SSM - Population Health 26 (2024) 101636

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Obesity contagion among classmates: Children's relation with each other regarding weight status, physical activity, and dietary intake

Yang Liu [a], Xiaobei Zhou [a], Ning Ding [b], Shenzhi Song [a], Joel Gittelsohn [c], Nan Jiang [b], Samantha M. Sundermeir [c], Yanan Ma [d], Deliang Wen [a,*]

[a] China Medical University, Health Sciences Institute, Address: No.77 Puhe Road, Shenyang North New Area, Shenyang, Liaoning Province, PR China
[b] China Medical University, Institute of International Medical Education, Address: No.77 Puhe Road, Shenyang North New Area, Shenyang, Liaoning Province, PR China
[c] Johns Hopkins Bloomberg School of Public Health, Department of International Health, Human Nutrition Center, Address: 615 North Wolfe St, Baltimore, MD, 21205-2179, USA
[d] China Medical University, School of Public Health, Address: No.77 Puhe Road, Shenyang North New Area, Shenyang, Liaoning Province, PR China

ARTICLE INFO

Keywords:
Childhood obesity
Social contagion
Physical activity
Dietary intake

ABSTRACT

A series of influential articles suggests that obesity may spread between couples, siblings, and close friends via an obesity contagion phenomenon. Classmates, as important structural equivalents in one's social network, may experience obesity contagion. However, this has rarely been examined. Anthropometric measurements, questionnaire surveys, and geographic information were collected from 3670 children from 26 schools in Northeast China. We found that classmates were positively related in terms of body mass index (BMI), body fat, physical activity, and intake of vegetables, fruits, fast food, snacks, and sugar-sweetened beverages. One standard deviation (SD) increase in classmates' mean BMI and percentage body fat was associated with 0.19 SD higher individual BMI (95% confidence interval [CI]: 0.00, 0.39) and 0.31 SD higher percentage body fat (95% CI: 0.13, 0.48). Coefficients ranged from 0.48 to 0.76 in models for physical activity, and the dietary intake of vegetables, fruit, fast food, snacks, and sugar-sweetened beverages. Children's BMI and body fat were more strongly associated with the maximum and minimum body fat levels of their same-sex classmates than with those of their general classmates. Their dietary intake and physical activity were more strongly associated with the mean/median levels of their general classmates than with those of their same-sex classmates. This study suggests that children's BMI, body fat, physical activity, and dietary intake may be related to those of their classmates. Modeling healthy behaviors in the classroom may help children develop habits that support achieving and maintaining a healthy weight. Future interventions should consider the inclusion of classmates as a social network strategy for obesity prevention.

Over the last 40 years, obesity has become a serious health concern among children and adolescents worldwide (Caprio et al., 2020; Lister et al., 2023). China has experienced a sharp increase in economic growth since 1978, and has become the country with the highest number of obese children worldwide (Wang et al., 2019; Zhou et al., 2017). Since 2007, a series of influential articles has shown substantial clustering of obesity, highlighting the important influence of social networks on obesity (Christakis & Fowler, 2007; Datar & Nicosia, 2018). An individual's obesity or weight status becoming more similar to their social ties over time suggests an interesting phenomenon of "obesity contagion" (Cohen-Cole & Fletcher, 2008; Shalizi & Thomas, 2011; Smith et al., 2020).

An important question concerning obesity contagion is who is "transmitting" obesity to an individual. Traditionally, close friends relate to each other in terms of physical activity, dietary intake, and weight loss through direct communication (Cunningham et al., 2012; Hammond, 2010; Piombo et al., 2022; Smith et al., 2020). This process is depicted as cohesion according to differential association theory (Fujimoto & Valente, 2012). However, a recent review of social networks found that connections to others alone cannot sufficiently explain

* Corresponding author. China Medical University, Health Sciences Institute. No.77 Puhe Road, Shenyang North New Area, Shenyang, Liaoning Province, PR China, 110122

E-mail addresses: yliu0568@cmu.edu.cn (Y. Liu), joe_xiaobei@hotmail.com (X. Zhou), nding@cmu.edu.cn (N. Ding), szsong@cmu.edu.cn (S. Song), jgittel1@jhu.edu (J. Gittelsohn), ndjiang@live.cn (N. Jiang), srex2@jh.edu (S.M. Sundermeir), ynma@cmu.edu.cn (Y. Ma), dlwen@cmu.edu.cn (D. Wen).

https://doi.org/10.1016/j.ssmph.2024.101636
Received 17 October 2023; Received in revised form 7 February 2024; Accepted 16 February 2024
Available online 11 March 2024

behavior spreading or diffusing across a network (Khalil et al., 2021; Montgomery et al., 2020). Instead, with fewer environmental and parental constraints, we join new social circles and become exposed to peers beyond our friends, such as classmates of school age, colleagues at work, and when being a member of a school gang or participating in organized activities. We encounter casual friends or proximate peers in social situations without befriending them, but are still exposed to their behaviors (Behler, 2017; Khalil et al., 2021; Lim & Cornwell, 2023). This type of exposure, defined as structural equivalence in social learning theory, can explain peer influence at the macro level in a sociological system and how social networks bring about the extensive spread of behavior or disease (Boone et al., 1977, p. 247; Burgess & Akers, 1966; Fujimoto & Valente, 2012; Kister & Tonetto, 2023). For example, an analysis based on teenage friends and lifestyle showed that proximity exposure can predict smoking, even among non-smokers without direct ties to friends who smoke (Khalil et al., 2021). One study using the U.S. Add Health data investigated two contagion mechanisms of peer influence and found that structural equivalence acted as a mechanism of contagion for drinking (Fujimoto & Valente, 2012). Several clues regarding the effect of structural equivalence on obesity have emerged in simulation studies and clinical trials. According to a simulation study, dieting with friends was shown to be an ineffective long-term weight loss strategy, whereas dieting with friends of friends can be more effective by forcing a shift in cluster boundaries (Bahr et al., 2009). A clinical trial showed that friends had little effect on weight loss outcomes, while casual friends were the only type of social contact that affected weight loss outcomes; participants with fewer overweight casual friends lost more weight (Leahey et al., 2015).

Childhood and adolescence are important stages when people formulate health behaviors, during which peer social networks are established when entering schools. At this stage, classmates constitute important, structurally equivalent actors who may have influenced children for more than a decade during their psychological and physiological development. We were interested in whether obesity and obesity-related behaviors spread across classmates. We hypothesized that the average, maximum, and minimum cases would have different effects on obesity contagion during the comparison process. In addition, obesity contagion may differ between same-sex and opposite-sex classmates.

Hence, three research questions were included in the present study: (1) Do children associate with their classmates with regard to body mass index (BMI), percentage of body fat, physical activity, and dietary intake of vegetables, fruits, fast food, snacks, and sugar-sweetened beverages to perform healthy behaviors? (2) Do children associate the average, maximum, or minimum cases in the classroom? (3) Are children more strongly associated with their sex-same classmates than with all their classmates?

1. Methods

1.1. Study design and participants

This cross-sectional study was conducted in Shenyang, which has the largest urban population in Northeast China. Two schools from each of the 13 administrative districts of Shenyang City and one class each from the fourth-, fifth-, and sixth-grade divisions of each school were randomly selected. All the students from the selected classes were invited to participate in the study.

In China, children go through 6 years of primary school, three years of junior high school, and three years of senior high school. During each of the three stages, each student is part of a "general class" where classmates attend all courses together as well as extracurricular activities as a group. The students were randomly assigned to classrooms at the beginning of each stage. According to the Compulsory Education Law of the People's Republic of China, the Chinese government forbids sorting school students into classes. There are two student assignment methods: purely random and balanced. A purely random assignment assigns students to various classes at random. Balanced assignment is a stratified random assignment method that distributes students evenly into classes according to their abilities. First, all the new students underwent an entrance exam and were stratified into N tiers based on their exam scores. Second, each class randomly selects the same number of students from each tier. Thus, the ability distributions were identical across classes after a balanced assignment. The random nature of this institutional setting has been well recognized in recent peer effect studies (Chung & Zou, 2020; Gong et al., 2019; Huang, 2019).

1.2. Procedures

Data were collected from May 2017 to June 2017, including anthropometric, survey administration, and built environment measurements. Child and household questionnaires were distributed to students three days before anthropometric measurements were taken and collected on the day the measurements were performed. Children completed individual-level questionnaires, whereas caregivers completed household questionnaires. Questionnaires were reviewed by research personnel (Shenzhi Song) to identify incomplete surveys or missing data and returned to the parents for the completion of any inadvertently missed portions.

2. Measurements

2.1. Anthropometrics

Child anthropometric measurements Height, weight, and body fat percentage were measured on a physical examination day at each school by trained investigators. Weight and body fat composition were measured using a portable Tanita DC-430MA dual-frequency body composition monitor (Tanita Corporation, Tokyo, Japan), with all outer clothing, heavy pocket items, metal objects, and shoes removed. Participants with internal metal implants were excluded. A 0.5 kg correction factor was used to account for indoor clothing. Standing height was measured without shoes using a Seca 213 portable stadiometer (Hamburg, Germany) with the participant's head in the Frankfurt plane. Both measurements were repeated and the average value was used. If the difference between two measurements exceeded 0.5 kg or 0.5 cm, respectively, a third measurement was conducted. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared. Age- and sex-specific BMI z-scores were generated relative to the 2007 WHO growth reference for 5–19 years (de Onis et al., 2007).

2.2. Obesity-related health behaviors

Physical activity Physical activity (PA) was reported by the children using a validated Chinese version of the Physical Activity Questionnaire for Older Children (PAQ-C), which is a 7-day recall assessing general physical activity levels during the school year (Kowalski et al., 2004; Wang et al., 2016). The PAQ-C includes 10 items that assess participation in various types of PA, including activity during physical education, lunch breaks, and after school, evenings, and weekends. Each item is scored according to a five-point scale, with "1" indicating low and "5" a high level of PA. A mean PA score was generated from items one through nine to measure the physical activity level. The tenth item was not included in the score calculation because it asked about the barriers that prevented children from engaging in regular PA.

Dietary intake The average weekly dietary intake of children over the last three months was reported by caregivers using a Chinese version of the food frequency questionnaire for children, which has modest and acceptable reproducibility and validity (Huang et al., 2017). Food groups included vegetables, fruits, fast foods, snacks, and sugar-sweetened beverages. The questionnaire was completed at home by caregivers. Caregivers were asked to complete the questionnaire in the presence of children if they did not know what their child ate at school. For food groups that included multiple items, the average intake frequency of all the food items was calculated and used as the frequency for that food group.

2.3. Family characteristics

The area of residence, monthly household income, and father's and mother's education levels were collected as the family characteristics of each child. The area of residence was determined based on the residential registration system of China and categorized as "urban" or "rural." In China, all families are required to register with the hukou system according to where they live and originate. This information was collected from household questionnaires. According to the Chinese education system, parents' education levels were classified into the following groups: none, primary school, middle school, high school, technical secondary school, junior college, bachelor's degree, and postgraduate.

2.4. Environment characteristics

Geospatial analyses were conducted using the SuperMap GIS 9D software. The school addresses of the participants were geocoded using longitude and latitude coordinates. A 1 km circular buffer from each participant's school was used. The objective built environment characteristics measured within the buffer area included the number of restaurants, supermarkets, convenience stores, physical activity areas, road intersections, and residential sites.

2.5. Statistical analyses

All analyses were performed using the STATA 14.0 (College Station, TX, USA) software. Statistical significance was defined using a p-value threshold <0.05.

Estimations of the obesity peer effect aim to disentangle the endogenous peer impact from the self-selection effect that people with similar obesity features have when selecting each other as friends as well as the contextual effect that people living in similar environments hold in terms of similar lifestyles. In this study, the random assignment of students per classroom helped to attenuate the problem of self-selection. The built environment, family, and child characteristics were collected and included in a Manski linear-in-means model as covariates to attenuate the problem of contextual effects. The model is as follows (Manski, 1993):

$$Y_{ics} = \beta_0 + \beta_1 Y_{(i)cst} + \beta_2 Child + \beta_3 Family + \beta_3 Environment + \mu_t + \varepsilon_{icst}$$

Where Y_{ics} is a measure for student i assigned to classroom c in school s, including the BMI, percentage body fat, physical activity score, vegetable intake, fruit intake, fast food intake, snack intake, and sugar-sweetened beverage intake. $Y_{(i)cst}$ is the same measurement for classmates (all or same-sex classmates) in the same classroom, excluding the students' own measurement. Classmates' mean, median, minimum, and maximum values were calculated and used as $Y_{(i)cst}$ to test whether children related to the majority or extreme cases in the classroom. For each of the eight variables (BMI, percentage body fat, physical activity score, vegetable intake, fruit intake, fast food intake, snack intake, and sugar-sweetened beverage intake), four models were formulated using the mean, median, minimum, and maximum values as measurements of $Y_{(i)cst}$. β_1 was estimated for the association between children and their classmates. All Y_{ics} and $Y_{(i)cst}$ measurements, which have different units, were standardized to make β_1 comparable in different models for BMI, percentage body fat, physical activity score, vegetable intake, fruit intake, fast-food intake, snack intake, and sugar-sweetened beverage intake.

Child represents the child's characteristic covariates, including age and sex. *Family* represents the child's family characteristic covariates, including the area of residence, monthly household income, and father's and mother's education levels. *Environment* represents the characteristic environmental covariates, including the number of restaurants, supermarkets, convenience stores, physical activity areas, road intersections, and residential sites. μ_t represents the school's fixed effects to account for the random assignment of students in classrooms within a school by using mixed regression models. ε_{icst} is the error term.

3. Results

In total, 3670 families completed the survey with 3670 children, accounting for 95% of the total number of enrolled students from grades 4, 5, and 6 in the 26 schools. As shown in Table 1, the average age of the children was 10.8 ± 1.0 years, the mean BMI was 18.9 ± 4.2 kg/m^2 and the mean percentage body fat was $20.8 \pm 3.1\%$.

As shown in Table 2, a SD increase in the mean class BMI (excluding the individual child) was significantly correlated with a 0.19 SD increase in the child's BMI. For body fat percentage, the coefficient was 0.31. Coefficients in models of same-sex classmates were lower than those in models of the overall class when using mean and median measurements (BMI: 0.06 vs. 0.19 for means, % body fat: 0.24 vs. 0.31 for means, 0.16 vs. 0.22 for medians); and higher when using maximum and minimum measurements (BMI: 0.23 vs. 0.15 for maximums, 0.07 vs. 0.06 for

Table 1
Demographic statistics and obesity measurements for 3670 children in this study.

Characteristic	Mean or percentage	SD
N	3670	
Demographics		
Child covariates		
Age, years	10.8	1.0
Sex, female	49.0	–
Family covariates		
Residence area, urban	44.8	–
Household income (monthly, RMB)		
<1000	6.9	–
1000–2999	24.0	–
3000–5999	31.2	–
6000–9999	19.4	–
≥10,000	9.0	–
Missing	9.7	–
Father's education level		
none or primary education	50.3	–
secondary education	37.4	–
post-secondary education	12.3	–
Mother's education level		
none or primary education	50.9	–
secondary education	36.3	–
post-secondary education	12.8	–
Obesogenic built environment covariates		
Number of restaurants near school	33.3	42.5
Number of supermarkets near school	0.3	0.6
Number of convenience stores near school	7.5	11.8
Number of physical activity areas near school [a]	4.3	3.4
Number of road intersections near school	32.6	35.4
Number of residential sites near school	11.1	13.3
Anthropometrics		
BMI (kg/m^2)	18.9	4.2
Obesity defined by BMI (%)	17.0	
Body fat (%)	20.8	3.1
Obesity-related health behaviors		
Physical activity (PAQ-C score)	2.9	0.7
Vegetable intake (times per week)	4.1	2.6
Fruit intake (times per week)	5.7	3.0
Fast-food intake (times per week)	0.7	1.1
Snack intake (times per week)	1.9	1.5
Sugar-sweetened beverage intake (times per week)	1.4	1.5

BMI, body mass index; PAQ-C score, Physical Activity Questionnaire for Older Children; RMB, renminbi; SD, standard deviation.
[a] Including parks, leisure squares, open places, and amusement parks.

Table 2
Association between children and their classmates for BMI and percentage body fat (coef. 95% CI) [a, b].

	Measurements for all classmates (excluding each individual child)			
	Mean	Median	Maximum	Minimum
Measurements for overall class				
BMI	0.19 (0.00, 0.39)	0.12 (−0.00, 0.25)	**0.15 (0.01, 0.29)** *	0.06 (0.00, 0.12)
% Body fat	**0.31 (0.13, 0.48)** **	**0.22 (0.09, 0.35)** **	**0.14 (0.08, 0.19)** ***	**0.46 (0.15, 0.77)** **
Measurements for same-sex classmates				
BMI	0.06 (−0.03, 0.15)	0.02 (−0.04, 0.08)	**0.23 (0.16, 0.31)** ***	**0.07 (0.04, 0.11)** ***
% Body fat	**0.24 (0.11, 0.37)** ***	**0.16 (0.07, 0.25)** **	**0.18 (0.13, 0.24)** ***	**0.49 (0.30, 0.68)** ***

[a] Analyses were adjusted for the children's age, sex, residential area (*urban/rural*), father's education level, mother's education level, monthly household income, number of restaurants, supermarkets, convenience stores, physical activity areas, road intersections, and residential sites around the school.
[b] All measures were standardized using z-scores (mean = 0, standard deviation = 1). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. BMI, body mass index; CI, confidence interval.

minimums; % body fat: 0.18 vs. 0.14 for maximums, 0.49 vs. 0.46 for minimums).

Cronbach's alpha of PAQ-C was 0.89 for that reported by grade 4 students, 0.90 for grade 5 students, and 0.89 for grade 6 students. As shown in Table 3 the coefficients of the relationship between classmates' mean values and those of an individual child were 0.76 for physical activity, 0.67 for vegetable intake, 0.48 for fruit intake, 0.68 for fast-food intake, 0.73 for snack intake, and 0.74 for sugar-sweetened beverage intake. Coefficients in models of same-sex classmates were lower than those in models of the overall class when using mean and median measurements (ranging from 0.22 to 0.65 vs. ranging from 0.48 to 0.76 for means, ranging from 0.27 to 0.58 vs. ranging from 0.23 to 0.81 for medians, respectively), and higher when using maximum and minimum measurements (ranging from 0.08 to 0.28 vs. ranging from 0.06 to 0.22 for maximums, ranging from 0.29 to 0.44 vs. ranging from 0.23 to 0.42 for minimums).

Table 3
Association between children and their classmates for physical activity and dietary intake [a, b].

	Measurements for all classmates (excluding each individual child)			
	Mean	Median	Maximum	Minimum
Measurements for the overall class				
Physical activity	**0.76 (0.66, 0.86)** ***	**0.67 (0.58, 0.76)** ***	**0.22 (0.15, 0.29)** ***	**0.35 (0.27, 0.42)** ***
Vegetable intake	**0.67 (0.55, 0.79)** ***	**0.66 (0.54, 0.77)** ***	**0.08 (0.06, 0.11)** ***	**0.36 (0.26, 0.46)** ***
Fruit intake	**0.48 (0.34, 0.63)** ***	**0.23 (0.11, 0.34)** ***	**0.06 (0.04, 0.08)** ***	**0.30 (0.20, 0.39)** ***
Fast-food intake	**0.68 (0.56, 0.80)** ***	0.04 (−0.06, 0.14)	**0.06 (0.05, 0.08)** ***	0.05 (−0.28, 0.38)
Snack intake	**0.73 (0.63, 0.84)** ***	**0.81 (0.67, 0.95)** ***	**0.09 (0.07, 0.11)** ***	**0.23 (0.05, 0.41)** *
Sugary beverage intake	**0.74 (0.64, 0.85)** ***	**0.69 (0.60, 0.79)** ***	**0.06 (0.05, 0.08)** ***	**0.42 (0.28, 0.56)** ***
Measures for same-sex classmates				
Physical activity	**0.65 (0.56, 0.74)** ***	**0.55 (0.46, 0.63)** ***	**0.28 (0.23, 0.34)** ***	**0.35 (0.28, 0.41)** ***
Vegetable intake	**0.50 (0.40, 0.61)** ***	**0.42 (0.32, 0.52)** ***	**0.11 (0.09, 0.14)** ***	**0.36 (0.27, 0.46)** ***
Fruit intake	**0.22 (0.09, 0.34)** **	**0.27 (0.16, 0.37)** ***	**0.08 (0.06, 0.09)** ***	**0.29 (0.22, 0.37)** ***
Fast-food intake	**0.52 (0.42, 0.62)** ***	−0.05 (−0.14, 0.02)	**0.11 (0.09, 0.12)** ***	0.05 (−0.28, 0.38)
Snack intake	**0.49 (0.39, 0.59)** ***	**0.58 (0.45, 0.71)** ***	**0.12 (0.11, 0.14)** ***	**0.31 (0.19, 0.43)** ***
Sugary beverage intake	**0.56 (0.46, 0.66)** ***	**0.53 (0.44, 0.62)** ***	**0.08 (0.06, 0.10)** ***	**0.44 (0.31, 0.57)** ***

[a] Analyses were adjusted for the children's age, sex, residential area *(urban/rural),* father's education level, mother's education level, monthly household income, number of restaurants, supermarkets, convenience stores, physical activity areas, road intersections, and residential sites around the school.
[b] All measures were standardized using z-scores (mean = 0, standard deviation = 1). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

As shown by the mean and median measurements in Tables 2 and 3, the coefficients in the models of physical activity and intake of vegetables, fruit, snacks, and sugar-sweetened beverages were higher than those in the models of BMI and percentage body fat.

4. Discussion

This study is one of the first to explore the spread of obesity in the classroom by examining children's weight status and health behaviors. Our findings suggest that children in grades 4–6 in China have obesity-related characteristics similar to those of their classmates, including BMI, percentage of body fat, physical activity, and dietary intake of vegetables, fruits, fast food, snacks, and sugar-sweetened beverages. Children's BMI and body fat were more strongly associated with the maximum and minimum body fat levels of their same-sex classmates than with those of their general classmates. The children's dietary intake and physical activity were more strongly associated with the mean/median levels of their general classmates than with those of their same-sex classmates.

The positive relationship between BMI and social ties is consistent with the results of studies conducted among students from the same school or community (Asirvatham et al., 2014; Lim & Meer, 2018; Loh & Li, 2013; Nie et al., 2015). Network interventions use social networks to accelerate behavioral change, which is believed to be more effective than non-network alternatives (Hene et al., 2022; Jancey et al., 2023; Polman et al., 2023; Valente, 2012). As suggested by several obesity treatment and simulation studies, focusing on broader social ties is an effective strategy (Bahr et al., 2009; Daw et al., 2015; Leahey et al., 2015; Lower-Hoppe et al., 2022). This study suggests that school-based obesity intervention studies should test social networking strategies focusing on classmates.

Obesity-related health behaviors were clustered among classmates. Some studies have reported that close friends have similar behaviors, and the present study results are consistent with those of studies conducted among classmates, where classmates had similar drinking and smoking behaviors (Ali & Dwyer, 2010; Balsa et al., 2011; Daw et al., 2015; Montgomery et al., 2020; Purwono & Rodkin, 2014). However, research on specific obesity contagion mechanisms remains limited. However, several possible mechanisms for obesity contagion have been identified, including behavioral modeling, social norms, social control, social support, and social comparison (Cunningham et al., 2012; Hammond, 2010; Smith et al., 2020). Relationships between broader social ties and health behaviors may suggest that homophily in behaviors may relate to where that behavior occurs through emotional salience and to the strength of the ties through the frequency of interaction (Bahr et al., 2009).

Previous studies have shown that children's weight status is more strongly associated with same-sex peers when close friends are used as a definition for peers (Chung et al., 2017; Renna et al., 2008; Salvy et al., 2012). However, in the present study, children's association with same-sex classmates was stronger than that with overall classmates in terms of maximum/minimum measurements, but weaker in terms of mean/median measurements. This difference may be attributed to the effect of close friends and broader social relationships on children's health. The findings of the present study are consistent with those of other studies that examined broader social relationships. For example, Nie et al. exploring peer effects from the same age group level of the community and showed that the association of children's weight status with same-sex peers was not stronger than that of mixed-gender associations (Nie et al., 2015). Loh and Li exploring peer effects at the same community age group level and found stronger same-sex peer associations only for female adolescents (Loh & Li, 2013). Further studies are needed to determine the different sexes and sex mechanisms at play that may influence an individual's weight status.

The mean, median, minimum, and maximum values were modeled in the present study to test whether children related to the majority or extreme cases in the classroom, which has not been reported before. Interestingly, children's BMI and body fat percentage were more strongly associated with extreme cases, especially minimum levels in classrooms, while children's health behaviors were more strongly associated with the mean levels in the class. These findings have implications for future intervention studies using social networking strategies. This is because maximum or minimum weight status cases in a class matter more in providing the correct social norms for body image, while most classroom members participating in healthy behaviors may help children form the same behaviors.

The present study has several limitations. First, the cross-sectional design only provides insight at one point in time and does not capture the causal effect of classmates on individual children. However, in the present study, students were randomly assigned to classrooms. It is unlikely that children's weight status affects the formulation of classmates' relationships, which may help attenuate the influence of self-selection or reverse causation. Second, although measurements of the built environment near schools were objectively included in the Manski linear-in-means model to control for the effects of the shared environment, in-school environments may also be a confounding factor. A fixed-effects model was used to mitigate bias.

5. Conclusions

Children's BMI, body fat percentage, physical activity, and dietary intake may be related to those of their classmates. Modeling healthy behaviors in the classroom may help children develop habits that support the achievement and maintenance of a healthy weight. Future interventions should consider the inclusion of classmates as a social network strategy for obesity prevention.

Funding

This work was supported by the National Natural Science Foundation of China [grant numbers 72004233].

Ethical statement

The study was conducted according to the guideline laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Shenyang City Board of Education and the China Medical University Ethics Committee (2017-055). Participants had the option to withdraw from the study at any point.

CRediT authorship contribution statement

Yang Liu: Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Xiaobei Zhou:** Writing – original draft, Visualization, Methodology, Formal analysis. **Ning Ding:** Writing – original draft, Formal analysis, Data curation. **Shenzhi Song:** Writing – original draft, Investigation, Data curation. **Joel Gittelsohn:** Writing – review & editing, Writing – original draft, Supervision. **Nan Jiang:** Writing – review & editing, Writing – original draft. **Samantha M. Sundermeir:** Writing – review & editing, Writing – original draft. **Yanan Ma:** Writing – review & editing, Writing – original draft, Validation. **Deliang Wen:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

Data will be made available on request.

Acknowledgements

The authors wish to thank Ji Qi, Peirong Gao, Min Ye, Xin Ai, Hong Wang, Dongman Ye, Jia Peng, Jie Li, Huayu Tang, Yingying Jiang, Fei Zhu, Mengke Zhang, Lianting Zhuang, Minzhi Zhou, Liyuan Xu, Ya Liu, Yue Xiao, and Chong He for help in data collection.

References

Ali, M. M., & Dwyer, D. S. (2010). Social network effects in alcohol consumption among adolescents. *Addictive Behaviors, 35*(4), 337–342. https://doi.org/10.1016/j.addbeh.2009.12.002

Asirvatham, J., Nayga, R. M., & Thomsen, M. R. (2014). Peer-effects in obesity among public elementary school children: A grade-level analysis. *Applied Economic Perspectives and Policy, 36*(3), 438–459. http://www.jstor.org/stable/43695834.

Bahr, D. B., Browning, R. C., Wyatt, H. R., & Hill, J. O. (2009). Exploiting social networks to mitigate the obesity epidemic. *Obesity, 17*(4), 723–728. https://doi.org/10.1038/oby.2008.615

Balsa, A. I., Homer, J. F., French, M. T., & Norton, E. C. (2011). Alcohol use and popularity: Social payoffs from conforming to peers' behavior. *Journal of Research on Adolescence, 21*(3), 559–568. https://doi.org/10.1111/j.1532-7795.2010.00704.x

Behler, R. L. (2017). You can't always get what you want: Network determinants of relationship inactualization in adolescence. *Social Science Research, 61*, 181–194. https://doi.org/10.1016/j.ssresearch.2016.06.012

boone, t., Reilly, A. J., Sashkin, M. J. G., & Management, O. (1977). *Social learning theory* (Vol. 1977, p. 247). Albert Bandura Englewood Cliffs, N.J.: Prentice-Hall. paperbound. 2, 384 - 385.

Burgess, R. L., & Akers, R. L. J. S. P. (1966). *A Differential Association-Reinforcement Theory of Criminal Behavior, 14*, 128–147.

Caprio, S., Santoro, N., & Weiss, R. (2020). Childhood obesity and the associated rise in cardiometabolic complications. *Nature Metabolism, 2*(3), 223–232. https://doi.org/10.1038/s42255-020-0183-z

Christakis, N. A., & Fowler, J. H. (2007). The spread of obesity in a large social network over 32 years. *New England Journal of Medicine, 357*(4), 370–379. https://doi.org/10.1056/NEJMsa066082

Chung, S. J., Ersig, A. L., & McCarthy, A. M. (2017). The influence of peers on diet and exercise among adolescents: A systematic review. *Journal of Pediatric Nursing, 36*, 44–56. https://doi.org/10.1016/j.pedn.2017.04.010

Chung, B., & Zou, J. (2020). Understanding spillover of peer parental education: Randomization evidence and mechanisms. https://EconPapers.repec.org/RePEc:hka:wpaper:2020-045.

Cohen-Cole, E., & Fletcher, J. M. (2008). Is obesity contagious? Social networks vs. environmental factors in the obesity epidemic. *Journal of Health Economics, 27*(5), 1382–1387. https://doi.org/10.1016/j.jhealeco.2008.04.005

Cunningham, S. A., Vaquera, E., Maturo, C. C., & Narayan, K. M. (2012). Is there evidence that friends influence body weight? A systematic review of empirical research. *Social Science & Medicine, 75*(7), 1175–1183. https://doi.org/10.1016/j.socscimed.2012.05.024

Datar, A., & Nicosia, N. (2018). Assessing social contagion in body mass index, overweight, and obesity using a natural experiment. *JAMA Pediatrics, 172*(3), 239–246. https://doi.org/10.1001/jamapediatrics.2017.4882

Daw, J., Margolis, R., & Verdery, A. M. (2015). Siblings, friends, course-mates, club-mates: How adolescent health behavior homophily varies by race, class, gender, and health status. *Social Science & Medicine, 125*, 32–39. https://doi.org/10.1016/j.socscimed.2014.02.047

de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World Health Organization, 85*(9), 660–667. https://doi.org/10.2471/blt.07.043497

Fujimoto, K., & Valente, T. W. (2012). Social network influences on adolescent substance use: Disentangling structural equivalence from cohesion. *Social Science & Medicine, 74*(12), 1952–1960. https://doi.org/10.1016/j.socscimed.2012.02.009

Gong, J., Lu, Y., & Song, H. (2019). Gender peer effects on students' academic and noncognitive outcomes: Evidence and mechanisms. *Journal of Human Resources, 56*, Article 0918. https://doi.org/10.3368/jhr.56.3.0918-9736R2, 9736R0912.

Hammond, R. A. (2010). Social influence and obesity. *Current Opinion in Endocrinology Diabetes and Obesity, 17*(5), 467–471. https://doi.org/10.1097/MED.0b013e32833d4687

Hene, N., Wood, P., Schwellnus, M., Jordaan, E., & Laubscher, R. (2022). Social network lifestyle interventions reduce non-communicable diseases risk factors in financial sector employees: Randomized controlled trial. *Journal of occupational and environmental medicine, 64*(4), 278–286. https://doi.org/10.1097/JOM.0000000000002474

Huang, Z. (2019). *Peer effects of migrant and left-behind children: Evidence from classroom random assignment in China*.

Huang, T., Beaty, T., Li, J., Liu, H., Zhao, W., & Wang, Y. (2017). Association between dietary fat intake and insulin resistance in Chinese child twins. *British Journal of Nutrition, 117*(2), 230–236. https://doi.org/10.1017/S0007114516004542

Jancey, J., Vidler, A. C., Leavy, J. E., Chamberlain, D., Riley, T., Pollard, C. M., Milligan, M., & Blackford, K. (2023). Understanding prevention networks in a local government area: Insights from a social network analysis among western Australian nutrition, physical activity, and obesity prevention programs. *Health Promotion Practice, 24*(1), 103–110. https://doi.org/10.1177/15248399211050661

Khalil, G. E., Jones, E. C., & Fujimoto, K. (2021). Examining proximity exposure in a social network as a mechanism driving peer influence of adolescent smoking. *Addictive Behaviors, 117*, Article 106853. https://doi.org/10.1016/j.addbeh.2021.106853

Kister, P., & Tonetto, L. (2023). On the importance of structural equivalence in temporal networks for epidemic forecasting. *Scientific Reports, 13*(1), 866. https://doi.org/10.1038/s41598-023-28126-w

Kowalski, K., Crocker, P., Donen, R., & Honours, B. (2004). *The physical activity questionnaire for older children (PAQ-C) and adolescents (PAQ-A) manual*.

Leahey, T. M., Doyle, C. Y., Xu, X., Bihuniak, J., & Wing, R. R. (2015). Social networks and social norms are associated with obesity treatment outcomes. *Obesity, 23*(8), 1550–1554. https://doi.org/10.1002/oby.21074

Lim, J., & Cornwell, B. (2023). Social network-structural position and obesity: Evidence from a national study. *Social Science & Medicine, 329*, 116006. https://doi.org/10.1016/j.socscimed.2023.116006

Lim, J., & Meer, J. (2018). How do peers influence BMI? Evidence from randomly assigned classrooms in South Korea. *Social Science & Medicine, 197*, 17–23. https://doi.org/10.1016/j.socscimed.2017.11.032

Lister, N. B., Baur, L. A., Felix, J. F., Hill, A. J., Marcus, C., Reinehr, T., Summerbell, C., & Wabitsch, M. (2023). Child and adolescent obesity. *Nature Reviews Disease Primers, 9*(1), 24. https://doi.org/10.1038/s41572-023-00435-4

Loh, C. P., & Li, Q. (2013). Peer effects in adolescent bodyweight: Evidence from rural China. *Social Science & Medicine, 86*, 35–44. https://doi.org/10.1016/j.socscimed.2013.02.042

Lower-Hoppe, L. M., Kim, A. C. H., Brgoch, S. M., Zwolski, C. M., Schmitt, L., Paponetti, M. K., & Quatman-Yates, C. C. (2022). Investigating the social network structure of physical literacy scholars to advance a paradigm for physical activity promotion. *Frontiers in sports and active living, 4*, Article 809946. https://doi.org/10.3389/fspor.2022.809946

Manski, C. F. (1993). Endogenous social effects: The reflection problem. *The Review of Economic Studies, 60*, 531–542.

Montgomery, S. C., Donnelly, M., Bhatnagar, P., Carlin, A., Kee, F., & Hunter, R. F. (2020). Peer social network processes and adolescent health behaviors: A systematic review. *Preventive Medicine, 130*, Article 105900. https://doi.org/10.1016/j.ypmed.2019.105900

Nie, P., Sousa-Poza, A., & He, X. (2015). Peer effects on childhood and adolescent obesity in China. *China Economic Review, 35*, 47–69. https://doi.org/10.1016/j.chieco.2015.06.002

Piombo, S. E., Huh, J., & Valente, T. W. (2022). Adolescent body mass index and exposure to peers with overweight and obesity: A structural equation model approach to longitudinal network data. *Childhood Obesity, 18*(7), 445–453. https://doi.org/10.1089/chi.2021.0270

Polman, M. A. A., Beckers, D., Burk, W. J., Smit, C. R., Buijzen, M., Vink, J. M., van den Broek, N., & Larsen, J. K. (2023). The effect of a multi-component school-based social network intervention on children's body mass index: A four-arm intervention study. *Psychology and Health*, 1–18. https://doi.org/10.1080/08870446.2023.2179084. *Advance online publication*.

Purwono, U., & Rodkin. (2014). Indonesian muslim adolescents' use of tobacco and alcohol: Associations with use by friends and network affiliates. *Merrill-Palmer Quarterly, 60*, 385. https://doi.org/10.13110/merrpalmquar1982.60.4.0385

Renna, F., Grafova, I. B., & Thakur, N. (2008). The effect of friends on adolescent body weight. *Economics and Human Biology, 6*(3), 377–387. https://doi.org/10.1016/j.ehb.2008.06.005

Salvy, S. J., Kluczynski, M. A., Nitecki, L. A., & O'Connor, B. C. (2012). Peer influence on youth's snack purchases: A laboratory analog of convenience store shopping. *Eating Behaviors, 13*(3), 233–239. https://doi.org/10.1016/j.eatbeh.2012.03.005

Shalizi, C. R., & Thomas, A. C. (2011). Homophily and contagion are generically confounded in observational social network studies. *Sociological Methods & Research, 40*(2), 211–239. https://doi.org/10.1177/0049124111404820

Smith, N. R., Zivich, P. N., & Frerichs, L. (2020). Social influences on obesity: Current knowledge, emerging methods, and directions for future research and practice. *Curr Nutr Rep, 9*(1), 31–41. https://doi.org/10.1007/s13668-020-00302-8

Valente, T. W. (2012). Network interventions. *Science, 337*(6090), 49–53. https://doi.org/10.1126/science.1217330

Wang, J. J., Baranowski, T., Lau, W. P., Chen, T. A., & Pitkethly, A. J. (2016). Validation of the physical activity questionnaire for older children (PAQ-C) among Chinese children. *Biomedical and Environmental Sciences, 29*(3), 177–186. https://doi.org/10.3967/bes2016.022

Wang, Y., Xue, H., Sun, M., Zhu, X., Zhao, L., & Yang, Y. (2019). Prevention and control of obesity in China. *Lancet Global Health, 7*(9), e1166–e1167. https://doi.org/10.1016/S2214-109X(19)30276-1

Zhou, Y., Zhang, Q., Wang, T., Zhang, Y., & Xu, B. (2017). Prevalence of overweight and obesity in Chinese children and adolescents from 2015. *Annals of Human Biology, 44*(7), 642–643. https://doi.org/10.1080/03014460.2017.1371224