.8] | 0.88 |
| unknown                                         | 63 (82) | 14 (18) | 77 (9.7)       |        |      |

| Total                                           | 592 (74) | 205 (26) | 797            |        |      |

*TABLE 3. Adjusted odds ratios for characteristics against adolescents’ overweight, Nanjing*
### Adjusted OR – Reduced Model

|                      | AOR[95%CI] | P      |
|----------------------|------------|--------|
| **Age**              |            |        |
| 12                   | —          |        |
| 13                   | 1.23 [0.9,1.8] | 0.247 |
| 14                   | 0.89 [0.6,1.3] | 0.549 |
| 15                   | 0.99 [0.6,1.6] | 0.96  |
| **Sex**              |            |        |
| females              | —          |        |
| males                | 2.01 [1.5,2.7] | <0.0001 |
| **Sport venues**     |            |        |
| no                   | —          |        |
| yes                  | 0.64 [0.4,1] | 0.037 |
| **Recreational areas** |          |        |
| no                   | —          |        |
| yes                  | 1.42 [0.8,2.4] | 0.194 |
| **Father's BMI**     |            |        |
| normal               | —          |        |
| underweight          | 1.01 [0.4,2.3] | 0.985 |
| overweight           | 1.82 [1.4,2.5] | <0.0001 |
| **Mother's BMI**     |            |        |
| normal               | —          |        |
| underweight          | 0.8 [0.5,1.4] | 0.426 |
| overweight           | 1.77 [1.2,2.6] | 0.003 |
| **Economic status**  | 0.75 [0.6,1] | 0.037 |
| **BBQ**              | 1.19 [1,1.4] | 0.019 |
| **Medium strength activity** | |        |
| < 30min | — |
| >30min | 1.36 [1,1.8] 0.031 |

Note: AOR: Adjusted odds ratio, P: p value at significance level of 0.05

Note: comparing with multilevel mixed-effect model, we did not observe statistically significant difference with GLM logistic regression model (p>0.05, interclass correlation < 0.01)

**TABLE 4. Adjusted odds ratios for characteristics against adolescents’ overweight, Changzhou**

| Adjusted OR - Reduced model | AOR [95%CI] | P |
|-----------------------------|-------------|---|
| **Age**                     |             |   |
| ≤ 13                        | —           |   |
| 14                          | 0.92 [0.6,1.4] | 0.67 |
| 15                          | 0.95 [0.4,2.1] | 0.91 |
| **Sex**                     |             |   |
| Females                     | —           |   |
| Males                       | 1.78 [1.3,2.5] | 0.001 |
| **Bus stops**               |             |   |
| ≤ 20                        | —           |   |
| > 20                        | 1.63 [1.1,2.4] | 0.011 |
| **Mother’s BMI**            |             |   |
| Normal                      | —           |   |
| Underweight                 | 1.03 [0.6,1.8] | 0.93 |
| Overweight                  | 3.57 [2.3,5.5] | <0.0001 |

Note: AOR: Adjusted odds ratio, P: p value at significance level of 0.05

Note: comparing with multilevel mixed-effect model, we did not observe statistically significant difference with GLM logistic regression model (p>0.05, interclass correlation < 0.01)