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Urban density, diversity and design: Is more always better for walking? A study from Hong Kong

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Many cities in China have undergone rapid urbanization and are experiencing a decline in residents' physical activity levels. Previous studies have reported inconsistent findings on the association between 3D's (density, diversity, design) and walking behavior, and few studies have been conducted in China. The aim of this study was to identify the association between objectively measured 3D's and different domains of walking (transport vs. leisure) in Hong Kong, China. A survey was conducted in 2014 to collect walking data and relevant individual data from 1078 participants aged 18–65. The participants were randomly selected from 36 Hong Kong housing estates with different built environment and neighborhood socioeconomic status (SES). Built environment factors—population design, land-use mix and street intersection density—were assessed using a geographic information system. Multi-level regression was used to explore the associations between walking behavior and built environment factors, while adjusting for covariates. Two out the three D's—land-use mix and street connectivity—are not significantly related to any domains of walking. Furthermore, the third D, population density, is only positively related to walking for transport and walking for leisure in the lower range of density, while is negatively related to walking for leisure in the higher range of density. The findings suggest that the association between original 3D's and walking may vary in different urban contexts. The policy or planning strategy—using three D's to promote physical activity—may be ineffective or even counterproductive in large and already dense cities in China.

1. Introduction

Many developing countries, such as China, have undergone rapid urbanization, which has contributed to the decline in physical activity and increased risk of many chronic diseases among residents (Ng et al., 2014; Ng et al., 2009). Research has concluded that physical activity among adults in China fell 32% between 1991 and 2006 (Ng et al., 2009). Consequently, many local governments, such as Hong Kong, promote physical activity in their health and disease prevention strategies (Department of Health, 2010). Numerous studies have found that people are more likely to walk, especially for transport purposes, in neighborhoods with certain environmental characteristics. However, most of these studies have been conducted in the Western countries, where urban population densities, public transportation systems, and social-economic status (SES) are different from those in China. Little is known about which factors in the physical environment are associated with walking in the local Chinese context.

There is compelling evidence that physical activity can benefit adults in numerous ways, including the prevention and treatment of chronic illnesses, and improved physiological and psychological health (Lee et al., 2012; Sallis et al., 2012). Several studies have also established that walking is the most popular habitual physical activity among adults because it can be done at any time, alone or in the company of others, requires no special equipment or clothing, and can easily be incorporated into the daily routine (Hamdorf et al., 2002; Tudor-Locke et al., 2002).

Environmental factors are increasingly recognized as having a crucial influence on walking in neighborhood environments. The fields of urban planning and public health have recently developed the concepts of community design, such as walkability to promote walking. Walkability is regarded as whether characteristics of the built environment may or may not support residents to walk for either leisure or access destinations (Leslie et al., 2007). Some studies have further pinpointed several variables within a framework of three D's supporting walkability: **d**ensity, land-use **d**iversity, pedestrian-oriented **d**esign (Cervero and Kockelman, 1997; Ewing et al., 2008).

1) Density measures the quantity of households, people, or jobs distributed over a unit of area (Frumkin et al., 2004). Density is regarded as important because it directly affects walking because areas with higher

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neighborhood density have more destinations such as retails, parks, and jobs nearby (Forsyth et al., 2007; Lee and Moudon, 2006). 2) Land-use diversity (land-use mix) measures how many types—e.g. offices, residences, retails—are available within an area (Frumkin et al., 2004). Entropy value of land-use mix is often used (Ewing and Cervero, 2010). 3) Design includes street connectivity—describing the degree to which destinations are connected by streets—is influenced by the design of the street network (Leslie et al., 2007). One commonly used connectivity variable is street intersection density (Frank et al., 2005; Li et al., 2005; Owen et al., 2007). Furthermore, a composite walkability index—combining density, land-use mix and street connectivity—has been used to predict walking (Frank et al., 2010; Frank et al., 2005; Glazier et al., 2014; Grasser et al., 2013; Sundquist et al., 2011).

Most evidences from North America, Australia and Europe have suggested that people walk more in areas with higher three D's: specifically, with higher neighborhood densities , increased street connectivity, and better access to a variety of destinations (mixed use) (Ewing and Cervero, 2010; Grasser et al., 2013; Saelens and Handy, 2008; Van Holle et al., 2012), albeit with changes of which variables, or which combinations of variables most account for walking. While, some recent studies from South America and Asia—having demonstrated non-significant or contrary findings—suggest more complex relationships between the three D's approach and walking or physical activity (Gomez et al., 2010; Salvo et al., 2014; Siqueira Reis et al., 2013; Su et al., 2014; Xu et al., 2010).

The inconsistent findings from previous studies may be explained by different urban contexts, such as population densities, land-use diversity, street network design, or social-economic status (SES). Despite the research activity to date, relatively few studies have addressed the association between objectively measured three D's: density, diversity (land-use mix), pedestrian-oriented design (street connectivity), and domain-specific walking in high-density cities in developed regions of China, although this association may potentially affect the physical activity levels of residents in many Chinese cities.

This cross-sectional study, conducted in 36 urban areas of Hong Kong with 1078 adult participants, examined the association between three "D's" and self-reported domain-specific walking (for leisure and for transport), controlling for potential confounding variables.

2. Method

Hong Kong is located on the southeast coast of China, with a land area of 1104 km^2. In 2015, the population was 7.29 million with a gross population density of 6603 people per km^2. The gross population density in Hong Kong is about 5 times that in Atlanta, USA, and 30 times that in the Twin Cities, US, and is comparable to Bogota (4964 people per km^2) and Cuernavaca (2308 people per km^2), where previous built environment-walking studies have been conducted.

2.1. Sampling

There were 487 major housing estates in Hong Kong as of 2011 (Census and Statistics Department of Hong Kong, 2013). A major housing estate in Hong Kong refers to a group of residential buildings developed by the same developer in a neighborhood and with at least 1000 residential units. Housing estates are the smallest units for which information on population, income, and other census data are available in Hong Kong. We selected 36 housing estates for the study according to two criteria: neighborhood built environment and neighborhood socioeconomic status (SES).

We purposely selected the study areas to maximize the variation in their built environment characteristics. Since land-use mix and street connectivity showed small variations across Hong Kong, we chose study areas based on low, medium, and high densities (Fig. 1). The neighborhood population density was measured with a geographic information system. Density was calculated within a straight-line 400-m buffer around each housing estate. The population density is defined as the residential population per unit of land area within the buffer. The population density calculations include all types of land area, such as parks or water. The population densities of each housing estate were divided into deciles. The housing estates within the second and third deciles were considered low-density estates, those within the fifth and sixth deciles were considered medium-density estates, and those within the eighth and ninth deciles were considered high-density estates.

Neighborhood SES was also included in the selection process to account for possible individual differences in physical activity that could be explained by neighborhood SES (Owen et al., 2007; Van Dyck et al., 2010). The average household incomes of each housing estate were used to assess neighborhood SES and these were also divided into 10 quantiles. The housing estates within the second, third, and fourth quantiles represented low SES and those within the seventh, eighth, and ninth quantiles represented high SES.

The 36 selected study areas were stratified into six groups with six housing estates in each group: high density/high SES, medium density/high SES, low density/high SES, high density/low SES, medium density/low SES, low density/low SES.

2.2. Objective measurement of the built environment

The characteristics of neighborhood built environment within a 400-m buffer around each housing estate were measured with three D's: population density, land-use diversity, and design (street connectivity). Street connectivity was assessed by street intersection density, defined as the number of intersections (three or more streets) per unit of land area. The land-use mix, or entropy score, was calculated by measuring the number of different land use types. Three land use types were considered: residential, retail, and office.

Fig. 1. Examples of study areas with low, medium, and high population densities in Hong Kong.

2.3. Participants

The study assessed 29–30 adults from each housing estate, with a total of 1078 participants. The participants were Chinese adults aged 18–65 who could perform physical activity independently and had lived in the estates for more than one year. The research team selected the participants from a stratified random sample in 2014.

2.4. Covariates

The participants are also required to fill in a questionnaire on their SES (measured by household income) and demographic characteristics including sex, age, and education. Those individual variables were treated as potential covariates in analysis.

2.5. Walking behavior

Walking behavior was measured by the International Physical Activity Questionnaire (IPAQ) long form, a standard questionnaire that has been tested for reliability and validity in a number of countries (Craig et al., 2003). The IPAQ was conducted through interviews, which ensured that no data were missing. The following three variables were used as to assess walking behavior, in minutes per week: a) walking for leisure; b) walking for transport, c) total walking.

3. Analyses

The descriptive statistics for the sample characteristics were grouped into low, medium, and high density using SPSS 21.0 (IBM Corp., Armonk, NY, USA). The mean, standard deviation (SD), minimum and maximum values were calculated for continuous variables. The counts and percentages were calculated for categorical variables. The participants reported duration of walking larger than 3 standard deviations were removed from analysis.

Generalized linear mixed models were conducted to examine the association between walking behavior and population density, using SPSS. Multi-level modeling (participants and neighborhoods) was applied to take into account the clustering of participants in neighborhoods. These two-level models were used to examine independent associations between the dependent variables and the population density (low, medium, high), land use mix, intersection density while adjusting for neighborhood SES, and participants' age, sex, education, and household income. We allowed neighborhood to have a random effect, which enables non-independence in the walking behaviors from participants within the same housing estate. Statistical significance was set at $p = 0.05$ for all analyses. Standardized coefficients (β), standardized errors, and p values are presented as measures of association.

4. Results

Table 1 shows the demographic characteristics and walking behavior of the participants. The average population density across our study areas was 61,879 people/km^2, which is substantially higher than that of the study areas reported in other studies. There was significant variation between the low-, medium-, and high-density areas, with means of 21,765, 67,165, and 96,485 people/km^2, respectively (see Fig. 1 for examples of study areas).

Table 2 shows the associations between population density, land use mix, intersection density and walking behavior using multi-level modeling, adjusting for all covariates. We found no significant linear association of intersection density with walking for leisure ($\beta = -0.144$, $p = 0.281$) or walking for transport ($\beta = 0.084$, $p = 0.423$), and found no significant linear association of land use mix with walking for leisure ($\beta = 0.087$, $p = 0.535$) or walking for transport ($\beta = 0.093$, $p = 0.398$).

The population density was associated with walking for leisure and walking for transport, albeit with complex relations. Compared with residents from the medium-density areas, residents in the low- and high-density areas spent less time walking for leisure $\beta = -0.498$, $p < 0.001$; $\beta = -1.536$, $p < 0.05$, respectively. Residents in the low-density areas, but not those in the high-density areas, spent less time walking for transport ($\beta = -0.582$, $p < 0.001$) and total walking ($\beta = -1.434$, $p < 0.001$), than those in the medium-density areas.

5. Discussion

After controlling for covariates—including neighborhood SES, and individual demographic variables—we observed three patterns regarding the associations between objectively measured 3D's of the built environments (population density, land use mix, design) and walking in Hong Kong, China, a high-income city featuring some unique built environment and socioeconomic characteristics.

1) The associations of the 3D's of the built environments and domain-specific walking for Hong Kong adults markedly contrast with those reported for western countries. Two out the three D's—land-use

Table 1
Descriptive information for walking activity, neighborhood-level characteristics, and individual characteristics of the 1078 study participants by population density level in Hong Kong, sampled in 2014.

	Low density ($N = 358$)	Medium density ($N = 360$)	High density ($N = 360$)	Overall ($N = 1078$)
	M(SD)	M(SD)	M(SD)	M(SD)
Outcomes				
Walking for leisure (min/week)	82.7 (76.9)	100.4 (93.0)	83.4 (104.6)	88.3 (68.5)
Walking for transport (min/week)	86.8 (99.2)	104.9 (106.8)	106.6 (93.5)	99.5 (64.5)
Total walking (min/week)	169.5 (132.0)	205.4 (130.8)	190.1 (144.1)	187.8 (110.2)
Neighborhood-level characteristics				
Population density (person/km^2)	21,765 (9963.5)	67,165 (7604.5)	96,485 (7566.0)	61,879 (31,882.9)
Median family income (in 000)	40.2 (28.4)	22.9 (8.4)	29.5 (18.9)	30.8 (21.5)
Intersection density (number of intersection/km^2)	40.2 (12.3)	33.3 (6.9)	38.3 (10.1)	37.3 (10.4)
Land use mix	0.5 (0.1)	0.5 (0.2)	0.3 (0.1)	0.4 (0.2)
Individual characteristics				
Family income (in 000)	21.7 (8.4)	21.6 (7.0)	22.4 (7.3)	21.9 (7.6)
Age	45.2 (16.0)	43.2 (16.5)	42.9 (13.3)	43.8 (15.4)
Gender N(%)				
Male	190 (53%)	190 (53%)	182 (51%)	562 (52%)
Female	168 (47%)	170 (47%)	178 (49%)	516 (48%)
Education N(%)				
Below university	228 (64%)	238 (66%)	276 (77%)	742 (69%)
University	130 (36%)	122 (34%)	84 (23%)	336 (31%)

Table 2
Associations between walking behavior and population density, intersection density, and land-use mix, after controlling for potential confounding variables.

	Walking for leisure			Walking for transport			Overall walking		
	β	Std. Error	p	β	Std. error	p	β	Std. Error	p
Population density									
Medium	Ref.								
High	−0.498**	0.312	0.001	0.126	0.246	0.609	−0.200	0.266	0.452
Low	−1.536*	0.270	0.049	−0.582*	0.213	0.007	−1.434**	0.230	0.001
Intersection density	0.144	0.133	0.281	0.084	0.105	0.423	0.153	0.114	0.178
Land-use mix	0.087	0.140	0.535	0.093	0.110	0.398	0.119	0.119	0.995

All reported estimates are adjusted neighborhood SES, and participants' age, sex, education, and household income.
* $p < 0.05$.
** $p < 0.01$.

mix and street connectivity—are not significantly related to any domains of walking. Furthermore, the third D—population density—is only positively related to walking for transport and walking for leisure in the lower range of density, while is negatively related to walking for leisure in the higher range of density.

Studies from the western countries generally showed positive associations between walking and density, land-use mix and street connectivity, or walkability index including all 3Ds (Frank et al., 2010; Frank et al., 2005; Glazier et al., 2014; Grasser et al., 2013; Sundquist et al., 2011).

However, the framework of 3D's may be not applicable for walking behaviors for some cities in non-western countries, such as Hong Kong. Additional studies from other non-western countries also demonstrated the non-applicability of 3D's. A study from Cuernavaca, Mexico reported that walkability index was inversely related to total MVPA based a study of 677 adults (Salvo et al., 2014). A study from Bogota, Colombia, reported no significant association between population density or land-use mix and physical activity (Gomez et al., 2010). Nevertheless, the findings from Curitiba, Brazil, a South American city, showed walkability index was positively associated with walking for transport and leisure-time moderate-to-vigorous physical activity (MVPA), although it was not related to walking for leisure after adjusting for individual covariates (Siqueira Reis et al., 2013). Curitiba is the fourth richest city in Brazil, is famous for its generous green space, transit-oriented system, mixed land use. Despite its reputation for its public transportation system, Curitiba has a high car ownership: 0.6 cars per resident. Those urban and socioeconomic features of Curitiba may account for the positive association.

Our findings also suggest that local urban context may moderate the association between the built environment and walking. For example, comparing with cities of western countries, Hong Kong features much higher population density, higher street connectivity, higher land-use mix, and better-developed public transportation systems, much lower private car ownership (0.07 per resident as of 2015) and lower violent crime rate (0.15 per 1000 population as of 2015). Therefore, in settings like Hong Kong, walkability is likely defined by other variables beyond the framework of original 3D's.

2) In terms of the association between walking for leisure and population density, residents from the medium-density areas walked significantly more than those from the low- and high-density areas. In other words, lower population density was positively associated and higher population density was negatively associated with walking for leisure. The association of population density with walking for leisure may be of an inverse U-shape.

Previous studies have reported inconclusive findings with regard to the association between walking for leisure and neighborhood density (Saelens and Handy, 2008). This association may be negative in a city with relatively high population density. This finding concurs with previous studies form China and South America (Gomez et al., 2010; Salvo et al., 2014; Su et al., 2014; Xu et al., 2010). The findings from Cuernavaca, Mexico reported medium and medium-high residential density in the 1-km buffer were negatively associated with total MVPA, using low density as the reference (Salvo et al., 2014). In Nanjing, China, population density was negatively related to student's leisure-time physical activity (Xu et al., 2010). Su et al. (2014) further demonstrated that the perception of residential density was inversely associated with walking for leisure among women but not men, in Hangzhou, another dense city in China.

The mechanism of the complex association between neighborhood density and walking for leisure is unclear. We offer two tentative explanations: 1) the availability of neighborhood open spaces and recreational facilities, and 2) the perception of personal safety. Open spaces such as parks, pedestrian running trails, or sports fields are important for residents to engage in walking for leisure (Gallimore et al., 2011; Koohsari et al., 2013). A medium-density area may have more diversified recreational opportunities within walking distance than low-density areas featuring single-family houses or town houses. In contrast, a high-density area with compact high-rise housing towers in Hong Kong may have fewer open spaces and recreational facilities, especially per capita, than medium-density areas. Post-hoc t tests confirm that medium-density areas in Hong Kong ($M = 84{,}034$ m^2, $SD = 20{,}653$) have more open spaces and recreational facilities within 400 m buffer than low-density ($M = 31{,}468$ m^2, $SD = 20{,}653$, $t(22) = 3.63$, $p < 0.05$) and high-density areas ($M = 43{,}508$ m^2, $SD = 32{,}578$, $t(22) = 5.50$, $p < 0.05$). The prevalence of open spaces and relational facilities in medium-density areas in Hong Kong may partly explain the prevalence of walking in those areas.

Another factor that might influence adults' leisure walking is personal safety. There are likely to be more pedestrians on the street in medium-density areas, which potentially increases the sense of personal safety. Beyond a certain threshold, however, a large flow of pedestrians on narrow sidewalks can lead to a sense of overcrowding, which may hinder walking for leisure purposes (Godbey et al., 2005). In Hong Kong and many other Chinese cities, narrow sidewalks are often so packed that some pedestrians can be found walking in streets. Variations in the sense of personal safety in different neighborhoods may explain the association we observed in this study.

3) In terms of the association of population density and walking for transport, residents from low-density areas walked significantly less than those from medium-density areas, while there was no difference between residents from medium- and high-density areas. In other words, population density was positively associated with walking for transport in the lower range of population density, but not in the higher range.

The result confirms the positive association between density and walking for transport in other studies, especially in areas with lower range of density (Atkinson et al., 2005; Besser and Dannenberg, 2005; Forsyth et al., 2007; Frank et al., 2008; Handy et al., 2005). Our result further suggests the threshold effect of density on walking for transport. Medium-density areas may have more destinations such as services, shops and employment opportunities within walking distance, compared with low-density areas in Hong Kong. However, those potential destinations are no closer to home in high-density areas, thus we failed to observe a further increase in walking for transport compared with medium-density areas.

The findings in the present study also have direct policy implications for the local government. Empirical findings from western countries often suggest, in order to promote residents' physical activity, neighborhoods should be designed with the characteristics of higher neighborhood densities, higher street connectivity, and better access to a variety of destinations. The suggestions may be ineffective for Hong Kong, which already have very high levels of neighborhood densities, street connectivity, and land-use diversity. We observed that street connectivity and land-use diversity was not associated with physical activity, while population density was negatively associated with walking for leisure in the higher range of population density. Hong Kong residents largely rely on walking and public transportation for daily travel, rather than private cars. The overall car ownership is as low as 0.07 per capita as of 2015. The typical transportation mode markedly differs from western countries. The number of population in Hong Kong increased from 5.7 million in 1990 to 7.07 million in 2011, making it one of densest cities in the world (Census and Statistics Department of Hong Kong, 2013). Those urban and socioeconomic contexts—in Hong Kong and many other coastal cities in China—create unique challenges to promote physical activity. Therefore, the applicability of the original 3D's needs further investigation in the local context of China.

Finally, we also urge caution in interpreting the results from this study. The cross-sectional research design cannot contribute to any causality between built environment and walking. Second, walking behavior was assessed with questionnaire, which may differ from objectively assessed walking behavior such as accelerometers. Three, we use straight-line buffer around each housing estates, which is less precise to define the neighborhood environment compared with street network buffer. Nevertheless, the present study also has several strengths. It objectively measured built environment with geographic information system (GIS) in conjunction with reliable GIS data from Hong Kong government. It also assessed the association of built environment and walking after adjusting for demographic characteristics and SES confounders with multilevel regression models. Another strength is that we split population density into three levels (low, medium, high), which enabled us to scrutinize its association with walking.

6. Conclusions

Promoting physical activity to maintain health among residents is an urgent need in Hong Kong. Contrasting to findings from western countries, we found that three objectively measured D's—density, land-use mix, or design—was either negative or not associated with walking in Hong Kong. The inconclusive findings from this study and previous studies implies that the local context, such as high population density, low car ownership in Hong Kong, may affects the direction and strength of the association between built environment and physical activity. The policy or planning strategy—using three D's to promote physical activity—may be ineffective in large cities in China.

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