Effects of urbanization on metabolic syndrome via dietary intake and physical activity in Chinese adults: Multilevel mediation analysis with latent centering

Ted Chun Tat Fong, Rainbow Tin Hung Ho, Paul Siu Fai Yip

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Authors: Ted Chun Tat Fong[a,b*], Rainbow Tin Hung Ho[a,b], Paul Siu Fai Yip[b,c]

Affiliations: [a] Centre on Behavioral Health, The University of Hong Kong, Hong Kong

[b] Dept of Social Work & Social Administration, The University of Hong Kong, Hong Kong

[c] Centre for Suicide Research and Prevention, The University of Hong Kong, Hong Kong

Correspondence: Ted C. T. Fong, Centre on Behavioral Health, University of Hong Kong, 2/F., HKJC Building for Interdisciplinary Research, 5 Sassoon Road, Pokfulam, Hong Kong

Phone no.: (852) 2831-5174 **Fax no.**: (852) 2816-6710 **Email**: ttaatt@hku.hk

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Introduction

China has undergone massive social and economic transformation in the past decades (H. Xu, 2018). The increasing urbanicity represents a growing population living closely together in a modernized environment with improved systems on transport, health care, education, infrastructure, and communication networks. The 21st century has witnessed an alarming rising trend in adult obesity worldwide including developed and developing countries (Abarca-Gómez et al., 2017). *Metabolic syndrome* refers to a cluster of cardiometabolic risk factors (Barber et al., 2018): abdominal obesity, raised triglycerides levels, low high-density lipoprotein, high blood pressure, and elevated blood glucose. Persons with metabolic syndrome are at an elevated risk of developing type II diabetes (American Diabetes Association, 2014) and cardiovascular diseases (Alberti et al., 2006). The prevalence of metabolic syndrome is estimated to be 14.4% to 26.9% among Chinese adults in recent studies (Guo et al., 2017; Lan et al., 2018; Li et al., 2018), with risk factors such as being female, older age, smoking, alcohol drinking, and elevated body mass index.

Apart from the individual-level risk factors, the rapid urbanization process of the Chinese society could play a contextual role at the community level that contributes to metabolic syndrome (Han et al., 2018). Existing studies on urbanization in China (Gu et al., 2005; Li et al., 2018; Xi et al., 2013) have only compared the prevalence of metabolic syndrome in rural vs. urban communities. Although these studies point to a higher rate of metabolic syndrome in the urban area, such a simple urban/rural dichotomy could hardly capture the dynamic nature of the urbanization process. Urbanization denotes the process of increasing urban size and population density as well as development in environments, landscapes, infrastructure, and markets (Cui & Shi, 2012). The continuous urbanization index encompasses the underlying complexity and heterogeneity of the community that would otherwise be missed in the urban/rural dichotomy measure.

The China Health and Nutrition Survey (CHNS) is a large-scale national study (Zhang et al., 2014) that evaluates the impacts of social and economic transformation of the Chinese society on the health and nutritional status of the population. Previous studies using the CHNS data have associated higher urbanization index with health issues such as inflammation (Thompson et al., 2014), reduced renal function (Inoue et al., 2017), and diabetes (Attard et al., 2012). Though Yan et al. (2012) established linkages between urbanization and components of metabolic syndrome (dyslipidaemia, hypertension, and raised plasma glucose), existing studies have not explicitly examined the effects of a continuous urbanization index on metabolic syndrome in the Chinese context. Thus, the first objective of the present study is to examine the effects of urbanization on metabolic syndrome in Chinese adults using the CHNS data. Urbanization is expected to positively predict the prevalence of metabolic syndrome.

The associations between urbanization as a community-level construct and metabolic syndrome are intricate with plausible multifaceted pathways. On one hand, urbanization could improve access to health care, basic infrastructure, and economic opportunities. On the other hand, Westernized diets (Rodríguez-Monforte et al., 2017) and diminished physical activity associated with urbanization could be detrimental. Existing studies have associated lower intake of vegetables and milk and higher meat intake with metabolic syndrome in Chinese adults (Cheng et al., 2017; Guo et al., 2017). Lower levels of physical activity (Laaksonen et al., 2002; Lakka & Laaksonen, 2007) have been linked with development of metabolic syndrome. Urbanization could influence the risk of metabolic syndrome through these two lifestyle factors since they both contribute to obesity. Given the established linkages among urbanization, dietary intake (Lutsey et al., 2008), and lifestyle transition (Popkin, 1999), the second objective of the current research is to evaluate the mediating role of dietary intake and physical activity in the potential urbanization effect on metabolic syndrome using multilevel mediation analysis.

From a methodological view, the effect of urbanization on metabolic syndrome only exists in the community level. Traditional multilevel modeling could bias the results by conflating the individual-level and community-level effects (Preacher et al., 2011). It remains unclear whether previous multilevel studies on CHNS (Attard et al., 2012; Inoue et al., 2017; Thompson et al., 2014) unequivocally estimated the between-level effects of urbanization on metabolic syndrome. Multilevel structural equation modeling with latent mean centering is a state-of-the-art modeling technique in multilevel analysis (Asparouhov & Muthén, 2018). This technique allows the use of latent covariate approach, which can produce accurate estimates of the indirect effects of urbanization in the community level. Given the relatively scant use in applied studies, the present study aims to illustrate the innovative application of this technique in the CHNS data via multilevel mediation analysis of urbanization on metabolic syndrome via dietary intake and physical activity.

Method

Study Design and Sample

The CHNS is a national longitudinal survey that began in 1989. The present study used the four waves of the CHNS taken in 2000, 2004, 2006, and 2009 (Zhang et al., 2014). This survey adopted a multistage, random cluster sampling process for recruitment of study participants from nine provinces (Guangxi, Guizhou, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Liaoning, Shandong) in China. Four counties were randomly selected under a weighted sampling scheme, and the provincial capital and a lower income city were chosen in each of the nine provinces. Three villages and a town were randomly selected from each of the 36 counties and four urban/suburban neighborhoods were randomly chosen from each of the 18 cities. A total of 218 communities (108 rural villages, 37 towns, and 73 urban/suburban neighborhoods) served as the primary sampling units of the survey. Twenty households were randomly sampled from each of the communities, resulting in a total of 4,519 recruited households (2,293 in rural villages, 759 in towns, 1,467 in neighborhoods) in the survey.

The CHNS sampled all members of the selected households in the survey and collected various information on health, diet, nutrition, income, and aging from the individuals as well as information about the sampled communities. The original recruited sample of 9,468 individuals provided biospecimen data on metabolic syndrome in 2009. The present study included only participants aged between 30- and 65-years old in 2009 in order to focus on the adult population. This exclusion criterion resulted in a final analytic sample of 6,217 adults. The majority of the study participants received prior assessments in 2000, 2004, or 2006. All participants provided voluntary written informed consent for data collection of self-report measures across the four waves of measurements and biomarkers in 2009. Ethical approval was obtained from the human research ethics committee (reference number = EA1809036) for this secondary analysis.

Conceptual Model

Figure 1 depicts the conceptual model of the present study. Presence/absence of metabolic syndrome in 2009 was the primary outcome. Growth in urbanization from 2000 to 2009 was the predictor variable and existed only in the between level. Change in physical activity from 2000 to 2009 and change in dietary intake from 2004 to 2009 were posited as potential mediators between urbanization and metabolic syndrome; body mass index (BMI) in

2009 was hypothesized as a sequential mediator. Model covariates at the individual (within) level included age, marital status, education, household income, smoking, alcohol drinking, and sedentary activities (watching TV, playing video games, surfing the internet, reading, and drawing). At the community (between) level, we controlled for the urban/rural status and province of the communities.

[INSERT FIGURE 1 ABOUT HERE]

Measures

Urbanization. Urbanization was indexed for the 218 sampled communities in the CHNS (Popkin, 1999) from 2000 to 2009, based on assessments of 12 components at community levels from local area administrators or official records on a 10-point anchored format (e.g., population density, housing, transportation, modern markets, economic activity, communications, income diversity, and health infrastructure). The 12 component scores were summed to produce the overall urbanization score, which has a possible range from zero to 120. The urbanization index has displayed adequate reliability and validity in previous studies (Cyril et al., 2013; Jones-Smith & Popkin, 2010) and showed good levels of reliability across the assessments from 2000 to 2009 in the present study (Cronbach's αs = 0.864 to 0.895).

Metabolic syndrome. The present study adopted the worldwide consensus definition of metabolic syndrome from the International Diabetes Federation (Alberti et al., 2006). As listed in Supplementary Table 1, central obesity (waist circumference ≥ 90cm/80cm for males/females) is the prerequisite risk factor for diagnosing metabolic syndrome in the present Chinese sample. In addition, the person must satisfy at least two of the following risk factors: raised triglyceride levels, reduced high-density lipoprotein cholesterol, raised blood pressure, and raised fasting plasma glucose.

Biomarkers. The China-Japan Friendship Hospital, the Ministry of Health collected biological specimens on a range of metabolic biomarkers from the study participants at 2009. Trained field interviewers collected 12 ml of blood samples by venipuncture from the consenting participants on an empty stomach. The participants were advised to maintain a regular pattern of life for three days prior to sample collection and to relax and wear loose clothing during the process of sample collection. Detailed procedures of the sample collection are described elsewhere (Yan, 2009). The blood samples were packaged and shipped to the Beijing Central Laboratory for processing and preservation. The whole blood was centrifuged, and the serum was tested for glucose, triglycerides, and high-density lipoprotein cholesterol in the laboratory under a standard protocol. The laboratory assay showed a coefficient of variation of < 7.0% across assays.

Anthropometric measures. Participants' height, weight, and waist circumference were measured under standard protocols at 2009. Height was assessed without shoes to the nearest 0.2 cm using a stadiometer and weight was measured without shoes and in minimal clothing to the nearest 0.1 kg on a calibrated beam scale. BMI was calculated as the ratio of weight (kg) to the square of height (m^2). Waist circumference was assessed midway between the lowest rib and the iliac crest using a non-elastic tape. Blood pressure monitors were used to measure the systolic and diastolic blood pressures.

Dietary intake. Dietary intake was obtained from the participants for three consecutive days on a 24-hour recall basis from 2000 to 2009. The participants were asked to report all food they consumed at home and away from home. Over 99% of the sample complied with the collection of dietary data. The field interviewers had received three days of training about the collection of dietary data and had prior experience in both nutrition work and national surveys.

The present study measured dietary intake (grams) of the participants on the following four food types: 1) cereals (rice, wheat, corn, and barley), 2) red meat (pork, beef, lamb, and horse), 3) dairy products (eggs, milk, yogurt, and cheese), and 4) fast food (convenience food, sugar drinks, cakes, and snacks) from 2004 to 2009. The intake was derived based on the Food Composition Table for China (Yang, 2005), which contains detailed lists of food types and nutrient values for all kinds of foods. The total caloric intake (kcals) of the participants derived at 2000 was entered into the model to adjust for the baseline energy intake.

Physical activity. The present study assessed physical activity of the participants in four domains: occupation, home, leisure, and transportation. To account for both intensity and time spent on the activities, the physical activity measures were measured in terms of Metabolic Equivalent of Task (MET)-hours per week (Sallis et al., 1985). Occupational activity was assessed via self-reported occupations and average number of work hours per week. Specific MET values were assigned to different occupations according to their activity levels (Ng et al., 2009). High-activity occupations such as farming, gardening, fishing, and working with livestock were assigned a MET value of 6 per work hour. Four METs per work hour were given to occupations such as craftsmen, foremen, ordinary laborers, loggers, drivers, homemakers, and students and two METs per work hour were assigned to administrators, executives, managers, professionals, and office staff. These MET values were multiplied by the corresponding time spent to derive the occupational activity. Participants also reported hours spent per week traveling to and from work/school which were multiplied by the specific MET values for the transportation mode: three for walking, four for cycling, and one and half for motorized vehicle use. Transportation activity was computed as the aggregate of these measures.

Home activity was evaluated based on five domestic activities: buying food, preparing food, house cleaning, childcare, and laundry. The average time spent in these activities was multiplied by the specific MET values based on the Compendium of Physical Activities (Ainsworth et al., 2000): 2.3 for buying food, 2.25 for preparing food, 3.0 for house cleaning, 2.75 for childcare, 2.15 for laundry. The total home activity was calculated as the sum of these MET-hours/week. Participants were asked about their participation in leisure activities including dancing, aerobics, jogging, swimming, martial arts, and various ballgames. The average time spent in these activities was multiplied by their specific MET values: 7.5 for jogging/swimming, 4.5 for martial arts, 5 for tennis/badminton/pingpong/dancing/aerobics, and 6 for soccer/basketball/volleyball. These MET-hours/week were aggregated to obtain the total leisure activity. The sum of occupational, transportation, home, and leisure activities provided the total physical activity from 2000 to 2009.

Data Analysis

Independent sample *t*-tests and χ^2 tests were carried out in SPSS 23 to compare the participants' demographic and health profiles across gender. Cohen *d* was calculated as the standardized gender difference to denote the effect size, with values of 0.2, 0.5 and 0.8 denoting small, medium, and large effect sizes, respectively. Latent growth modeling was performed to derive the growth in urbanization, dietary intake, and physical activity. Because of gender differences in the criteria of classifying metabolic syndrome, the present study conducted multilevel mediation analysis stratified by gender in Mplus 8.1 (Muthén & Muthén, 2017). The community identity variable was specified as the cluster variable to account for complex survey design. BMI, metabolic syndrome, and changes in dietary intake and physical activity were specified to have within-level and between-level variations. The filled circles at the arrows' end in the within level of Figure 1 denote the random intercepts in the between part of the model. The design effect was computed using the intraclass correlation coefficients (ICC) and this formula: design effect = 1 + (cluster size - 1) × ICC. The ICC denotes the degree of within-cluster dependence or relatedness.

The present study estimated the between-level direct effect and indirect effect (IE) of changes in urbanization on metabolic syndrome via changes in dietary intake and physical activity. The present analysis considered control variables such as baseline statuses, rural/urban status, and province in the model. Latent mean centering was adopted using Bayesian estimation to decompose the mediator and outcome variables into within-level and between-level components. This approach accounts for the measurement errors (Asparouhov & Muthén, 2018). The Bayesian multilevel model was estimated with default uninformative priors with two Markov chain Monte Carlo chains and probit link over a minimum of 10,000 iterations (Asparouhov & Muthen, 2010). Mplus used the latter half of the iterations to empirically derive the posterior parameter distribution of the parameters without the normality assumption.

Model convergence was checked using the trace plots, autocorrelation plots, and potential scale reduction criterion (Gelman et al., 2014), with a value of less than 1.05 implying small between-chain variation relative to within-chain variation and thus model convergence. Via the Bayesian posterior predictive checking, the multilevel path models were deemed to fit the observed data well with large posterior predictive *p* values (*ppp*s > 0.10). Missing data were handled using full information maximum likelihood under the missing-at-random assumption (Little & Rubin, 2014). The direct and indirect effects were statistically significant if their 95% credibility intervals (*CI*) excluded zero. The non-symmetric credibility intervals could accommodate the likely skewed indirect effect.

Results

Profiles of CHNS Participants

The overall sample had a mean age of 39.2 years (*SD* = 9.2) and received 18.5 years of education. The study sample comprised more females than males. The majority of the sample was married (84%), resided in rural areas (68%), and did not smoke cigarettes (68.3%) or drink alcohol (64.8%). Male participants (Table 1) reported significantly higher proportions of smoking and alcohol drinking as well as higher levels of education, sedentary activities, and total caloric intake (ds = 0.29 to 0.62, ps < 0.01) than females. No gender differences appeared in age, household income, and BMI (ds ≤ 0.03, ps > 0.30). Males showed significantly higher levels of waist circumference, triglycerides, blood pressures, and blood glucose, but lower high-density lipoprotein cholesterol (ds = 0.12 to 0.35, ps < 0.01) than females. Females showed a higher prevalence (26%) of metabolic syndrome over males (19%).

[INSERT TABLE 1 ABOUT HERE]

Changes of Urbanization, Dietary Intake, and Physical Activity

Table 2 displays the profiles of urbanization, physical activity, and dietary intake of the sample across gender. Urbanization index and dairy products intake did not differ significantly (ds ≤ 0.05, ps > 0.11) across gender. There were significant but trivial gender differences in physical activity and fast food intake (ds ≤ 0.15, ps < 0.05) and males reported significantly higher levels of intakes of red meat and cereals (ds = 0.21 to 0.46, ps < 0.01) than females. Latent growth modeling revealed a linear trend in urbanization with an annual increase of 0.93 ($p < 0.01$) in urbanization index from 2000 to 2009. There was significant variation (*SD* = 0.83, $p < 0.01$) in the change across the communities. The participants reported a significant linear increasing trend in intakes of red meat, dairy products, and fast food, with mean annual changes of 1.42, 1.19, and 3.19, respectively; significant decreasing trends were found for cereal intake (mean annual change = -6.89) and physical activity (mean annual change = -6.41). There were inter-individual variations in the changes of dietary intake (*SD*s = 0.79 to 6.29, *p*s < 0.01) and physical activity (*SD* = 9.46, *p* < 0.01).

[INSERT TABLE 2 ABOUT HERE]

Multilevel Path Models and Direct Effects

The male and female subsample had an average cluster size of 13.3 and 15.3, respectively. The two subsamples showed low degrees of cluster relatedness in BMI and metabolic syndrome (ICCs = 0.04 to 0.11). The design effects for changes in dietary intake ranged from 2.1 to 6.5 in males (ICCs = 0.09 to 0.34) and females (ICCs = 0.08 to 0.38). The design effects for physical activity were 5.0 and 5.4 in male (ICC = 0.32) and female subsample (ICC = 0.31), respectively. All of the multilevel path models for the mediators converged within 11,000 and 22,500 iterations in male and female subsamples, respectively. Acceptable fit was found for these models to the data across gender (*ppp*s = 0.11 to 0.37). The absence of upward/downward trends across iterations in the trace plots and the diminishing trend of the autocorrelation plots at increasing lag supported good mixing of the parameters.

Table 3 displays the between-level estimates among the main study variables in the multilevel path models across gender. Controlling for rural status, province, and baseline statuses, urbanization slope significantly predicted physical activity slope and cereal intake slope (*β*s = -0.10 to -0.19, *p*s < 0.05) in males. For females, urbanization slope significantly predicted cereal intake slope and fast food slope (*β*s = -0.09 to 0.17, *p*s < 0.05). Urbanization slope did not have significant effects on intakes slopes of red meat and dairy products (*β*s = 0.06, *p*s > 0.05) across gender.

[INSERT TABLE 3 ABOUT HERE]

The direct effects of urbanization slope (Table 3) on metabolic syndrome were positive but non-significant across gender (βs = 0.12, *p*s < 0.05). Similarly, BMI did not have a significant effect on metabolic syndrome (βs = -0.01 to 0.10, *p*s > 0.05) across gender. Physical activity slope significantly and negatively predicted both BMI and metabolic syndrome (βs = -0.34 to -0.41, *p*s < 0.05) in males but not females (βs = -0.03 to -0.17, *p*s > 0.05). Slope of cereal intake and dairy products only had trivial effects on metabolic syndrome across gender (βs = -0.15 to 0.23, *p*s > 0.05). Red meat intake slope had significant and positive effects on BMI and metabolic syndrome across gender (βs = 0.36 to 0.52, *p*s < 0.05). Slope of fast food intake had positive effects on metabolic syndrome (βs = 0.38 to 0.48, *p*s < 0.05) across gender.

Indirect Effects of Urbanization on Metabolic Syndrome

For males, the indirect effects from urbanization slope to metabolic syndrome via carious slopes of dietary intake were not statistically significant with the 95% *CI*s including zero (e.g., *IE* via fast food intake slope = 0.022, 95% *CI* = -0.013 to 0.069). Urbanization slope showed a significant and positive indirect effect (*IE* = 0.062, 95% *CI* = 0.024 to 0.112) on metabolic syndrome via change in physical activity. Change in physical activity mediated 39.5% of the total effect (*B* = 0.157, 95% *CI* = 0.027 to 0.291) of urbanization slope on metabolic syndrome. The model explained 70.2%, 78.7%, and 85.6% of the variance of physical activity slope, BMI, and metabolic syndrome in the between level.

For females, the indirect effect from urbanization slope to metabolic syndrome via change in physical activity was not statistically significant (*IE* = 0.009, 95% *CI* = -0.005 to 0.033). The same held for the intakes of cereal, red meat, and dairy products. There was a significant and positive indirect effect from urbanization slope to metabolic syndrome via change in fast food intake (*IE* = 0.049, 95% *CI* = 0.008 to 0.108). Change in fast food intake mediated 45.0% of the total effect (*B* = 0.109, 95% *CI* = -0.005 to 0.223) of urbanization slope on metabolic syndrome. The multilevel mediation model explained 66.3%, 59.3%, and 55.7% of the variance of fast food intake slope, BMI, and metabolic syndrome in the between level.

Discussion

The present study is the first to evaluate the effects of urbanization on metabolic syndrome via changes in lifestyle factors in the CHNS data using multilevel mediation analysis. Overall, the rising urbanization index reflects the social and economic development of the Chinese society and the increasing intake of meat, dairy products, and fast food denotes a shift in dietary pattern of Chinese adults as a result of urban lifestyle (Hawkes et al., 2017). The declining levels of physical activity across time for both males and females are consistent with findings of previous CHNS studies (Ng et al., 2014; Ng et al., 2009). Our results suggest that participants situated in communities with faster urbanization showed sharper decreases in physical activity and cereal intake and greater increases in fast food intake. Increases in intake of red meat and fast food were found to increase the risk of metabolic syndrome in both males and females. These effects in general resemble recent findings that linked dietary patterns with obesity in adolescents (Zhen et al., 2018) and older people (X. Y. Xu et al., 2015). Though intake of cereals such as rice or wheat remains the major caloric source among Chinese adults, the present study found trivial effects for cereal intake on metabolic syndrome across gender.

Gender Discrepancy in the Urbanization Effect on Metabolic Syndrome

In line with previous studies (Attard et al., 2012; Yan et al., 2012), the present study found a positive total effect from urbanization to metabolic syndrome in the CHNS participants. There was a positive but non-significant direct urbanization effect on metabolic syndrome in both males and females. Our gender-stratified analysis reveals different significant indirect effects from urbanization to metabolic syndrome across gender. The urbanization effect appears to act through decreases in physical activity and increases in fast food intake, respectively, in males and females. These results support gender-specific mediating roles for physical activity and fast food intake in the urbanization effect.

The present gender discrepancy in the indirect pathways is illuminating. A recent study (Xu et al., 2017) among 6,739 Chinese adults observed a negative association between physical activity and risk of obesity only in males but not females. Another study (Hu et al., 2014) among 1,706 Taiwanese adults also found significant associations between occupational activity and risk of cardiovascular disease in males but not females. Given the dominant occupational role for Chinese males and that occupational activity is the major component of physical activity (Ng et al., 2009), it is plausible that physical activity exerts greater influences on health outcomes in males than females.

In contrast, our findings suggest that fast food intake might mediate the urbanization effect on metabolic syndrome in females rather than males. Women have shown higher snacking frequency than men in a previous study (Forslund et al., 2005). Urbanization not only improves education levels and economic opportunities for females but also leads to surging costs of living for households, all of which could lead to the steady rise in female labor force participation in China during the 2000s (Yuxiao Wu & Zhou, 2015). Since more women need to play dual roles as caregivers and income earners in urbanized communities (Cook & Dong, 2011), they likely have less time to cook and eat at home. The work-family conflict implies that females could shift to increased intakes of fast food in order to save time and effort.

Methodological Implications

The existence of community-level variations and sizable design effects confirm the need to use multilevel analysis. The present study is a first application of multilevel mediation analysis with latent mean centering. The existence of a categorical outcome, small cluster size (*N* ≤ 15), and missing data in study variables could well lead to biased results in the use of observed mean centering (Lüdtke et al., 2008). Latent mean centering clearly separates the within-level and between-level effects and is the most accurate and easily interpretable method of centering in multilevel analysis (Asparouhov & Muthén, 2018). The present study focused on the indirect effects of urbanization on metabolic syndrome via dietary intake and physical activity. The conventional a × b product formula remains valid for the indirect effect on the continuous latent response variable underlying the binary metabolic syndrome. The present analysis demonstrates the viability and usefulness of this novel technique in multilevel mediation analysis. Urbanization as a community-level construct could show cross-level interaction effect and moderate the individual-level health risk of BMI on metabolic syndrome. Potential interactions among urbanization, dietary intake, and physical activity could be explored in their influences on metabolic syndrome in future studies.

Limitations

There are several limitations in the present study. First, sampling weights are not available for multilevel analysis in the CHNS data. This warrants cautions in generalizing our findings to the general Chinese population and replication studies on the urbanization effect are needed in other waves or datasets. Second, the present CHNS study did not include rigorous measures of physical inactivity, which could be another relevant lifestyle factor of metabolic syndrome. A recent study (Mielke et al., 2018) has found higher prevalence of inactivity in women than in men. It would be of interest to compare the role of physical inactivity with physical activity in future research. Third, the present study focused on the overall degree of urbanization and did not assess the effects of its twelve components. Since different components may have varying effects on the lifestyle factors, further studies are needed to explore the possible diversity within these domains.

Fourth, the present study found significant differences in the study variables across provinces. For instance, two provinces (Heilongjiang and Guizhou) displayed significantly lower urbanization growth than Jiangsu province. Given the CHNS sample recruitment from provinces with distinct geographical locations and settings, spatial autocorrelation could exist and lead to non-independence at the community level. Future studies should attempt to account for the spatial autocorrelation to enable precise analyses and unbiased estimates. A larger sample size (at least 20) at the province level would make possible extending the present two-level model to three-level model. The three-level model would allow researchers to incorporate province-level characteristics that could explain the spatial autocorrelations.

Practical implications

Urbanization has been linked with increased availability of fast food restaurants within the communities (Y. Wu et al., 2017). Such an urbanized food environment could boost the community norm for fast food preference. The increased intake of unhealthy diets such as convenience food and sugar-sweetened beverages likely contributes to dietary excess and obesity. Public health interventions on dietary pattern should be conducted to raise the citizens' awareness of the health risks of unhealthy diets and promote better dietary knowledge. Mass media campaigns at the community level could help change individual dietary behaviors (Wakefield et al., 2010). The Chinese government could establish laws to regulate menu labeling, restrict marketing of unhealthy junk food, and ban the use of trans fats to discourage fast food consumption and protect the public health.

Technological advance in urbanizing communities contributes to declining levels of physical activities at workplace and home together with increasing sedentary activities. Given the crucial role of physical activity in sustaining metabolic balance, urban planning policies should be considered to promote overall physical activity (Ng et al., 2014). First, architectural design of new buildings should make stairways more centrally located to encourage walking in indoor environments. Second, more pathways in the urban area could foster a favorable environment for bicycles and pedestrians which promotes active transport activities. Similarly, the bicycle-sharing system could facilitate access to bicycles and promote the healthy habit of cycling. Third, the Chinese government could discourage motorized transportation via imposing higher sales taxes on automobiles. Fourth, more sport facilities could be set up for indoor and outdoor exercise and public health programs can be launched via mass media to encourage a healthy lifestyle of engaging in regular leisure activities.

Conclusions

The growth in urbanization has brought the Chinese society economic prosperity and advances in infrastructure and transportation networks. Despite the improved healthcare access and increased life expectancy for Chinese adults (Zhu et al., 2011), the increasing incidence of chronic, non-communicable disease such as metabolic syndrome imposes enormous health burdens to the urbanizing communities. Built on the existing findings of CHNS, the present study elucidates our understandings on the urbanization effect on metabolic syndrome via changes in lifestyle factors. We demonstrated that urbanization led to reduced physical activity levels and increased fast food intake which in turn predicted a higher risk of metabolic syndrome. Future waves of the CHNS data are needed to closely monitor the developmental trends of urbanization, lifestyle factors, and metabolic syndrome among this cohort of Chinese adults.

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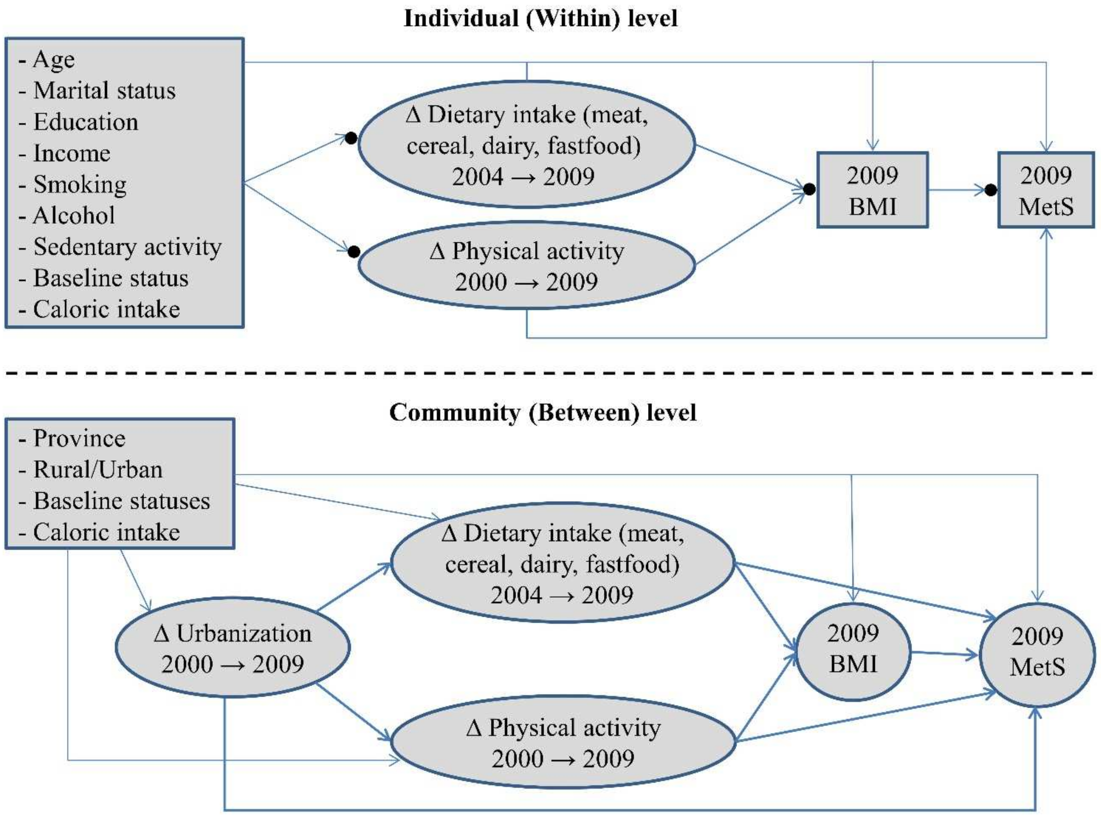

Figure 1. Multilevel mediation model of the effects of growth in urbanization from 2000 to 2009 on metabolic syndrome (MetS) via changes in dietary intake (meat, cereal, dairy, fastfood) and

physical activity and body mass index (BMI). The filled circles in the within level denote the random intercepts. Baseline statuses denote the baseline levels of the predictor and mediators at 2000.

Table 1. Demographic and health profiles of the CHNS adult participants across gender.

	Male	Female			
Variables	*N (%)*	*N (%)*	χ^2	*p*	
Married	2132 (74)	3148 (95)	253.6	<0.01*	
Smokes cigarettes	1850 (64)	116 (4)	2618.8	<0.01*	
Drinks alcohol	1879 (65)	304 (9)	2117.0	<0.01*	
Resides in rural area	1971 (68)	2248 (68)	0.18	0.67	
Metabolic syndrome	546 (19)	864 (26)	44.05	<0.01*	
Variables	*M (SD)*	*M (SD)*	*t*	*p*	*d*
Age at 2000 (years)	39.3 (9.3)	39.1 (9.2)	0.82	0.42	0.02
Education (years)	20.8 (5.8)	16.3 (8.6)	19.3	<0.01*	0.62
Household income (1000 Rmb)	5.68 (5.56)	5.72 (5.58)	-0.23	0.82	0.01
Sedentary activities	0.30 (0.16)	0.26 (0.14)	9.48	<0.01*	0.29
Total caloric intake (kcal)	2506 (643)	2175 (588)	17.1	<0.01*	0.54
Body mass index (BMI)	23.6 (3.3)	23.7 (3.4)	-1.02	0.31	0.03
Waist circumference (cm)	84.9 (9.9)	81.5 (9.8)	13.5	<0.01*	0.35
Triglycerides (mmol/L)	1.92 (1.85)	1.59 (1.30)	8.26	<0.01*	0.21
HDL cholesterol (mmol/L)	1.39 (0.56)	1.47 (0.46)	-5.47	<0.01*	0.14
Systolic BP (mmHg)	124.9 (16.1)	121.9 (18.5)	6.66	<0.01*	0.17
Diastolic BP (mmHg)	82.6 (10.9)	79.4 (11.2)	11.30	<0.01*	0.29
Blood glucose (mmol/L)	5.50 (1.65)	5.32 (1.32)	4.78	<0.01*	0.12

HDL = high-density lipoprotein; BP = blood pressure; *d* = Cohen *d*. **p* < 0.05.

Table 2. Profiles of urbanization, dietary intake, and physical activity across gender.

Variables	Male *M (SD)*	Female *M (SD)*	*t*	*p*	*d*
2000 Urbanization	57.8 (18.3)	58.2 (18.2)	-0.95	0.34	0.02
2004 Urbanization	61.2 (19.8)	61.5 (20.0)	-0.59	0.56	0.02
2006 Urbanization	63.1 (20.4)	63.4 (20.4)	-0.63	0.53	0.02
2009 Urbanization	66.8 (19.4)	67.1 (19.4)	-0.66	0.51	0.02
2000 Physical activity (MET-hrs)	312 (164)	288 (155)	4.74	<0.01*	0.15
2004 Physical activity	276 (233)	255 (227)	3.02	<0.01*	0.09
2006 Physical activity	271 (238)	255 (231)	2.35	0.02*	0.07
2009 Physical activity	254 (220)	236 (223)	3.04	<0.01*	0.08
2004 Cereal intake (g)	486 (207)	421 (171)	11.3	<0.01*	0.35
2006 Cereal intake	459 (187)	396 (165)	12.2	<0.01*	0.36
2009 Cereal intake	452 (178)	377 (151)	17.9	<0.01*	0.46
2004 Red meat intake (g)	79.1 (84.3)	62.8 (70.3)	6.93	<0.01*	0.21
2006 Red meat intake	84.3 (84.5)	68.1 (69.7)	7.12	<0.01*	0.21
2009 Red meat intake	87.1 (77.0)	70.4 (66.2)	9.04	<0.01*	0.23
2004 Dairy product intake (g)	35.9 (63.3)	33.0 (57.4)	1.57	0.12	0.05
2006 Dairy product intake	40.7 (66.2)	38.7 (60.1)	1.08	0.28	0.03
2009 Dairy product intake	42.3 (62.8)	40.5 (57.7)	1.15	0.25	0.03
2004 Fast food intake (g)	6.2 (24.7)	5.7 (23.1)	0.77	0.44	0.02
2006 Fast food intake	16.3 (50.1)	13.0 (38.5)	2.51	0.01*	0.08
2009 Fast food intake	24.0 (63.0)	19.2 (47.7)	3.31	<0.01*	0.09

Sample size = 1900-2854 for males and 2201-3271 for females; *d* = Cohen's *d*. **p* < 0.05.

Table 3. Between-level estimates of the multilevel mediation models across gender.

	Males (N = 2,893)			Females (N = 3,324)		
	B	95% *CI*	*β*	*B*	95% *CI*	*β*
Urbanization slope to						
Physical activity slope	**-1.464***	**-2.200 to -0.696**	**-0.193**	-0.824	-1.719 to 0.068	-0.106
Cereal intake slope	**-0.550***	**-0.821 to -0.280**	**-0.101**	**-0.447***	**-0.676 to -0.221**	**-0.089**
Red meat intake slope	0.024	-0.024 to 0.073	0.056	0.024	-0.019 to 0.066	0.059
Dairy product intake slope	0.036	-0.057 to 0.131	0.057	0.035	-0.054 to 0.127	0.059
Fast food intake slope	0.257	-0.149 to 0.666	0.075	**0.415***	**0.112 to 0.719**	**0.172**
BMI on						
Physical activity slope	**-0.071***	**-0.105 to -0.039**	**-0.344**	-0.005	-0.043 to 0.032	-0.028
Cereal intake slope	**0.091***	**0.045 to 0.139**	**0.334**	0.020	-0.036 to 0.076	0.074
Red meat intake slope	**1.912**	**0.965 to 2.918**	**0.518**	**1.606***	**0.875 to 2.356**	**0.480**
Dairy product intake slope	**-0.742***	**-1.435 to -0.099**	**-0.311**	-0.843	-3.451 to 0.105	-0.318
Fast food intake slope	0.094	-0.023 to 0.211	0.215	**0.442***	**0.316 to 0.580**	**0.786**
Metabolic syndrome on						
BMI	-0.002	-0.202 to 0.177	-0.001	0.038	-0.183 to 0.200	0.101
Physical activity slope	**-0.042***	**-0.069 to -0.020**	**-0.411**	-0.011	-0.026 to 0.005	-0.165
Cereal intake slope	0.030	-0.003 to 0.067	0.225	0.008	-0.016 to 0.033	0.078
Red meat intake slope	**0.769**	**0.186 to 1.429**	**0.422**	**0.455***	**0.001 to 0.953**	**0.358**
Dairy product intake slope	-0.183	-0.647 to 0.232	-0.154	-0.163	-1.477 to 0.243	-0.137
Fast food intake slope	**0.083***	**0.016 to 0.164**	**0.375**	**0.103**	**0.006 to 0.250**	**0.477**
Urbanization slope	0.095	-0.034 to 0.225	0.122	0.060	-0.057 to 0.175	0.116

CI = credibility interval; B = unstandardized coefficient; β = standardized coefficient. *p <0.05.

Highlights

- Multilevel mediation analysis conducted with 6217 Chinese adults.
- There are increasing trends in urbanization and dietary intake except for cereals.
- Urbanization showed a positive direct effect on metabolic syndrome in males only.
- Physical activity mediated the urbanization effect on metabolic syndrome in males.
- Dietary intake mediated the urbanization effect on metabolic syndrome in females.