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Associations of Residential Density with Adolescents' Physical Activity in a Rapidly Urbanizing Area of Mainland China

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ABSTRACT *In the context of recent social and economic transitions in China, lack of physical activity among adolescents is an emerging health risk, particularly so in rapidly expanding urban areas. Evidence from Western countries suggests that built environment attributes can influence the physical activity participation of young people, but whether or not this is the case for China is unknown. We recruited high school students from ten urban districts in Nanjing, Mainland China (n=2,375; mean age=13.9± 1.0 years old; 46% boys; survey response rate=89%). The outcome variable was self-reported recreational physical activity time; the primary explanatory variable was the residential density of the urban districts. Analysis was conducted using mixed-effects logistic regression models. After adjustment for potential confounding variables, including sedentary behavior and green space, there was a consistent and graduated association between residential density and physical activity; residential density was significantly negatively associated with recreational physical activity time for students from the higher tertile of residential density (OR; 95% CI=0.64; 0.42 to 0.97) compared to those from the lower tertile. The direction and magnitude of the negative association between residential density and physical activity was similar for boys and girls. It should be a public health priority to identify the particular urban environment attributes that can encourage and support young people's participation in physical activity.*

KEYWORDS *Built environment, Residential density, Physical activity, Sedentary behavior, Adolescents, China*

INTRODUCTION

Mainland China is the most populous country in the world. It has undergone rapid economic growth and the consequent concentration of populations in urban areas, especially since the "Open Door Policy", which committed China to adopting a free-market economic system and promoting foreign trade and economic investment, was adopted in 1978. Rapid social, economic, and environmental changes have caused major lifestyle transitions: an increasing number of Chinese people, particularly in urban areas, now own private vehicles, television sets, and computers

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with access to the Internet. These changes and associated declines in physical activity, in particular, will have serious health consequences.[1,2] Lack of physical activity is an emerging public health issue that needs to be addressed in urban areas of China.[3]

In the context of economic, social, and epidemiological transition, a particular public health concern for China is the physical activity of young people. It is known that levels of physical activity decline throughout adolescence.[4] This decline is considered to be partly responsible for adolescent obesity,[5] which is likely to lead to greater health risk in adulthood.[6] Given that the prevalence of overweight or obesity in adolescents living in China's urban areas has been increasing dramatically since the early 1990s—and is now equivalent to the level of some developed countries[7]—increasing participation in physical activity in youth is a public health priority.

Chinese rapid economic growth and urbanization have led to significant changes in the built urban environment and greater numbers of people are exposed to the potential health effects of urbanization and reduction of green space. In Western countries, researchers and policy makers are recognizing the significance of the built environment for physical activity. Research conducted mainly in the USA and Australia has shown that neighborhood environmental factors such as residential density, land use mix, access to destinations, sidewalks, and esthetics are associated with residents' physical activity.[8,9] However, Chinese urban environments may be different from those in USA or Australia, and Chinese people may interact with the built environment attributes of their neighborhoods differently from those in the Western countries. Thus, there is the need for research on the built environment correlates of physical activity in the Chinese urban context.

Residential density is one of the key environmental attributes relevant to physical activity.[10–12] Generally, it is known to be associated with adults' transport-related physical activity, as higher residential density means more destinations such as shops, services, and public transport stops nearby.[13] With regard to the association between adolescents' recreational activity and residential density, mixed findings have been reported from a small number of studies. One such study conducted in the USA showed that an index of neighborhood walkability, which includes residential density, to be positively associated with moderate-to-vigorous physical activity in adolescents aged 14–17 years.[14] Young people living in higher-density, more-walkable neighborhoods, where recreational destinations (and more transport options to get there) are more-readily available, may thus be more likely to participate in recreational activity. However, research in Australia has shown that boys (13–15 years) living in cul-de-sacs, which are typically found in lower residential-density neighborhoods, engage in more moderate-to-vigorous physical activity compared to those living in neighborhoods with higher street connectivity, which tends to typify areas with higher population densities.[15] Another study in the USA reported that no link between residential density and accelerometer-measured physical activity among 11–15 year olds.[16] Although the quantity of relevant literature is modest, these differing associations for two Western countries suggest associations between residential density and physical activity may vary in different contexts, reinforcing the need to understand how aspects of urban form are associated with adolescents' recreational physical activity in the rapidly urbanizing context of Mainland China.

This large-scale population-based study, conducted in urban areas of Nanjing, Mainland China, examines the association between residential density and adolescents' recreational physical activity, controlling for potential confounding variables.

METHODS

Sample Selection

The Nanjing High School Students' Health Survey was conducted in Nanjing Municipality between September and November 2004. Nanjing is located in Eastern China, and had a population of approximately six million in 2004. It comprises 13 administrative units; ten urban districts and three suburban/rural counties since 2003. All ten urban districts were included in this study. The study used a multi-stage proportional sampling method to recruit participants, which has been described in detail elsewhere.[17]

Participants

The target population was junior high school students (grade 7–9; age 13–15 years) living in urban districts within Nanjing Municipality. Twenty-four junior high schools were randomly selected from the ten urban districts, and all students in three classes from each selected school were invited to participate. After informed consent was obtained from involved schools and participants, the students were interviewed face-to-face by trained healthcare professionals. The conduct of the study was approved by the academic and ethical committee of Nanjing Municipal Center for Disease Control and Prevention in accordance with internationally agreed ethical principles for medical research involving human subjects (World Medical Association Declaration of Helsinki).

Measures

The outcome measure of the study, time spent in recreational physical activity (PA time), was identified through the question "How much time (in minutes) did you ever spend in doing recreational physical activity on a typical weekday in the past two weeks?" The same question was repeated to gather information for a typical weekend day. PA time was calculated as the average time spent in recreational physical activity per week. For the analyses, PA time was dichotomized at the median (11.0 hrs/wk). Time spent sitting for TV viewing and course study were each recorded in a similar manner to PA time. Sedentary behavior time (SB time) was computed by adding these times. The questions regarding physical activity and sedentary behavior were based on the validated Chinese version of International Physical Activity Questionnaire, with a slight modification on the recall period—extending from the last 1 week to the last 2 weeks.[18]

Residential density was the main independent variable, and calculated as the number of regular urban residents divided by district size (km^2) for each urban district. Numbers of urban residents and district size in 2004 were obtained from the Nanjing Municipal Bureau of Statistics.[19] We defined public green space as green space residents have free access to, not including private and industrial green spaces. For each district, we recorded green space as the total area of public green space (km^2) divided by district size (km^2). All students in the same district share the same residential density and green space.

The questionnaire gathered socio-demographic and anthropometrical information such as age, sex, total weekly pocket money, body weight and height, and parents' employment status. Body mass index (BMI) was calculated from self-report weight and height. Overweight was defined as a BMI $\geq$ 85th percentile value for age- and sex-specific reference data according to the recommendation for Chinese adolescents by the Group of China Obesity Task Force.[20] In China, all students are

required to have their body weight and height measured in the commencement month (generally September) of each academic year. Hence, we conducted our survey from September to November to minimize potential recall error. Parents' employment status was categorized as both parents being unemployed, one parent employed, or both parents employed.

Data Analysis

Associations between study characteristics and two key variables (sex and residential density) were examined using analysis of variance (continuous variables) or chi-square test (categorical variables). We examined the association between physical activity and residential density using mixed-effects logistic regression models. Three models were examined: model 1 is a univariable analysis with residential density as the single predictor; model 2 is a multivariable analysis, adjusting for participants' age, sex, overweight, pocket money and parents' employment status; and model 3 is a multivariable analysis further adjusted for sedentary behavior and green space in addition to the covariates included in model 2. In all models, we allowed district to have a random effect, thus, allowing for non-independence in results from participants within the same district. Data were double-entered and cleaned with EpiData 3.0 (The Epidata Association, Odense, Denmark), and managed and analyzed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA) and Stata 10.1 (StataCorp, College Station, TX, USA).

RESULTS

The total number of survey respondents was 2,375 with a response rate of 89.3%. There were no significant demographic differences between respondents and those not taking part in this survey, in terms of age and sex.

The median residential density was 7,862 persons/km^2, while the minimum and maximum values were 559 and 30,779 persons/km^2, respectively. The cut-off values for the tertiles were 3,586 and 12,665 persons/km^2.

Table 1 displays demographic characteristics of our overall sample by sex and residential density tertile. There were more girls (53.8%) than boys in the sample. Boys were more likely to be overweight and spent more time on physical activity, but less time in sedentary behavior relative to girls. Students in the higher residential density tertile spent significantly less time on physical activity but more time on sedentary behaviors ($P<0.01$), and they were also more likely to be overweight compared to their counterparts in the low-density areas. There was significant variation in physical activity across districts ($\chi^2=10.17$, $P=0.0007$). Districts contributed approximately 2.3% to the total variation in physical activity (ICC=0.023).

Table 2 presents odds ratios (OR) (95% [Confidence Interval] CI) of being in the higher physical activity group relative to being in the lower group. Compared to students from the lower residential density tertile, students in the higher and middle residential tertile had lower odds (OR=0.64, 95%CI=0.42 to 0.97; OR=0.83, 95% CI=0.59 to 1.18, respectively) of being in the higher physical activity category, after adjusting for potential confounding variables including sedentary behavior time and green space (model 3). The difference between the higher- and lower-density areas was statistically significant ($P=0.03$). The direction and magnitude of the effect of residential density on physical activity was similar across all three models. The negative association between residential density and physical activity remained for

TABLE 1 Participant characteristics by sex and residential density. Results presented as mean ± standard deviation for continuous data, and as percentages for categorical data

	Overall	Gender			Residential density[a]			
		Boys	Girls	*P* value	Lower	Middle	Higher	*P* value
Number	2,375	1,098	1,277		919	732	724	
Age	13.9 ± 1.0	13.9 ± 1.0	13.8 ± 1.0	0.20	14.0 ± 1.0	13.8 ± 1.0	13.8 ± 1.0	<0.01
Overweight (%)[b]	8.3%	12.4%	4.7%	< 0.01	5.3%	9.4%	10.8%	<0.01
Physical activity time (hr/wk)	11.6 ± 5.3	11.9 ± 5.4	11.4 ± 5.3	<0.05	12.1 ± 5.3	11.6 ± 5.2	10.9 ± 5.4	<0.01
Sedentary behavior time[c] (hr/wk)	70.5 ± 20.3	69.9 ± 20.3	71.0 ± 20.2	0.16	66.9 ± 19.2	72.3 ± 20.6	73.3 ± 20.6	<0.01
Parents' employment status[d] (%)	6.1%	5.4%	6.7%	0.32	5.7%	5.3%	7.3%	<0.01

[a]Residential density tertile cut-off values are 12,665 and 3,586 persons/km^2.
[b]Overweight defined as BMI ≥ 85th percentile value for age- and sex-specific reference data according to the recommendation for Chinese adolescents by Group of China Obesity Task Force.
[c]SB time is the sum of time spent in sitting for viewing TV and courses study.
[d]Percent in subgroup of both unemployed.

TABLE 2 Odds ratio (95% CI) for being in the higher physical activity group relative to being in the lower group among urban junior high school students in Nanjing, China

		Mixed-effects logistic regression models					
		Model 1[b]		Model 2[c]		Model 3[d]	
Residential density[a]	Participants in higher physical activity category (% and n/N)[a]	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Overall							
Lower	56.5 (520/919)	1.00		1.00		1.00	
Middle	51.9 (380/732)	0.87 (0.59-1.28)	0.48	0.85 (0.59-1.22)	0.38	0.83 (0.59-1.18)	0.31
Higher	45.4 (329/724)	0.67 (0.42-1.05)	0.08	0.66 (0.43-1.01)	0.05	0.64 (0.42-0.97)	0.03
Boys							
Lower	58.5 (250/427)	1.00		1.00		1.00	
Middle	53.4 (179/335)	0.80 (0.52-1.25)	0.33	0.77 (0.51-1.16)	0.21	0.77 (0.52-1.14)	0.19
Higher	48.2 (162/336)	0.65 (0.40-1.07)	0.09	0.66 (0.41-1.04)	0.07	0.63 (0.41-0.97)	0.04
Girls							
Lower	54.9 (270/492)	1.00		1.00		1.00	
Middle	50.6 (201/397)	0.94 (0.60-1.48)	0.79	0.92 (0.60-1.42)	0.72	0.88 (0.58-1.34)	0.55
Higher	43.0 (167/388)	0.68 (0.40-1.15)	0.15	0.67 (0.41-1.10)	0.11	0.64 (0.39-1.05)	0.08

[a]Residential density was analyzed as a trichtomous variable; physical activity was analyzed as a dichotomous variable.
[b]Model 1 is the unadjusted model.
[c]Model 2 adjusted for age, sex (overall model only), overweight, pocket money, and parents' employment status.
[d]Model 3 adjusted for age, sex (overall model only), overweight, pocket money, parents' employment status, sedentary behavior time, and green space.
n number of participants within higher physical activity category, *N* total number of participants within sub-group of residential density

boys but not for girls in the final model (model 3), with or without consideration of potential confounders.

DISCUSSION

In this representative sample of urban Chinese adolescents, we found that after statistical adjustment for potential confounding variables, including sedentary behavior and green space, there was a consistent and graduated association between residential density and physical activity: residential density was negatively associated with recreational physical activity time for students from the higher tertile of residential density (OR=0.64; 95%CI=0.42 to 0.97) compared to those from the lower tertile. Studies conducted in the USA and Australia[14–16] are inconclusive with regard to the association between adolescents' physical activity and residential density. Our findings suggest there may be a negative association between population density and recreational physical activity for adolescents, in a rapidly expanding urban area of China.

A potentially important environmental element that may link residential density with recreational physical activity is neighborhood spaces or facilities in which young people can engage in physical activity, such as parks, sports fields, and indoor sport facilities. Research has shown, for instance, that the number of parks within an 800-m distance from home is associated with adolescent girls' non-school physical activity.[21] It has also been found that adolescents who have a park within a walking distance are likely to do physical activity regularly.[22] However, the spatial data available to us for our study did not allow the proximity to students' residential addresses of parks and other outdoor recreation facilities to be examined, given the district-based recruitment method that was used.

The association between population density and recreational facilities is complex. On one hand, a city center with higher population density may have more recreational opportunities within an accessible distance from home, compared to lower-density suburban areas. On the other hand, a dense residential area with many multi-story dwellings may have less recreational facilities. These scenarios may apply to different ranges of population density: the former relationship may be pertinent to a relatively lower-density range, while the latter is likely to be the case with a higher density range. Mixed findings on the association of recreational physical activity with residential density may be at least in part due to this complex association between density and the availability of recreational facilities.

Another element that might influence adolescents' physical activity is traffic. Research has shown that children (aged 11–16 years) who reported heavy traffic and parked cars on local streets were less likely to perceive their neighborhood as a safe place for outdoor activities.[23] In large Chinese cities, high population density areas typically have narrower roads and higher traffic volume. Variations in traffic conditions in areas with different levels of residential density may have contributed to the association we observed in this study.

The mean population density of the overall Nanjing urban region is 2,346 persons/km^2, which is much higher than in American and Australian cities where environmental correlates of physical activity have been examined.[24,25] For instance, the city of Atlanta in the USA has a density of 1,220 persons/km^2.[26] The population density of the city of Adelaide, one of the capital cities of Australia, is 1,138 persons/km^2.[27] In Western countries, neighborhoods with residential density greater than 500 persons/km^2 are usually classified as densely populated areas for epidemiologic

studies.[28] However, in China, a residential density of 500 persons/km^2 may be considered a sparsely populated area. This is likely to be an important factor contributing to the differences in the associations of residential density with physical activity in this study compared previously reported studies from Western countries. The differences between our findings and those of studies conducted in Western countries suggest that the association between residential density and physical activity may operate differently in different contexts, and suggest the need for careful attention to definitions of "high" residential density in epidemiological studies regarding the impact of urban form on physical activity behavior.

This is the first study reporting the impact of residential density on the time that young people spend in recreational physical activity in China. One of its strengths is that in our multilevel regression models, we adjusted for sedentary behavior time (TV time and study time) and green space as, well as demographic and social confounders. Another strength of our study is the representativeness of the urban population achieved by using multi-stage proportional sampling methods from all ten urban districts of Nanjing City. Despite these strengths, this study has a number of limitations. First, no causality can be inferred nor implied, due to the study' cross-sectional nature. Second, physical activity time was self-reported, which may be subject to recall bias. However, self-reported data on physical activity are common in the field and remain the primary source for epidemiological research in large-scale studies like this one.[29,30] Finally, the findings should be interpreted with particular caution, as the association between residential density and physical activity is very complex in that any single factor is expected to be limited in explanatory value due to the large number of possible correlates for physical activity.

The rapid social and economic changes in Mainland China have resulted in major lifestyle transitions and rapid urbanization. The number of regular urban residents increased from 0.37 billion in 1997 to 0.59 billion in 2007 in Mainland China, excluding residents in Hong Kong and Macao.[31] With such rapid urbanization, large cities in developed regions of Mainland China are becoming increasingly densely populated in residential areas. For example, in the urban area of Nanjing, our survey city, the mean residential density increased from 1,376 persons/km^2 in 1997 to 2,346 persons/km^2 in 2007.[19] Therefore, there is a unique opportunity to further understand the impact of relatively rapid changes in residential density on physical activity in the current context of Mainland China. Further well-designed projects are needed to explore this issue in these newly expanding urban regions.

In conclusion, using data from a large representative population sample, our findings showed a consistent and graduated negative association between residential density and physical activity in urban Chinese adolescents: those who live in higher-density areas are less physically active. Promoting adolescents' physical activity is a high priority health issue for China's urban areas, given the rapid increase in the prevalence of overweight or obesity in this population. Further well-designed research is needed to identify more specific urban environmental attributes that can make positive contributions to young people's physical activity.

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