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Walking, obesity and urban design in Chinese neighborhoods

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ABSTRACT

Objective: We examined the connections (1) between the design of the built environment and walking, (2) between the design of the built environment and obesity, and (3) between walking and obesity and income in urban settings in China.

Methods: Six neighborhoods with different built environment characteristics, located in the Chinese cities of Shanghai and Hangzhou, were studied. Data on walking and other physical activity and obesity levels from 1070 residents were collected through a street intercept survey conducted in 2013. Built environment features of 527 street segments were documented using the Irvine–Minnesota Inventory-China (IMI-C) environmental audit. Data were analyzed using the State of Place™ Index.

Results: Walking rates, household income and Body Mass Index (BMI) were related; neighborhoods with a higher State of Place™ Index were associated with higher rates of walking.

Conclusion: This study began to establish an evidence base for the association of built environment features with walking in the context of Chinese urban design. Findings confirmed that the associations between “walkable” built environment features and walking established in existing research in other countries, also held true in the case of Chinese neighborhoods.

Introduction

China faces growing problems with obesity and chronic disease (Wang et al., 2005; Wang et al., 2007). A recent survey in ten Chinese provinces found that 34% of adults between the ages of 20 and 69 are overweight (Xiaochen and Lei, 2013). In fact, one-fifth of all overweight or obese people in the world are Chinese. Obesity and chronic diseases cause 80% of deaths in China, costing billions in lost productivity (Bekedam, 2006). Existing research links obesity to affluent populations and to urban areas in China (Wu et al., 2005). The association of obesity and income has typically been assumed to be a direct one: higher income has been associated with greater obesity and has been explained by shifts to Western diet, sedentary work, and motor transportation (Wang et al., 2007). The association of obesity with urban residence is particularly concerning given China's rapid urbanization. By 2025, China will have 221 cities with one million+ people (The State of China's Cities, 2010). There is a pressing need to reduce obesity in China's growing urban population. We also need to better understand the link between income and obesity, especially given China's increasing middle class, to effectively target interventions.

Obesity and chronic disease in China have been linked to decreasing physical activity and to other factors, especially changing diets and environmental pollution (Wang et al., 2005; World Health Organization, 2008). In the last two decades, physical activity declined by over 30% among Chinese adults, including reduced walking and bicycling (Ng et al., 2009). For men, self-reported occupational, domestic, transportation, and leisure physical activity, fell from 350 MET (metabolic equivalent) hours per week in 1997 to 253 MET hours per week in 2006.[1] Women's physical activity declined from 390 MET hours per week in 1996 to 246 MET hours in 2006. Few studies of physical activity in China have distinguished between walking and other forms of physical activity. At the same time, the odds of being obese were found to be 80% higher for Chinese adults who own a motorized vehicle, compared to those who did not; this discrepancy is linked to differences in travel behavior, including walking or bicycling versus motorized travel (Bell et al., 2012). Declining walking in China has been exacerbated by Chinese development patterns that encourage sprawl and impede active modes of travel (Day et al., 2013a; Quan and Sun, 2011; Shi et al., 2011; Xu et al., 2011). China's urbanization goals are expected to spur massive additional development, including an estimated 170 mass-transit systems, 5 billion square meters of road and 40 billion square meters

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[1] A MET unit is the ratio of a person's working metabolic rate relative to his/her resting metabolic rate (Sallis et al., 1998).

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of floor space (The State of China's Cities, 2010). The urban development patterns these new cities adopt are likely to impact future rates of walking and bicycling for transportation and for recreation. While rapid urbanization in its current form poses a threat to the health of Chinese cities, it also presents an important opportunity to adopt new, more sustainable, urban development patterns that include urban design that supports active living (i.e., being physically active as a part of everyday life, including increased walking for recreation and for travel).

Chinese cities differ significantly from many Western cities in terms of their urban design (Day et al., 2013a,b). Chinese cities are extremely dense compared to cities in the USA or other Western countries; for example, the density of Shanghai suburbs exceeds that of many urban neighborhoods in Western cities. Also, inward-facing or gated communities are very common in China; a majority of residential buildings are oriented around internal courtyards or lanes, surrounded by gates that create blank or inactive street facades. This design feature reflects historical patterns in which daily life—including some forms of physical activity—was conducted "inside" the community. It is unclear whether findings on the association between built environment features and walking and other physical activity from Western cities can be directly applied to China.

Research on the links between walking and the built environment in Chinese cities is thin. The few empirical studies conducted have produced some counterintuitive findings: in the Chinese context, high density has been associated with reduced recreational physical activity (Xu et al., 2009) and increased overweight (Xu et al., 2010). Extremely high density may limit open space and parks, leaving little space for walking or other physical activity. Extremely high density may also cause severe traffic nuisances and safety and pollution concerns, which could further discourage walking and other outdoor physical activity.

Existing research on these issues in Chinese cities have measured built environment features somewhat crudely. For example, in the studies noted above, the density measure was based on the aggregate of 13 districts within a city of 8 million people (Xu et al., 2009). At this level, the density measure may be capturing confounding effects from some unobserved or unmeasured built environment factors. Supplementing density measures with measures of micro-scale built environment features like urban form and pedestrian amenities, assessed at the neighborhood or segment (street block) level, may support a more nuanced understanding of the relationship between the built environment, walking and obesity.

Finally, existing literature may oversimplify the relationship between overweight and income. Some studies have focused on differences in overweight and obesity between urban and rural residents, finding that residents of the former were more likely to be overweight or obese than the latter, and then have drawn a parallel divide between lower income and higher income residents (Xu et al., 2005; Wang et al., 2007). In studies that observed the impact of income directly and found a positive association relationship between income and BMI, samples were still drawn from urban and rural residents, making it difficult to separate out the impact of income from that of the urban rural divide on BMI, especially as these two factors are positively related (Popkin et al., 1995; Reynolds et al., 2007).

This paper aimed to expand the fledgling evidence base on the association between built environment features and walking and obesity in China, using a more inclusive definition of walking (for both travel and recreation) and employing micro-scale measurements of built environment features at the segment level. The study also attempted to increase our understanding of the relationship between income and obesity by examining income in more detail within urban areas.

Methods

Neighborhood selection

This study was based in Shanghai, the largest city in China, and Hangzhou, the provincial capital city of Zhejiang Province, which have urban populations of more than 22 million and 6 million respectively (http://www.demographia.com/db-worldua.pdf). Both cities are located in the Yangtze River Delta region. These cities were selected because of their varied size and density levels and because they each included a wide range of neighborhood types. These cities were also proximate to East China Normal University, where student research assistants for this study were based. Within these cities, we identified six distinct neighborhoods with different development patterns—three in Shanghai and three in Hangzhou.

Neighborhood selection was based upon a typology we developed based on three information sources: existing literature on urban design in Chinese cities, systematic field observations in several Chinese cities, and interviews with several Chinese urban development experts (Table 1) (Day et al., 2013b). The typology characterized Chinese neighborhoods according to primary and secondary urban design elements that strongly differentiate various development types and that were hypothesized to impact walking and other forms of physical activity. The typology was not mutually exclusive; many neighborhoods displayed elements of more than one type.

Three neighborhood types were selected for inclusion in this study: (1) the "urban center" neighborhood developed before the 20th century; (2) the "inner suburban" neighborhood located right outside the urban center, primarily developed in the 1980s and 1990s; and (3) the "outer suburban" neighborhood based in the suburbs and developed primarily after 2000. Selected neighborhoods in Shanghai were all located within a 10 to 15 minute walking distance from a subway station. This criterion was intended to control for the effect of access to transit, which has been associated with walking in existing research (c.f., Saelens and Handy, 2008). Hangzhou did not have an operating subway system at the time of our data collection and so subway access was not considered in selecting neighborhoods. (Note that all of the Hangzhou neighborhoods in the study now have a subway station under construction.) See Table 2 for the names, typology, and location of the six neighborhoods. We assigned each neighborhood a typology code: S-UC = Shanghai Urban Center, S-IS = Shanghai Inner Suburban, S-OS = Shanghai Outer Suburban, H-UC = Hangzhou Urban Center, H-IS = Hangzhou Inner Suburban, and H-OS = Hangzhou Outer Suburban. We used these codes throughout the paper when referring to the six neighborhoods.

Independent variables: built environment

Environmental audits were conducted to collect data on built environment features. The audit used in this study was a revised and expanded version of the Irvine–Minnesota Inventory (IMI) (Day et al., 2006), which was a tool designed to objectively measure "micro-scale" built environment features, such as sidewalks, street trees, benches, street width, curbcuts, or building facades. The IMI was originally developed by members of the research team to measure built environment features tied to walking and bicycling in the USA and other Western cities. Based on several sources of information (including a literature review, Day et al., 2013a; observations of built environments in Shanghai, Guangzhou, and Beijing; and interviews with several experts on Chinese urban development), the IMI was expanded from 162 to a total of 286 items. The new audit tool was called the Irvine–Minnesota Inventory-China (IMI-C). Examples of new items added to the IMI-C included measures of obstruction of sidewalks by vendors or parked cars (common in high-density Chinese cities), visible air pollution, presence of overhead pedestrian bridges (which require more effort for street crossing), barriers in bicycle lanes, and others. The IMI-C is available from the authors as an iPad application.

Built environment data collection

Research assistants audited all segments (or street blocks) in each of the six neighborhoods for a total of 527 segments, including 286 in Shanghai (129 segments in S-UC, 60 segments in S-IS, and 97 segments in S-OS) and 243 in Hangzhou (95 segments in H-UC, 18 segments[2] in H-IS, and 127 segments in H-OS).

State of Place™ Index

IMI-C data were analyzed using the State of Place™ Index, a proprietary algorithm that was developed by one of the members of the research team (Leinberger and Alfonzo, 2012). The State of Place Index™ is a score composed of eleven sub-scores (Table 3) that measure urban design dimensions

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[2] See note in the Built Environment Characteristics sub-section within the Results section for an explanation on why the number of segments in the H-IS was lower than that of the other neighborhoods.

Table 1
Primary and secondary elements of current Chinese urban development types.

	(1) Outer Suburban	(2) Old Urban Tower	(3) New Urban Tower	(4) Inner Suburban	(5) Mixed Use Block	(6) Urban Center	(7) Exurban
Primary elements							
Orientation	Tower in the park	Discrete buildings	Tower in the park	Oriented towards block interior	Linear	Linear: Historical District	Interior orientation
Density	Tall (16–30 stories)	Tall (16–30 stories)	Super tall (>30 stories)	Mid rise (4–15 stories)	Mid rise and tall	Low rise (1–3 stories)	Low to mid rise
Diversity of land uses	Single use (residential)	Mixed use	Predominantly single use	Single use (residential)	Mixed use	Mixed use	Single use (residential)
Location	Suburban	Old urban center	New urban center	Right outside urban center	Edge of urban center	Urban center	Exurban/ new town
Secondary elements							
Compactness	Medium	High	Medium to high	Medium to high	High	High	Low
Age	1990's to present	2000 to present	1990's to present	1980's	1950's to 1980's	Before 1950's	After 2000
Block size	Large (>1 sq km)	Small to medium (<1 sq km)	Medium to large (0.1 to 1 sq km)	Medium to large (>0.1 sq km)	Small to medium (<1sq km)	Small (<0.1 sq km)	Large (>1 sq km)
Street width	Wide (>40 meters)	Narrow (<12 meters)	Wide (>40 meters)	Medium to wide (>12 meters)	Medium (12–40 meters)	Narrow (<12 meters)	Wide (>40 meters)
Streetscape	Discontinuous	Continuous	Discontinuous	Mostly continuous	Mostly continuous	Continuous	Discontinuous
Shopping options	Shopping mall	Street retail	Shopping mall	Street retail and shopping center	Street retail	Street retail	Shopping mall

Note: Shaded cells are elements that are hypothesized will be associated with higher walking and bicycling. In this study, the "tower in the park" type roughly corresponded with the new suburban neighborhoods; the "mixed use block" type roughly corresponded with the inner suburban neighborhoods, and the "old urban tower" and "historic district" types roughly corresponded with the dense urban neighborhood.

empirically tied to walking (10 sub-scores) and bicycling (1 sub-score). Each of the eleven dimensions was composed of a subset of the 286 individual built environment items contained in the IMI-C. Scores were normalized so that each dimension was scored on a scale of 0 to 100, where 100 represents the highest observed score at the segment level. The State of Place™ Index is an aggregate of the scores along the 11 individual dimensions. The State of Place™ Index was calculated for each segment and then aggregated at the neighborhood level. The State of Place™ Index was converted into a dichotomous variable for the purposes of the linear regression analysis: below and above the average State of Place™ Index at the segment level (Average = 0 or 42.7%, normalized; Max = 90.47; Min = −67.48 (not normalized)).

Dependent variables: individual health and physical activity data

A survey of residents in six neighborhoods was conducted to collect information on walking and on other forms of physical activity and health. The survey was adapted from the China Health and Nutrition Survey (2012). The survey measured rates of walking and bicycling for travel and recreation, rates of other forms of physical activity, health outcomes including Body Mass Index (BMI) as a measure of obesity and also the presence of various health conditions, environmental perceptions and attitudes, and demographic information. Specifically, the survey asked residents to report how many minutes they spent daily traveling to or from work or school (commuting) and to places other than work or school (destinations). The survey also asked respondents to indicate how many minutes they spent on a variety of other physical activities (such as martial arts, tai chi, exercising at a gym, walking for exercise, etc.) on a typical day. Respondents' heights and weights were measured; respondents also had the option to self-report their height and weight. Overweight was defined as ≥25 BMI, and obesity was ≥30 BMI.

Table 2
Name, type, and location of six neighborhoods in Shanghai and Hangzhou, China.

Typology	Urban center	Inner suburban	Outer suburban
Shanghai	Xintiandi (S-UC)	Zhongshan Park (S-IS)	Lianhua Lu (S-OS)
Hangzhou	Fengqi Lu (H-UC)	Cuiyuan (H-IS)	Guihua Cheng (H-OS)

Individual health and physical activity data collection

Undergraduate and graduate student research assistants surveyed residents in one or more central public spaces in each neighborhood (e.g., outside grocery stores or farmers markets). A total of 455 resident surveys were completed in Shanghai, including 101 in Shanghai-Urban Center (S-UC), 172 in Shanghai-

Table 3
Description of State of Place™ Index dimensions and examples.

State of Place^{TM} Index dimensions	Description/example items
Density/building height	Measure of density based on building concentration and heights
Proximity/land use mix	Presence of non-residential land uses
Connectivity	Measure of connectivity; lack of potential barriers (e.g., six land roads)
Form	Measure of streetscape continuity (e.g., lack of driveways, podium buildings, etc.)
Parks and public space	Presence, quality, and access of parks, playgrounds, plazas, etc.
Pedestrian infrastructure/ amenities	Features that provide pedestrian comfort (e.g., sidewalks, sidewalk widths, street furniture, etc.)
Bike infrastructure/ amenities	Features that provide bicyclist comfort (e.g., bike lanes, bike racks, bike parking, etc.)
Personal safety	Features related to perceived safety (e.g., graffiti, litter, bars on windows, etc.)
Traffic safety	Features intended to increase traffic safety (e.g., traffic signals, traffic calming measures, etc.)
Aesthetics	Measures of pleasurability and maintenance (e.g., outdoor dining, building transparency, etc.)
Recreational facilities	Presence of gyms and fitness facilities and other outdoor recreational uses

Table 4
Descriptive statistics of respondents and ANOVA results comparing neighborhoods in Shanghai and Hangzhou, China in 2013.

Variables	Hangzhou			Shanghai			ANOVA	
	Fengqi Lu Urban Center (H-UC)	Cuiyuan Inner Sububan (H-IS)	Guihua Cheng Outer Suburban (H-OS)	Xintiandi Urban Center (S-UC)	Zhongshan Park Inner Sububan (S-IS)	Lianhua Lu (Outer SuburbanS-OS)	F	N valid
Total walk time/day (minutes)	18.692	15.558	11.876	45.871	27.785	29.440	15.48	1070
Walk commute (minutes)	2.591	2.935	3.073	7.129	4.267	2.846	2.68	1070
Walk destinations (minutes)	3.994	1.659	2.171	9.851	6.116	7.198	4.47	1070
Walk exercise (minutes)	12.107	10.963	6.632	28.891	17.401	19.396	12.37	1070
Total bike time/day (minutes)	4.933	5.613	6.162	4.851	5.081	1.346	1.30	1070
Total transit time/day (minutes)	27.756	25.355	25.425	19.416	37.081	38.291	6.07	1069
Total sedentary time/day (minutes)	174.430	169.155	181.967	142.766	140.370	181.766	2.06	1070
BMI	21.740	21.615	21.520	22.656	22.121	24.015	8.01	1070
Obesity (yes/no, BMI ≥ 30)	0.043	0.005	0.013	0.069	0.023	0.126	10.00	1070
Overweight (yes/no, BMI ≥ 25)	0.134	0.074	0.115	0.149	0.134	0.231	4.49	1070
Physical activity important? (1–5)	2.153	1.940	2.177	2.050	2.012	2.066	2.32	1067
Health diet important? (1–5)	1.796	1.673	1.880	1.723	1.622	1.676	3.72	1067
Female	0.470	0.410	0.406	0.505	0.436	0.440	0.83	1070
Household size	2.637	2.601	2.534	2.788	2.987	2.966	3.44	918
Own auto? (yes/no)	0.293	0.309	0.231	0.139	0.366	0.412	6.66	1070
Age	29.890	34.788	29.419	45.257	33.727	34.588	24.37	1070
Married (yes/no)	0.366	0.567	0.462	0.792	0.547	0.687	14.40	1070
Years in current residence	6.299	6.368	3.588	11.358	6.981	6.207	11.80	1021
Income level (1–6 from low to high)	2.065	2.357	2.166	1.988	2.327	2.269	4.16	885
Education level	4.012	4.249	3.987	3.089	4.064	4.101	11.74	1063
Labor intensive work (yes/no)	0.104	0.078	0.090	0.089	0.076	0.126	0.76	1070
Rural status	0.390	0.244	0.470	0.267	0.285	0.253	8.08	1070
Sample Size (Total = 853)	164	217	234	101	172	182		

Inner Suburban (S-IS), and 182 in Shanghai-Outer Suburban (S-OS). A total of 615 resident surveys were completed in Hangzhou, including 164 surveys in Hangzhou-Urban Center (H-UC), 217 in Hangzhou-Inner Suburban (H-IS), and 234 in Hangzhou-Outer Suburban (H-OS). As not all respondents answered all survey questions, sample sizes varied among regression models. One hundred seventy-two was the minimum required sample size to detect a small effect size (.10) at a .80 power level, with 10 predictors, using a .05 alpha.

Control variables

A set of control variables were included in the survey, including demographic characteristics such as income, age, gender, marital status, education, and household size. Two attitudinal factors were also controlled: attitudes towards physical activity and attitudes towards healthy eating. Respondents ranked the importance of being physically active and of eating a healthy diet using Likert scales that ranged from 1 to 5. Respondents also estimated how much time they spent on a typical day on sedentary activities such as watching TV, playing computer games, reading, or surfing the Internet. Participation in sedentary activities also served as a control variable. Income was measured in six categories ranging from ≤¥2000 per month (approximately US $320) up to ≥¥50,000 per month (approximately US $8000). Finally, we controlled for the number of years respondents had lived in their current residences, since the level of "exposure" to the neighborhood built environment could impact walking levels and consequently BMI.

Statistical analysis

Descriptive statistics were run on the independent, dependent, demographic and control variables, which are reported in Table 4, separated by city and neighborhood type. One-way ANOVAs were also run to determine if there were differences among the six neighborhoods (also reported in Table 4). Independent samples t-tests were then run to identify specific differences among neighborhoods, which are reported within the text in the Analysis and results section below (these were not reported in a table format as the combination of independent t-tests comparing potential differences between the six neighborhoods individually would be too onerous to present in table format). The State of Place™ Index was used to analyze the built environment data, as mentioned previously. These results were reported in Table 5, which include the means for each of the 11 dimensions and the overall State of Place™ Index for each neighborhood as well as the results of ANOVAs testing for differences with respect to the State of Place™ Index among the neighborhoods[3].

Two sets of multiple linear regression models were developed using the software package SPSS 22.0. The first model examined the impact of walking on BMI; the second tested the relationship between the built environment and physical activity focusing on walking. Two interaction terms were created: one for walking for commuting and income and one for walking for destinations and income using standardized scores (z-scores) for all three variables. Additional independent t-tests were conducted examining the differences between BMI, walking for commuting, and walking for destinations across income groups (low and high vs. middle) to further examine the interaction effect.

Analysis and results

Demographics

This study's sample primarily included middle-income young adults (Table 4). The average age was 33.6; 55% were married with 3an average household size of 2.7. About 53% of respondents earn between US $325 and $1295 per month. On average, respondents had lived in their current residences for 6.3 years; 30% owned cars.

There was a large variation in demographic characteristics among the six neighborhoods. Hangzhou respondents were younger (31.4 vs. 36.6; t = 5.993, $p < .001$), had smaller households (2.6 vs. 2.9; t = 3.922, $p < .001$), had lower car ownership (27% vs. 33%; t = 2.077, p = .038), and included more single adults (53% vs. 44%; t = 6.125, $p < .001$) and more new residents (5.3 vs. 7.7 years; t = 4.082, $p < .001$) as compared to Shanghai respondents. Average household incomes were comparable between the two cities but variation occurred between neighborhoods and within the same neighborhood. For example, in S-UC, there appeared to be a bimodal income distribution. Luxury condominiums were juxtaposed with old vernacular housing that served low-income residents. Finally, Hangzhou neighborhoods had a significantly higher

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[3] See note on why the H-IS neighborhood is excluded from Table 5 in the Built Environment Analysis in the Results section below.

Table 5
Means for State of Place™ Index and dimensions with summary ANOVA for five neighborhoods in Shanghai and Hangzhou, China in 2013.

Neighborhood		Form	Density	Prox.	Conn.	Parks & public spaces	Pedestrian amenities	Bicyclist amenities	Personal safety	Traffic safety	Aesthetics	Rec. facilities	State of Place^{TM} Index
Xintiandi Shanghai Urban Center (S-UC) N = 129		74.4%	65.2%	20.3%	76.6%	10.6%	42.9%	51.9%	84.1%	51.9%	63.0%	3.5%	54.8%
Zhongshang Park Shanghai Inner Suburban (S-IS) N = 60		67.1%	65.7%	24.7%	72.6%	3.0%	33.5%	51.4%	78.8%	35.5%	53.3%	9.1%	42.2%
Fengqi Lu Hangzhou Urban Center (H-UC) N = 95		75.9%	67.7%	18.7%	75.2%	3.5%	27.1%	48.2%	77.7%	49.4%	52.5%	3.9%	41.9%
Lianhua Lu Shanghai Outer Suburban (S-OS) N = 97		60.4%	65.7%	9.6%	81.3%	17.3%	26.0%	51.5%	83.6%	49.6%	52.3%	15.4%	40.7%
Guihua Cheng Hangzhou Outer Suburban (H-OS) N = 127		71.7%	65.2%	9.9%	81.7%	10.3%	22.2%	46.4%	80.7%	42.2%	48.1%	3.9%	34.8%
ANOVA	F	13.74	1.28	13.70	4.73	11.24	58.21	6.16	7.66	12.25	21.03	7.82	32.01
	p-Value	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

share of rural households than did Shanghai neighborhoods (36.9% vs. 26.8%; $t = 3.545$, $p < .001$); H-UC and H-OS had the highest percentages of rural households at 39% and 47%, respectively, which suggests these two neighborhoods may have included young migrant worker enclaves. However, of these two neighborhoods, only H-OS had a significantly higher percentage of rural residents as compared to the rest ($t = 5.082$, $p < .001$).

Neighborhoods in the two cities had a similar average BMI, but varied with respect to levels of obesity and overweight. In Shanghai, twice the number of S-OS respondents was obese or overweight, compared to S-UC respondents (although this difference was not statistically significant). In H-UC, respondents had higher levels of obesity than did respondents in H-OS (although this difference was not statistically significant). On average, 17.6% of Shanghai respondents were overweight as compared to 10.6% in Hangzhou ($t = 3.224$, $p = .001$); 7.5% of Shanghai respondents were obese as compared to 1.8% of Hangzhou respondents ($t = 4.226$, $p < .001$).

Shanghai respondents were significantly more physically active than were Hangzhou respondents in all categories except bicycling (Hangzhou has the largest bike share program in the world with more than 50,000 bikes; Shaheen et al., 2011) and walking for commuting. Shanghai respondents spent an extra 4.9 min walking for destinations ($t = 4.168$, $p < .001$), 11.1 min walking for exercise ($t = 6.197$, $p < .001$), and 7.6 min on transit ($t = 3.208$, $p = .001$) compared to Hangzhou respondents. (Note that Hangzhou did not have a subway system while Shanghai had one of the largest subway networks in the world.) The Shanghai sub-sample also included more seniors who are known to walk for exercise more often ($t = 5.993$, $p < .001$). In both cities, respondents from Urban Center neighborhoods walked more than did respondents from other neighborhoods (29 min versus 20; $t = 2.783$, $p = .006$). Respondents of Outer Suburban neighborhoods spent more time on sedentary activities such as watching TV or surfing the Internet than did respondents in Urban Center neighborhoods or Inner Suburban neighborhoods (181 vs. 163; $t = 2.080$, $p = .038$). Overall, Hangzhou respondents spent 22 additional minutes daily on sedentary activities as compared to Shanghai respondents (although this difference was not statistically significant).

Built environment characteristics

As mentioned previously, the built environment data was analyzed using the State of Place™ Index. Table 5 displays the State of Place™ Index for each dimension grouped by neighborhood and also provides summary statistics for the results of an ANOVA that tested for differences among the neighborhoods. Note that this table includes data for only five of the six neighborhoods in which built environment data was collected. Technical glitches in the software used for data collection resulted in a loss of built environment data for 40 segments within the Inner Suburban neighborhood in Hangzhou. Accordingly, we were unable to generate a State of Place™ Index for the entire neighborhood; however, the segment level built environment data collected from this neighborhood was matched to survey respondents and included in the analysis of the association between the built environment and physical activity. Additionally, all health survey data collected from this neighborhood was included in the analysis between physical activity and BMI.

The State of Place™ Index and profiles of these neighborhoods mostly reflect the built environment differences that we expected to see based on the initial typology and neighborhood selection rationale. S-UC scored significantly higher than did all other neighborhoods in terms of its State of Place™ Index ($t = 10.316$, $p < .001$). H-OS scored significantly lower than did all other neighborhoods ($t = -7.734$, $p < .001$). However, note that: S-UC scored significantly higher than did H-UC ($t = 6.900$, $p < .001$) and H-UC's State of Place™ Index was not significantly different from that of S-IS's ($t = .105$, $p = .917$) or S-OS ($t = -.569$, $p = .563$). These findings suggest that the built environment of Shanghai's urban neighborhoods may have been more walkable in terms of their built environment features, compared to the walkability of the Hangzhou neighborhoods in this study. Stated another way, the dense urban neighborhood in Hangzhou in this study was more akin to the inner suburban neighborhood in Shanghai. This fact may reflect both real differences in the urban character of neighborhoods in the two cities, as well as the neighborhood selection process for this study. Additionally, while S-IS did not differ significantly from S-OS in terms of overall State of Place™ Index ($t = .575$, $p = .566$), there were significant differences between these two neighborhoods on the eleven urban design dimensions (including form, proximity, connectivity, parks and public spaces, pedestrian amenities, personal safety and traffic safety). In fact, the five neighborhoods had significant variations with respect to all eleven dimensions. These differences may be what ultimately influence outcomes such as walking rates and BMI. For this paper, we focused on the overall impact of the State of Place™ Index first; future studies will examine the physical activity impact of the eleven individual dimensions.

Modeling results: demographic characteristics, walking and obesity

Table 6 summarizes the results of the multiple linear regression model examining the impact of walking and BMI. Some variables had missing values so the sample size was smaller than the initial sample collected. The relationship between BMI and commuting walking was moderated by income. Spending more time walking for commuting purposes was tied to a greater decrease in BMI in higher income respondents as compared to lower income respondents. That is, as income increased, walking for commuting had a more significant impact on lowering BMI. For example, for low income respondents, the average difference in BMI between those who walked a below average amount for commuting and those who walked an above average amount for commuting was .43; for higher income people, the difference was 4.9, which equated to more than 10 times the impact. This interaction was in line with the parallel non-linear relationships between BMI and income and between walking for commuting and income, both of which displayed a slight bi-modal split. Respondents at either end of the income spectrum had lower BMIs ($t = -2.149$, $p = .032$) and walked more for commuting ($t = 3.797$, $p = .018$) than did middle-income respondents. The average BMI and daily commuting walk time for our lowest two income groups, respectively was 22.7 and 5.9 min, 23.9 and 1.3 min for our middle two income groups, and 22 and 3.3 min for the highest two income groups. While the interaction term for walking for destinations was not significant, it was left in the model as its exclusion may have resulted in omitted variable bias.

This model also revealed that older respondents were more likely to have higher BMIs, while female respondents and long-time residents were more likely to have lower BMIs, which is in line with previous empirical findings. Respondents who believed physical activity was important were more likely to have lower BMIs; however, those who believed having a healthy diet was important were actually more likely to have higher BMIs. Finally, while BMI varied significantly by neighborhood type, neighborhood type dummy variables were insignificant and did not significantly change the model fit; accordingly, they were left out of the model. The inclusion of the dummy variables added little to the explanatory power of the model as it is likely that the independent variables already included in the model captured most of the variation between the neighborhoods. This was true for both the social environment and physical environment of the neighborhoods in this study.

Modeling results: walking and built environment

Table 7 summarizes the effect of the built environment on total overall walking time as well as on three types of walking: commuting, non-commuting, and exercise. Respondents who lived in neighborhoods with an above average State of Place™ Index were more likely to spend more time walking for commuting, non-commuting, and exercise, as well as on overall walking, compared to respondents who lived in neighborhoods with a below average State of Place™ Index. Specifically, on average, respondents living in areas with an above State of Place™ Index walked overall 21.86 min more daily, and 3.5, 4.58, and 13.52 min more daily for commuting, destinations, and exercise, respectively, than those who lived in areas with a below average State of Place™ Index.

Table 6
Multiple linear regression model examining the impact of physical activity on BMI for residents of six neighborhoods in China in 2013.

Dependent variable = BMI	Coefficient	t
Constant	21.817	14.979
Household size	−.049	−.364
Own auto? (yes/no)	−.728	−1.800
Age	.062	2.719
Female	−2.532	−7.147
Married	.839	1.910
Rural household status (yes/no)	.005	.012
Years in current residence	−.095	−3.028
Education level (0–6 from low to high)	−.054	−.318
Income level (1–6 from low to high)	.519	2.458
Labor intensive job (yes/no)	−.472	−.765
Physical activity important? (1–5)	.472	1.982
Health diet important? (1–5)	−.649	−2.286
Sedentary time/day (minutes)	.000	−.155
Total bike time/day (minutes)	−.011	−1.500
Total transit time/day (minutes)	−.002	−.370
Walk commute (minutes)	.231	1.077
Walk destinations (minutes)	.277	1.954
Walk exercise (minutes)	.009	1.458
Walk commute × income	−.447	−2.252
Walk destinations × income	−.028	−.151

$N = 522$.
R square = 0.205.
$F = 6.485$, $p < .001$.

Respondents who believed their neighborhood's built environment was less convenient for walking actually spent more time walking overall and specifically walking for non-commuting purposes. Groups that spent more time walking overall included older respondents, women (who walked overall 8.32 min more daily), employed respondents (who walked overall 13.71 min more daily), and those with rural[4] registrations (who walked overall 8.55 min more daily). Groups that spent more time walking for exercise included older respondents and female respondents (who walked 6.44 min more). Older respondents and employed respondents both spent more time walking for commuting compared to other groups (employed respondents walked 5.37 min more). Higher income respondents spent less time walking overall and specifically less time walking for exercise.

Discussion

Based on the State of Place™ Index, key built environment differences among the urban center, inner suburban and outer suburban Chinese neighborhoods were related to form, parks and public spaces, pedestrian amenities, traffic safety, and esthetics. Dense urban neighborhoods (our urban centers) had better form and esthetics. Inner suburban neighborhoods lacked in parks and public spaces and esthetics, and new suburban neighborhoods (our outer suburban neighborhoods) had good parks and public spaces. Traffic safety features varied in a random pattern. Further, the State of Place™ analysis revealed that inner suburban neighborhoods offered a mixed bag of built environment features related to walking and to other forms of physical activity. These inner suburban neighborhoods revealed high levels of proximity and also bicyclist amenities (S-IS did have the highest amount of biking), but demonstrated low levels of connectivity, traffic safety and personal safety. Finally, there was little variation with respect to density across neighborhood types.

Findings confirmed the relationship between walkable built environment features and walking. In particular, neighborhoods that had a higher State of Place™ Index also had higher rates of walking. While not surprising, this finding is important, as it demonstrates that the association between the design of the built environment and walking, which have been found to be linked in research in Western countries (see Saelens and Handy, 2008), also holds true in China. This finding is part of an emerging evidence base that will be of critical importance to persuade local government officials and developers of the value of pursuing more walkable urban development patterns.

Income played a key role in the relationship between the built environment and walking in this study. In particular, in our findings, the relationship between income and BMI was not linear as suggested in existing research on obesity in China (c.f., Gui et al., 2010). Rather, our findings identified a bimodal relationship between income and BMI, with both higher and lower income respondents having lower BMI, compared to middle income respondents. Also, middle income respondents were more likely to live in neighborhoods with a lower State of Place™ Index, compared to both higher and lower income respondents. Neighborhoods with a lower State of Place™ Index were more "suburban" in nature, with good access to parks and public spaces and recreation but lower proximity to non-residential land uses, a lack of pedestrian amenities, and auto-oriented urban form. Respondents in these middle income neighborhoods with a lower State of Place™ Index did less walking for various purposes, which may at least partly explain their higher BMIs. Findings also challenged existing research (Xu et al., 2009, 2010) that linked high density with low levels of (recreational only) physical activity.

This study did not examine the food environment, but dietary intake likely impacts BMI levels. Existing research has found that more affluent residents in China are more likely to consume high fat, high salt, high sugar "Western" diets (Gui et al., 2010; Reynolds et al., 2007). It may be

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[4] Rural registrants are people who live in either Shanghai or Hangzhou but whose official registration, or "hukuo" is from a rural area.

Table 7

Multiple linear regression model examining the impact of the built environment on different types of walking for residents of six neighborhoods in China in 2013.

Dependent variable =	Total walk		Walk commute		Walk destination		Walk exercise	
	Beta	t	Beta	t	Beta	t	Beta	t
Constant	4.49	0.39	−2.74	−0.71	4.81	1.59	6.34	0.90
Own auto (yes/no)	5.55	1.71	1.12	1.02	−0.57	−0.41	3.85	1.88
Age	0.66	4.15	0.11	2.08	0.78	1.47	0.47	4.60
Female	8.33	2.84	1.36	1.38			6.44	3.45
Income levels (1–6)	−5.21	−2.60	−1.19	−1.76	−0.12	−0.17	−4.19	−3.51
Employed (yes/no)	13.72	2.61	5.37	3.02				
Household size	0.79	0.75	0.12	0.31				
Perception of convenience for walking level (1–5)	−4.74	−2.08	−0.33	−0.43	−2.51	−2.51	−2.65	−1.85
Perception of traffic safety level (1–5)	−0.70	0.29	0.90	1.12	0.65	0.61	−1.38	0.92
Above average SoP (yes/no)	21.86	4.53	3.50	2.15	4.58	2.18	13.52	4.48
Married	−1.82	−0.51	−1.53	−1.26			−0.51	−0.23
Rural household status	8.55	2.49	1.75	1.51			3.69	1.67
Education level (0–6)	1.14	0.84	0.61	1.33			0.61	0.71
Sample N	750		750		877		873	
R square	0.1527		0.0589		0.0203		0.119	
F	11.084		3.849		3.008		11.655	
p-Value	<.001		<.001		.006		<.001	

that middle income respondents may be more likely to partake of unhealthy fast foods in comparison with lower income residents, who cannot afford these foods, or higher income residents, who may be more informed about the negative impacts of fast food. In fact, this study found that those who reported valuing healthy eating actually had higher BMIs, which may raise questions regarding what Chinese residents believe constitutes a healthy diet. Future research should explore the link between income, obesity, and walking further. In particular, future studies should continue to differentiate between middle and upper income groups and should include built environments that serve lower, middle and upper income residents.

Findings showed that respondents who believed that their neighborhood's built environment was less convenient for walking actually spent more time walking compared to other respondents. It may be that groups with lower automobile access (including women and older adults) continue to walk even when they do not perceive the environment as supportive of walking, if their alternatives to walking are limited. Thus, neighborhoods perceived as unwalkable may still be associated with walking where there are few other alternatives.

Conflict of interest statement

None.

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